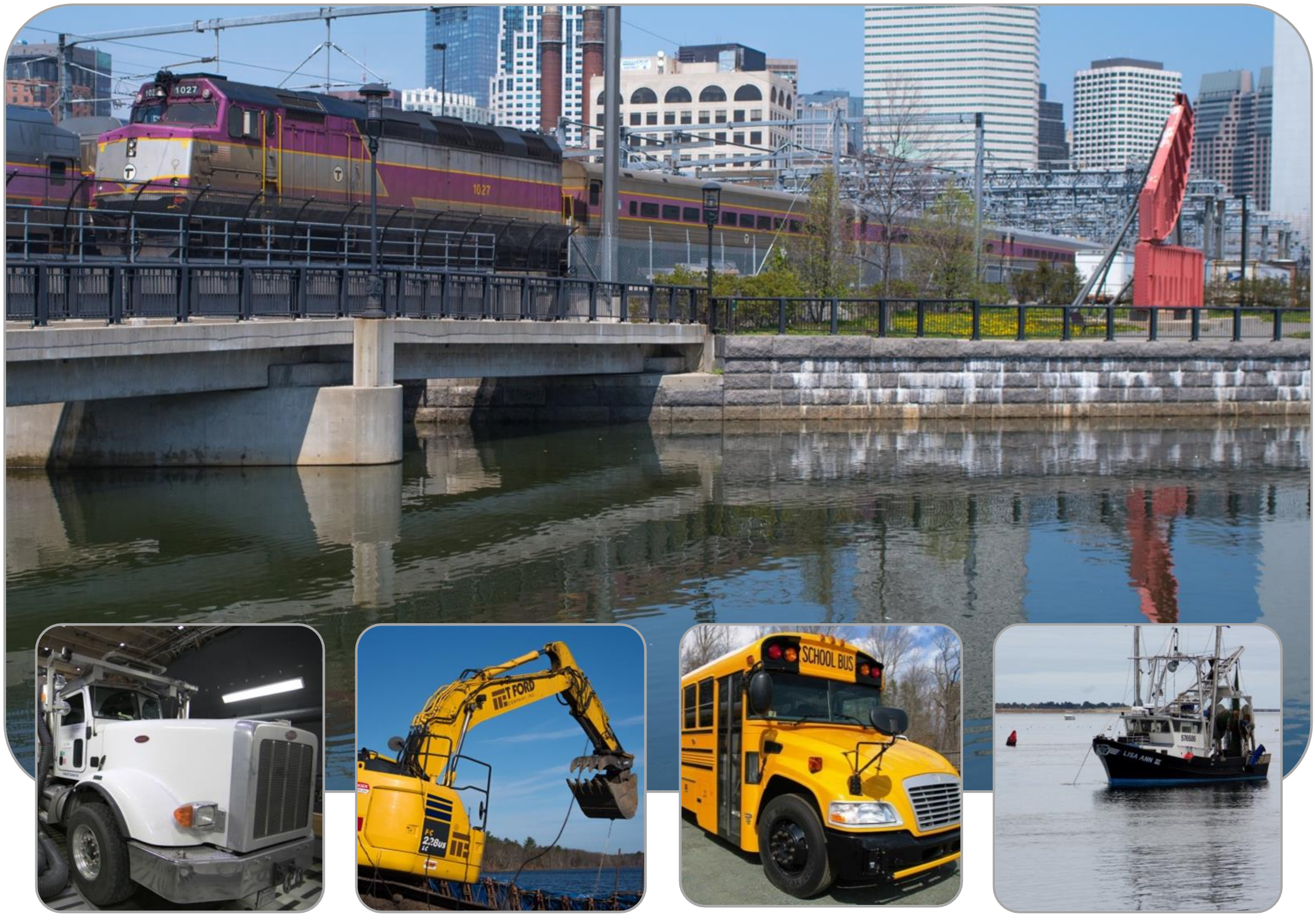

Massachusetts 2016 Diesel Particulate Matter Inventory

April 2018

Massachusetts Department of Environmental Protection
Bureau of Air and Waste

Contents

Appendix 4.3 Off-Road MA NONROAD_Calculations_Inputs_Outputs to post.xlsx

Contact MassDEP for the large output file below.

Appendix 3.9 On-Road MA MOVES_Outputs_out.zip

Acronyms

AADT	annual average daily traffic
ALVW	adjusted loaded vehicle weight
AVFT	Alternative Vehicle Fuel Table
BACT	Best Available Control Technology
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
CFV	clean fuel vehicle
CMR	Code of Massachusetts Regulations
CNG	compressed natural gas
CO	carbon monoxide
CO_2	carbon dioxide
D/l	Displacement/liter
DMF	Division of Marine Fisheries (Massachusetts)
DMVT	daily vehicle miles traveled
EPA	Environmental Protection Agency (U.S.)
ERTAC	Eastern Regional Technical Advisory Committee
FHWA	Federal Highway Administration
FIPS	Federal Information Processing Standards
FR	Federal Register
FRA	Federal Railroad Association
g/bhp-hr	grams per brake horsepower-hour
g/mi	grams per mile
g/kW-hr	grams per kilowatt hour
GVWR	gross vehicle weight rating
HAP	hazardous air pollutant
HC	hydrocarbons
HDV	heavy duty
HDDV	heavy-duty diesel vehicle
hp	horsepower
HPMS	Highway Performance Monitoring System
IFTA	International Fuel Tax Association
IRP	International Registration Plan
ILEV	Inherently Low Emission Vehicle
kWh	kilowatts hour
LDV	light duty vehicle
LDDV	light-duty diesel vehicle
LDGT	light-duty gas truck
LDGV	light-duty gas vehicle
LDT	light duty trucks
LEV	Low Emission Vehicle
LSD	low sulfur diesel
LVW	loaded vehicle weight

MANE-VU	Mid-Atlantic and Northeast Visibility Union
MassDEP	Massachusetts Department of Environmental Protection
MassDOT	Massachusetts Department of Transportation
MBTA	Massachusetts Bay Transportation Authority
MDPV	medium duty passenger vehicle
MDO	marine diesel oil
MHD	Massachusetts Highway Department
MJO	multi-jurisdictional organization
MOBILE-6	On-road Mobile Source Emissions model version 6 (EPA)
MOVES	MOtor VEhicle Emissions Simulation model (EPA)
mpg	miles per gallon
mph	miles per hour
MW	megawatt
MWh	megawatt hour
NAAQS	National Ambient Air Quality Standard
NACAA	National Association of Clean Air Agencies
NAICS	North American Industry Classification System
NEI	national emissions inventory
NESCAUM	Northeast States for Coordinated Air Use Management
NH_3	ammonia
NLEV	National Low Emission Vehicle
NOx	nitrogen oxides
NSPS	New Source Performance Standards
OLE	Office of Law Enforcement (Massachusetts)
PM	particulate matter
ppm	parts per million
RMV	Registry of Motor Vehicles
RO	residual oil
RTA	Regional Transit Authority
SCC	Source Classification Code
SO_2	sulfur dioxide
SSEIS	Stationary Source Emissions Inventory System
STB	Surface Transportation Board
SUV	sport utility vehicle
TPD	tons per day
TPY	tons per year
TLEV	Transitional Low Emission Vehicle
UCS	Union of Concerned Scientists
ULSD	ultra low sulfur diesel
ULEV	Ultra Low Emission Vehicle
USACE	U.S. Army Corps of Engineers
USCG	U.S. Coast Guard
VID	Vehicle Inspection Database
VIN	vehicle identification number
VIUS	Vehicle Inventory and Use Survey
VMT	vehicle miles traveled
VOCs	volatile organic compounds
ZEV	Zero Emission Vehicle

1.0 Introduction and Key Findings

Engines powered with diesel fuel are a 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) from diesel engines can be harmful to our health, causing short-term problems such as coughing and exacerbation of asthma as well as long-term impacts such as respiratory damage and cancer.

In response to these public health concerns the Massachusetts Department of Environmental Protection (MassDEP) developed the *2002 Diesel Particulate Matter Inventory* to estimate the number of diesel-fueled engines in Massachusetts and their PM emissions. This 2016 report is an update of the 2002 inventory. It tracks changes in diesel engine counts, emissions standards, and total emissions. Similar to the 2002 inventory, this inventory will help identify strategies to reduce diesel PM emissions and limit exposure of Massachusetts residents to diesel PM.

For any questions regarding this report please contact: Kenneth Santlal at kenneth.santlal@state.ma.us.

1.1 Fine vs. Coarse Particulate Matter

PM consists of dust, dirt, soot, fly ash, and smoke. It is a mixture of microscopic and visible solid particles and minute liquid droplets known as aerosols. PM is generated by natural sources (such as wind-blown dust and fires) and anthropogenic sources (such as on-road and off-road vehicles, power plants, and home heating systems). PM includes 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).

Many sources burning diesel fuel (such as highway trucks, transit buses, school buses, and marine engines) emit almost exclusively fine PM, or particles that are 2.5 microns or less in diameter – this is known as $PM_{2.5}$. Fires and dust from natural sources primarily generate coarse PM, or particles that are greater than 2.5 microns. $PM_{2.5}$ and coarse PM between 2.5 and 10 microns in diameter are together known as PM_{10}.

The PM of greatest health concern is fine PM ($PM_{2.5}$) because fine particles can be inhaled more easily than coarse PM and can lodge deep in the lungs. Due to the health effects associated with $PM_{2.5}$ this inventory focuses on the $PM_{2.5}$ emitted from diesel-powered sources.

1.2 Health Effects of Diesel $PM_{2.5}$

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] The International Agency for Research on Cancer (IARC), which is part of the World Health Organization (WHO), classified diesel engine exhaust as carcinogenic to humans based on sufficient evidence that exposure is associated with an increased risk for lung cancer. Other studies have not found a safe exposure level for $PM_{2.5}$ – exposure to even small amounts of $PM_{2.5}$ is associated with adverse health effects.[2]

[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).

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 are the elderly, children and people with existing heart disease, lung disease, and diabetes. Children are more vulnerable to air pollution than healthy adults because their respiratory systems are still developing and they have a faster breathing rate.

In Massachusetts, $PM_{2.5}$ is thought to be associated with the state's high rate of asthma.[3] The Massachusetts Department of Public Health and the Asthma Regional Council, in the most comprehensive examination of asthma in New England in 2006 found that 1 in 10 children in the state had asthma. For 2016 it had increased to 1 in 7 children. Asthma affects over 1,140,000 Massachusetts residents (approximately 17%), including about 210,000 children (approximately 16%). For the 110,000 Massachusetts children who live with asthma, $PM_{2.5}$ causes 55% of them to limit their physical activity and 41% to miss days at school. It also causes 60% and 24% of 500,000 adults living with asthma to limit their physical activity and miss work, respectively. Asthma is also expensive, costing Massachusetts $172 million in 2011.[4,5]

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 17 to 48 miles on the 10% most impaired days.[6] In addition, black carbon is a climate pollutant and "the most strongly light-absorbing component of particulate matter (PM), and is formed by the incomplete combustion of fossil fuels, biofuels, and biomass."[7] Over 50% of the black carbon emissions in the U.S. come from mobile sources, particularly diesel engines.[8]

Diesel PM can persist in the environment and get into the food chain potentially causing adverse effects to aquatic and soil ecological receptors.[9] 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 giving it 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.[10] Increased diesel PM in urban areas can also cause 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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3 The New England Asthma Regional Council (ARC). Available on-line at: http://www.asthmaregionalcouncil.org/actionplan/actionplan.html.

4 Email from Stacey Chacker ARC with data from Massachusetts Department of Public Health. November 21, 2017.

5 Massachusetts Demographics for Poor Children 2015. http://www.nccp.org/profiles/MA_profile_7.html

6 MANE-VU FTP site run by Maine DES, file MANE-VU 2000-16 RHII & III Speciation plots final.xlsx, RAW DATA, SVR (Standard Visual Range) average for 2016 for 10% most impaired days (RANK-IMPAIRMENT = 90). http://www.maine.gov/dep/ftp/MVTSC/RH_METRICS_TRENDS/MANEVU%20Trends%202004-16%20Report%201st%20SIP%20Metrics%20DRAFT%202017-12-27.docx

7 See EPA's Report to Congress on Black Carbon, March 2012, at https://www3.epa.gov/airquality/blackcarbon/

8 See https://www3.epa.gov/airquality/blackcarbon/basic.html#where

9 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).

10 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 estimates diesel engine counts and their emissions for the following sectors.

On-Road engines – automobiles, trucks, and buses (registered in-state and out-of-state) that travel on public and private roads.

Off-Road, land-based engines – Nine equipment groups including construction and mining equipment, commercial diesel engines, and industrial equipment.

Marine engines – recreational, commercial and institutional engines (e.g., pleasure craft, fishing, and police vessels).

Locomotive engines – interstate and intrastate lines including commuter, line-haul freight, and switchyard train operations.

Stationary engines – generators (including turbines) and fire pumps using diesel fuel.

Stationary engines are those that report to MassDEP under the Source Registration program. These are either large engines or smaller engines at facilities with larger facility-wide emissions. Smaller engines (e.g., small emergency generators) are classified as area sources and do not report emissions. Area source engines are not covered in this report because there was no means to meaningfully estimate the number of those small engines.

Diesel fuels are part of the broad petroleum category known as distillate fuel oil. Distillate fuel oil also includes No. 1 fuel oil (used in portable outdoor stoves) and No. 2 fuel oil (more commonly known as heating oil and 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 (kerosene) is not a diesel fuel. Finally, this inventory does not include emissions resulting from diesel spills (spilled fuel emits volatile organic compounds (VOCs) rather than PM).

1.5 Key Findings

Below are the key findings of this inventory. See Table 1-1 for a summary of the data.

- In 2016 approximately 833,000 diesel engines operated in Massachusetts – an increase of 22% from 2002.

- On-Road diesel engines remain by far the largest category with numbers greater than all other categories of diesel engines combined. The largest segment of on-road engines are those traveling on Massachusetts roads but registered out-of-state (Figure 1-1).

- The largest percent change in diesel engines from 2002 is a 46% increase in off-road land based engines followed by a 36% increase in on-road engines registered in Massachusetts and a31% increase in stationary engines . In absolute numbers, on-road diesel engines registered out-of-state had the largest increase followed by on-road diesel engines registered in Massachusetts.

- Despite the number of diesel engines increasing, emissions dropped by about 2/3 since 2002. This was due to diesel engines becoming much cleaner – per engine emissions also dropped by 75% since 2002. Figure 1-2 shows decreases in emissions across all categories.

- The largest emissions source is no longer on-road engines – it is now off-road engines (e.g., construction vehicles) as shown in Table 1-1 and Figure 1-2. In 2002 on-road and off-road emissions were nearly identical, but this is now changed with off-road emissions nearly 50% greater than those from on-road vehicles.

- On-road and off-road land-based diesel engines together make up nearly all of the engines (99%) and a large majority of the emissions (88%).

- The largest change in emissions from 2002 is a 1,363 ton per year[11] (73%) drop in emissions from on-road engines due to tighter emissions standards and fleet turnover.

- Per engine emissions, however, are very different across sectors, with locomotives emitting the most PM per engine – from 17 to 73 times as much as other diesel engines.

- Since 2002 on- and off-road per engine emissions dropped dramatically – 80% and 71% respectively. However, off-road engines still emit over 2 times the $PM_{2.5}$ of on-road engines per engine.

Table 1-1 Diesel Engines and $PM_{2.5}$ Emissions in Massachusetts 2002 and 2016

	Engines			$PM_{2.5}$ Emissions (tons)*			$PM_{2.5}$ Emissions Per Engine (tons)*		
	2002	2016	% Change	2002	2016	% Change	2002	2016	% Change
On-Road (registered out-of-state)	481,000	556,639	16%						
On-Road (registered in MA)	121,476	164,640	36%						
On-Road ALL	602,476	721,279	20%	1860	497	-73%	0.015	0.003	-80%
Off-Road Land-based	71,964	104,855	46%	1726	718	-58%	0.024	0.007	-71%
Marine	6,787	5,797	-15%	187	75	-60%	0.028	0.013	-53%
Locomotives	259	299	15%	142	66	-54%	0.548	0.221	-60%
Stationary	1,081	1,415	31%	32	19	-41%	0.030	0.013	-55%
Total	682,567	833,645	22%	3947	1375	-65%	0.020	0.005	-75%
Total (excluding registered out-of-state)	201,567	277,006	37%						

* In this inventory, a “ton” is a short ton (i.e., 2,000 pounds).

[11] In this inventory, a “ton” is a short ton (i.e., 2,000 pounds)

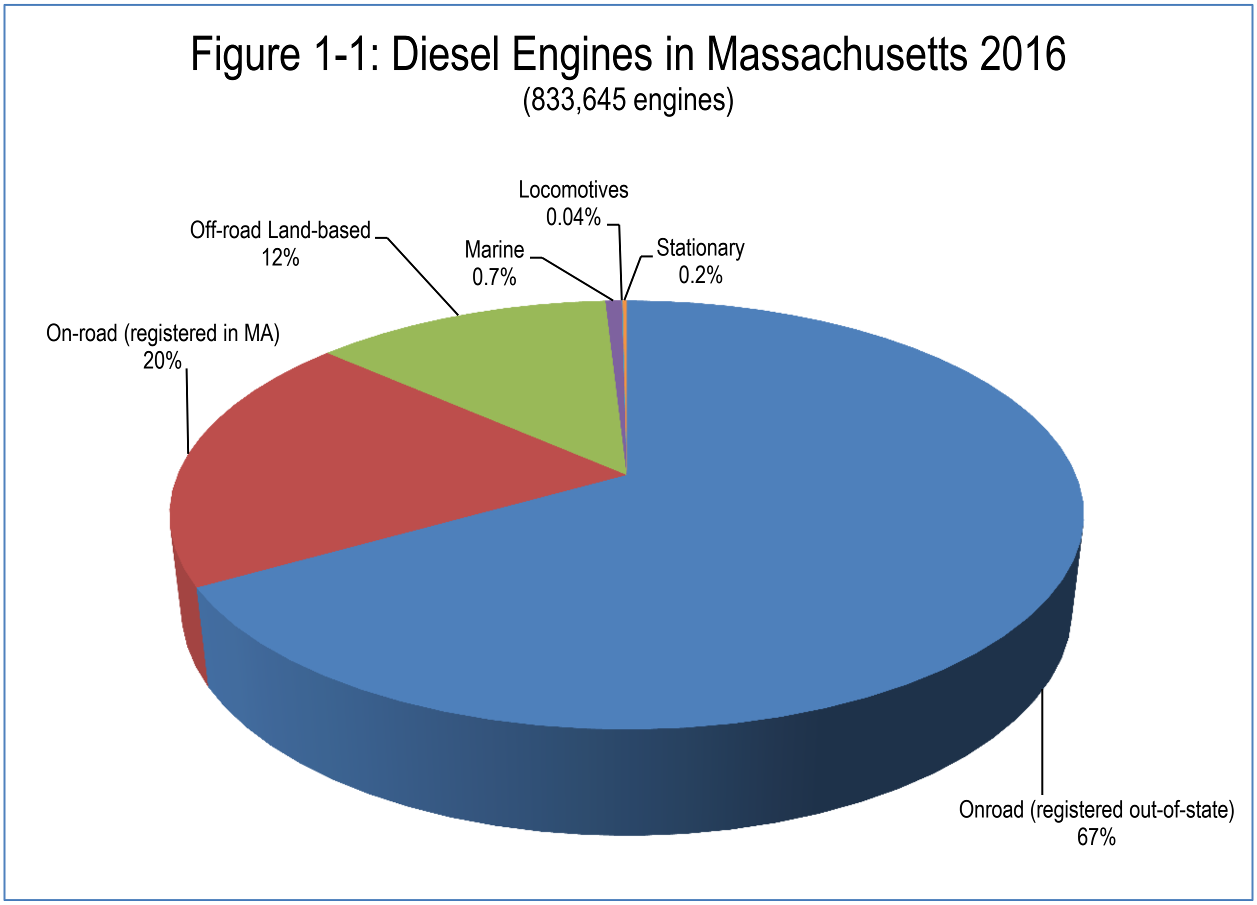

Figure 1-1 Diesel Engine Population by Sector in Massachusetts in 2016

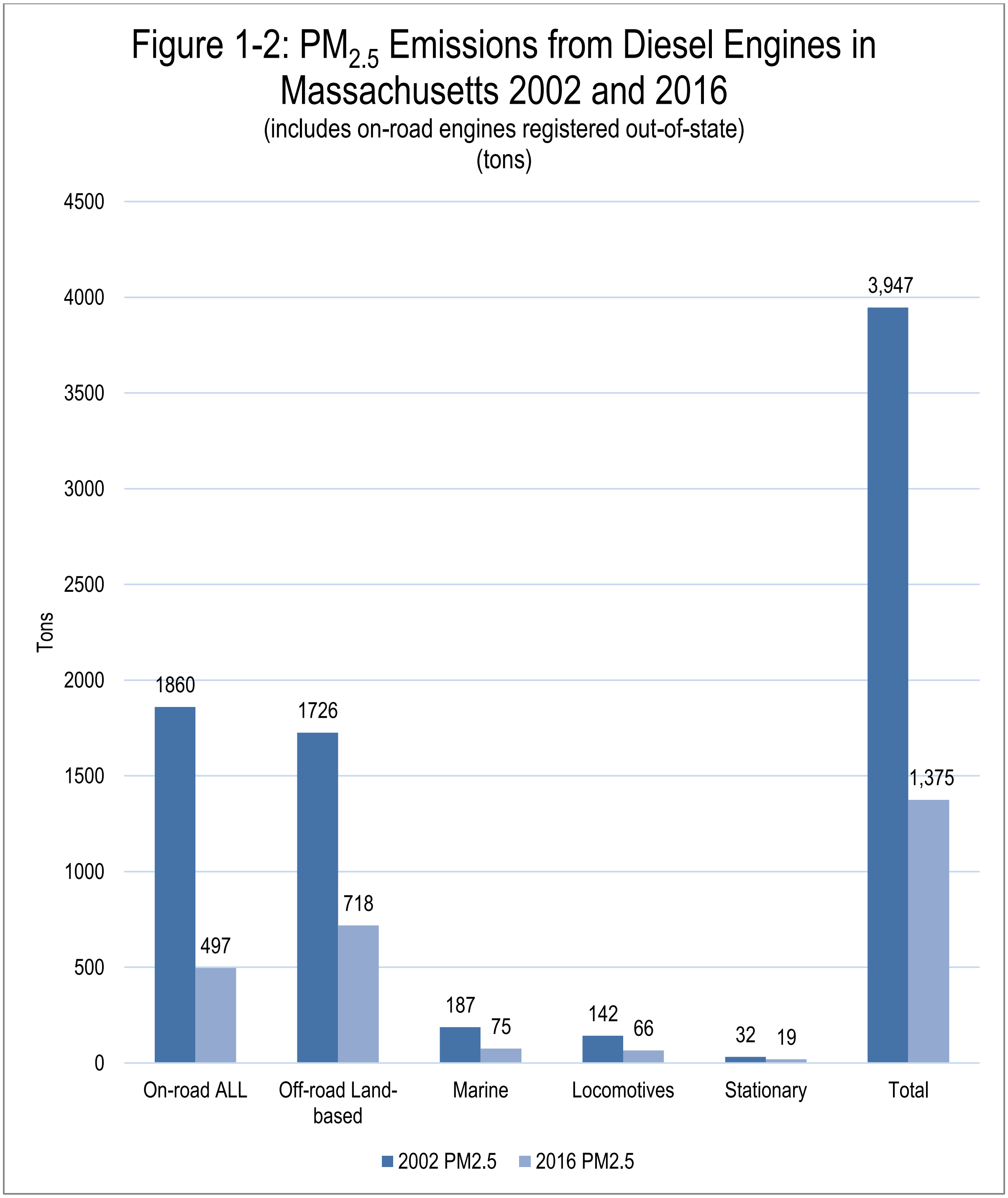

Figure 1-2 PM$_{2.5}$ Emissions from Diesel Engines in Massachusetts 2002 and 2016

1.8 References for Introduction and Key Findings

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 summarizes the diesel engines and emissions data for on-road vehicles, off-road land-based equipment, marine vessels, locomotives, and stationary sources. This section presents the total number of engines as well as the total amount of $PM_{2.5}$ emissions in the state in 2016 and compares these to the 2002 inventory. Chapters 3 through 7 of this document explain the sources and assumptions behind the number of engines and emission estimates presented here.

2.1 Total Number of Diesel Engines in Massachusetts

In 2016, approximately 833,000 diesel-powered engines operated in Massachusetts, an increase of 22% from the 2002 inventory. The on-road sector had the most diesel-powered engines with 164,640 engines registered in Massachusetts and an estimated 556,639 engines in trucks traveling through Massachusetts from other states. The off-road land-based engine sector, which includes nine diesel equipment groups,[1] had the next highest number with 104,855 engines. Table 2-1 shows the number of diesel engines in each sector operating in Massachusetts.

Table 2-1 Number of Diesel-Powered Engines Operating in Massachusetts in 2002 and 2016

Engine Sector	2002 Population	2002 Percent of Total	2016 Population	2016 Percent of Total	Percent change
On-Road (registered out-of-state)	481,000	70%	556,639	67%	16%
On-Road (registered in MA)	121,476	18%	164,640	20%	36%
Off-Road Land-Based	71,964	11%	104,855	12%	46%
Marine	6,787	1%	5,797	0.7%	-15%
Locomotives	259	0.04%	299	0.04%	15%
Stationary*	1,081	0.2%	1,415	0.2%	31%
Total	682,567		833,645		22%
Total - excluding out-of-state	201,567	30%	277,006	33%	37%

* Engines that report emissions to MassDEP's Source Registration program – generally large engines and small engines at facilities with larger emissions or potential emissions. Area source engines are stationary engines at facilities too small to report under the Source Registration program – area source engines are not included in this report due to a lack of data on their numbers.

Figure 2-1 shows the percent of the total number of engines accounted for by each engine group, including engines registered out-of-state. At nearly 70% of the total, heavy-duty trucks registered out-of-state but traveling in Massachusetts far outnumbered all other diesel engines. This is not surprising as

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

Massachusetts serves as the northern transportation gateway for three other New England states and Canada.

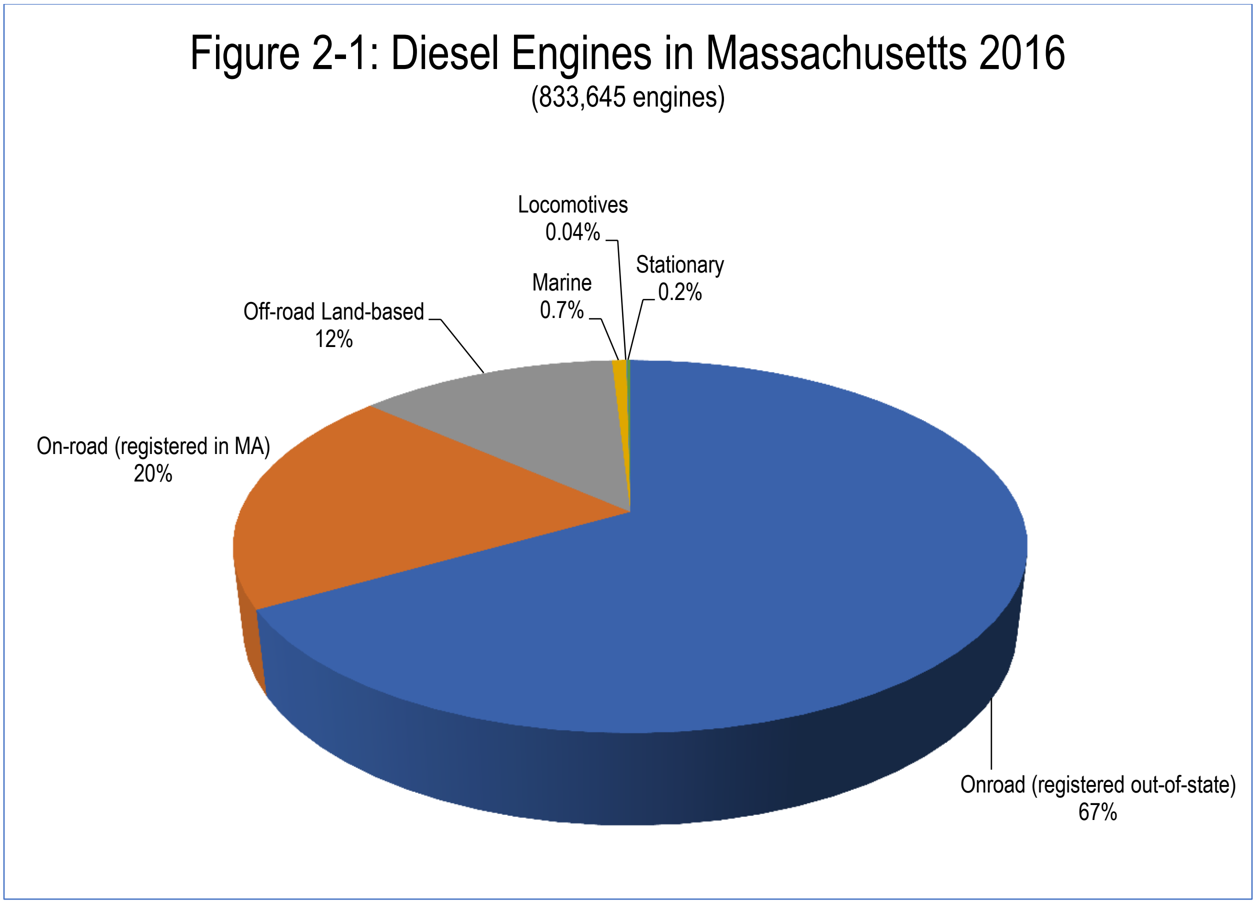

Figure 2-1 Diesel Engine Population by Sector in Massachusetts in 2016

Engines registered in Massachusetts only comprise about 30% of all diesel engines used in Massachusetts. The two largest sectors registered in Massachusetts were on-road engines (20%) and off-road land-based engines (12%). Stationary, marine, and locomotive engines together were only 1% of the total engine population in 2016.

Figure 2-2 shows the percentage each engine group represents of the total number of engines excluding on-road engines registered out-of-state. Of these engines, on-road vehicles registered in Massachusetts comprised 59% of total in-state engines in 2016 and off-road, land-based engines made up another 38%. Stationary, locomotive, and marine diesel engines together account for only 3% of the state's engines.

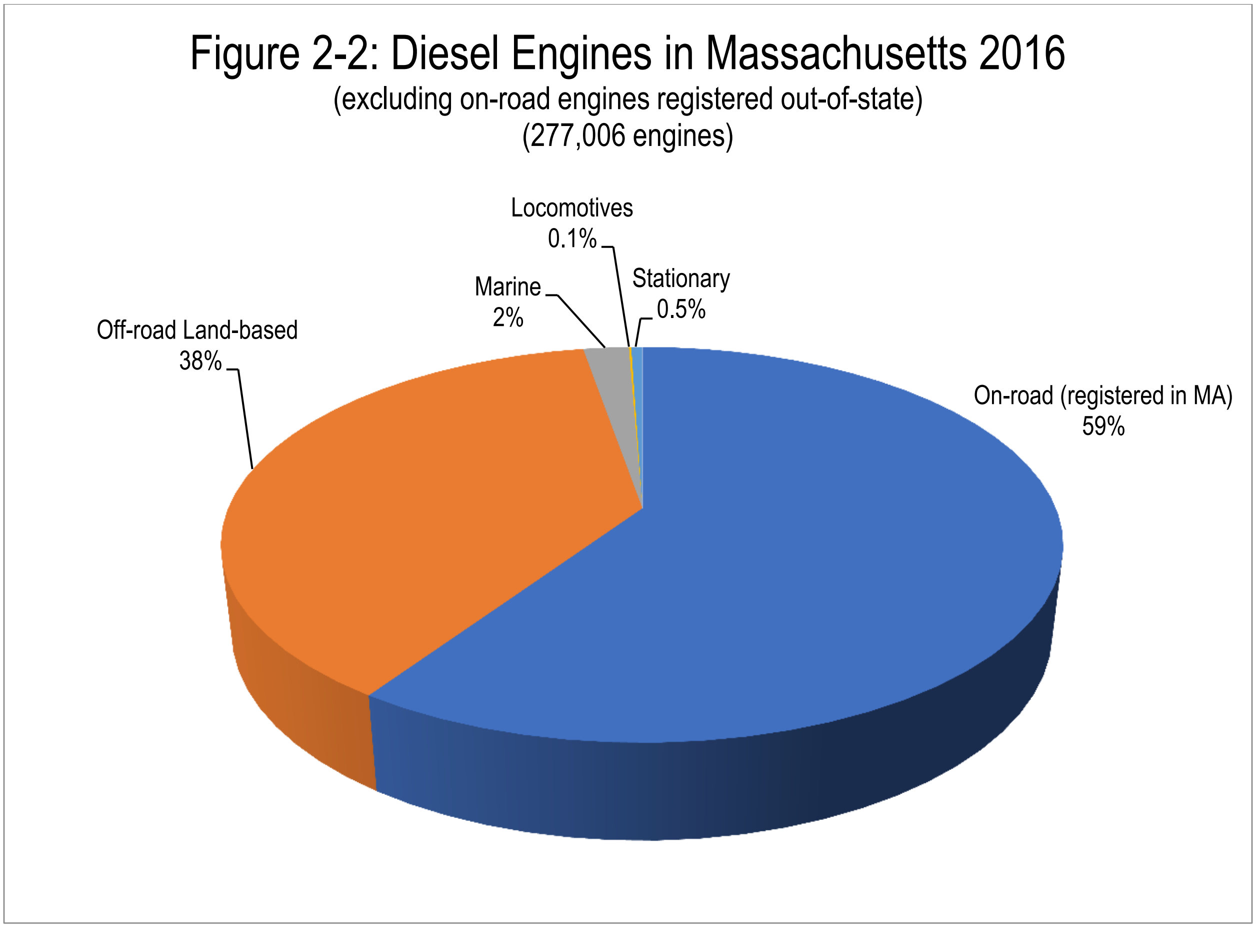

Figure 2-2 Diesel Engine Population by Sector in Massachusetts in 2016
(excluding on-road engines registered out-of-state)

Table 2-2 shows the data by engine groups within the largest sectors. Figure 2-3 shows the same data by the percentage of all diesel engines in Massachusetts.

- **The total on-road diesel engine population registered in Massachusetts grew 36% from 2002 to 2016.**

- **Among on-road diesel engines registered in Massachusetts in 2016 single unit trucks were most numerous at 34%**.[2] Combination unit trucks also represented a significant portion of the population (15%). The total on-road vehicle population grew 22% from 2002 to 2016.

- **Construction and commercial off-road equipment also represented a significant population of diesel engines.** Each of these groups had over 30,000 diesel engines in 2016. Since 2002 these two categories of off-road equipment grew 38% and 50% respectively.

[2] Includes motorhomes and refuse trucks where these are not separately listed.

- **Marine, stationary, and locomotive diesel engines represented only about 3% of the total population in 2016.** The stationary and locomotive engines increased 31% and 15% since 2002, but the number of marine engines fell by 15%.

Table 2-2 Number of Diesel Engines Operating in Massachusetts in 2002 and 2016
(excluding on-road engines registered in other states)

Diesel Equipment Group	2002 Population	2002 Percent of total	2016 Population	2016 Percent of total	Percent change from 2002 to 2016
On-Road Engines Registered in MA	121,476	60%	164,640	59%	36%
Passenger Cars			*14,981*	*5%*	
Light Trucks			*4,206*	*2%*	
Buses			*11,413*	*4%*	
*Single Unit Trucks***			*93,490*	*34%*	
Combination Unit Trucks			*40,550*	*15%*	
Off-Road Engines	71,964	36%	104,855	38%	46%
Construction Equipment	*29,226*	*14%*	*40,273*	*15%*	*38%*
Commercial Equipment	*22,921*	*11%*	*34,457*	*12%*	*50%*
Industrial Equipment	*10,679*	*5%*	*15,327*	*6%*	*44%*
*6 Off-Road Equipment Groups**	*9,138*	*5%*	*14,798*	*5%*	*62%*
Marine Engines: C1 and C2	6,787	3%	5,797	2%	-15%
Stationary Engines	1,081	1%	1,415	0.5%	31%
Locomotives	259	0.1%	299	0.1%	15%
Total	201,567		277,006		37%

* These include agricultural equipment, airport ground support equipment, commercial lawn and garden equipment, logging equipment, railroad equipment, and recreational equipment.

** Includes motorhomes and refuse trucks.

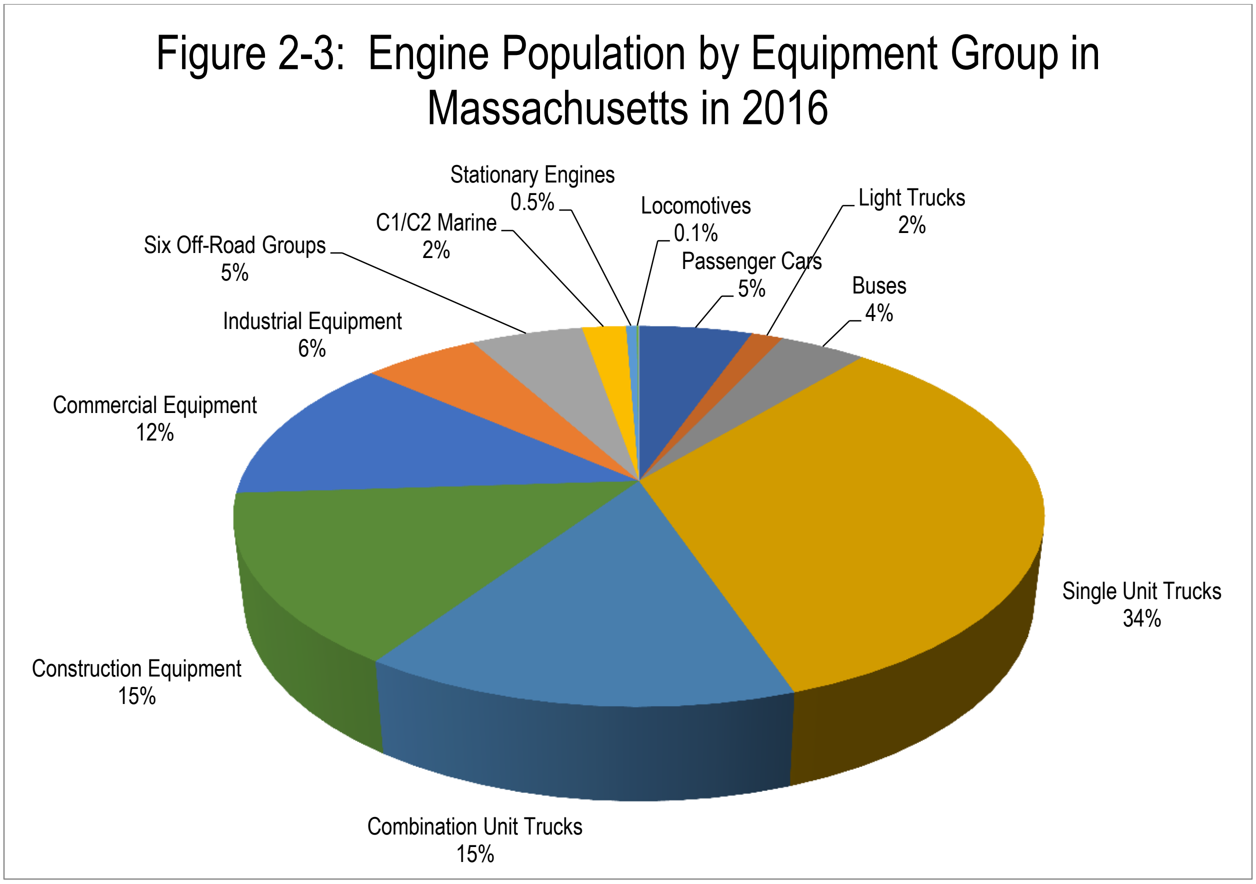

Figure 2-3 Engine Population by Equipment Group in Massachusetts in 2016
(excluding on-road engines registered out-of-state)

2.2 Total Amount of Diesel PM Emissions in Massachusetts

Diesel engines released 1,375 tons of $PM_{2.5}$ in Massachusetts in 2016. Table 2-3 lists the 2002 and 2016 $PM_{2.5}$ emissions for engine groups. Table 2-4 shows similar information specific to the on-road sector. Figure 2-4 shows the percentage contribution of diesel $PM_{2.5}$ emissions in 2016 by engine group. Highlights of the data are given below.

- **Diesel $PM_{2.5}$ emissions decreased 65% from 2002 to 2016** (from 3,947 to 1,375 tons).

- **Together, off-road land-based and on-road diesel engines emitted 88% of all diesel $PM_{2.5}$ in 2016.** Their relative contribution in 2002 was similar (91%), although their total (3,585 tons) decreased by 66% to 1,215 tons in 2016 due to increasingly stringent emission standards, lower sulfur content diesel fuel, and fleet turnover.

- **On-road vehicles emitted the most $PM_{2.5}$ in 2016.** With 497 tons, they represented 36% of the statewide diesel $PM_{2.5}$ emissions.

- **Construction equipment engines emitted the second highest amount of $PM_{2.5}$ in 2016.** With 449 tons, they represent 33% of statewide diesel $PM_{2.5}$ emissions.

- **Locomotive, marine, and stationary engines together emitted 12% of $PM_{2.5}$ in 2016.** Locomotives emitted 66 tons representing 5.1% of the statewide total, while marine engines emitted 75 tons (5.4%) and stationary sources emitted 19 tons (1%).

Single unit tucks are the most numerous engines (93,490 or 34%) but with 78 tons represent only 6% of the statewide diesel $PM_{2.5}$ emissions. Construction and mining, however, has half as many engines (40,273 or 15%) but emits 33% (449 tons) of the statewide diesel $PM_{2.5}$ emissions. A linear relationship does not exist between the number of engines and their annual $PM_{2.5}$ emissions because of differences in emission standards, engine usage, and the age of the fleets.

Table 2-3 Diesel $PM_{2.5}$ Emissions by Engine Group Operating in Massachusetts in 2002 and 2016
(excluding on-road engines registered in other states)

Engine Group	2002 $PM_{2.5}$ (tons)	2002 Percent of total	2016 $PM_{2.5}$ (tons)	2016 Percent of total	Percent Change
On-Road Vehicles Registered In-State	1,860	47%	497	36%	-73%
Off-Road Construction & Mining Equip	1,113	28%	449	33%	-60%
Off-Road Commercial Equipment	198	5%	113	8%	-43%
Off-Road Industrial Equipment	289	7%	86	6%	-70%
Six, Off-Road, Land-Based Engines*	126	3%	70	5%	-45%
C1 and C2 Marine Engines	187	5%	75	5%	-60%
Locomotive Engines	142	4%	66	5%	-54%
Stationary Engines	32	1%	19	1%	-41%
Total	3,947		1,375		-65%

* These include agricultural equipment, airport ground support equipment, commercial lawn and garden equipment, logging equipment, railroad equipment, and recreational equipment.

Table 2-4 shows similar information as Table 2-3 above, but for on-road vehicles only. The categorization of vehicles changed significantly between the 2002 and 2016 inventories because of a shift in EPA's mobile source emissions model from MOBILE (with weight-based vehicle classes) to MOVES (with usage-based vehicle classes). Highlights of the data are given below.

- **Statewide on-road diesel $PM_{2.5}$ emissions declined 73% from 2002 to 2016 despite a 20% increase in engine population.**
- **The highest on-road contributors in both 2002 and 2016 to the statewide totals were the heaviest vehicle class.** Vehicles greater than 26,001 lbs. emitted 85% of on-road diesel $PM_{2.5}$ in 2002, and combination unit tucks emitted 81% of the 2016 on-road total.

Table 2-4 On-Road $PM_{2.5}$ Engine Count and Exhaust Emissions by Engine Group Operating in Massachusetts in 2002 and 2016
(excluding on-road engines registered in other states)

	2002 On-Road Vehicle Class	2002 Engines	2002 $PM_{2.5}$ (tons)		2016 On-Road Vehicle Class	2016 Engines	2016 $PM_{2.5}$ (tons)	Engine Percent Change	$PM_{2.5}$ Percent Change
1	<10,000 lbs	35,548	107	1	Passenger Cars	14,981	4		
2	10,000 – 19,500 lbs	23,925	56	2	Light Duty Trucks	4,206	4		
3	19,501 – 26,000 lbs	13,378	110	3	Buses	11,413	11		
4	>26,001 lbs	48,625	1,587	4	Single Unit Trucks	93,490	78		
				5	Combination Unit Trucks	40,550	401		
	Total On-Road	121,476	1,860		Total On-Road	164,640	497	36%	-73%

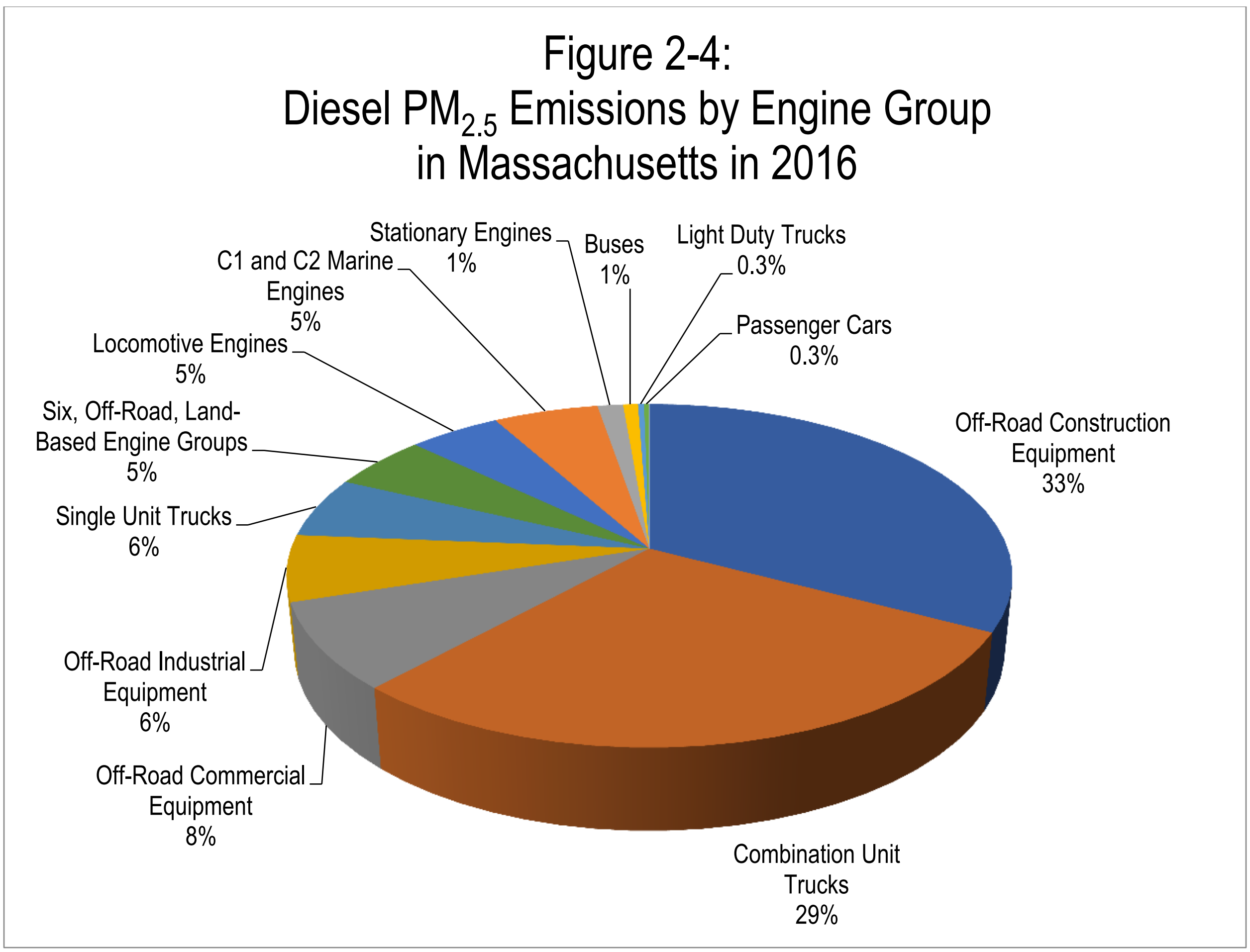

Figure 2-4 Diesel $PM_{2.5}$ Emissions by Engine Group in Massachusetts in 2016

To show the relative emissions by engine types, the per-engine PM2.5 emission rate was estimated for each sector. In the 2002 inventory locomotive engines emitted the greatest amount of PM2.5 per engine (0.55 tons per engine). In 2016 locomotives are still the highest emitters at 0.22 tons per engine. The per-engine values for all other sectors are less than a tenth of the locomotives. Table 2-5 and Figure 2-5 show the PM2.5 emissions per engine within the sectors.

Figure 2-6 presents more detail in the estimates of per engine PM2.5 emissions. Besides locomotives, per engine emissions from off-road construction engines, on-road combination unit truck engines, marine engines, and stationary engines were among the highest of the diesel engine groups, while on-road passenger cars, light trucks, buses, and single unit trucks had among the lowest per engine emissions.

Table 2-5 and Figures 2-5 and 2-6 show the on-road per engine emissions calculated using all on-road emissions from EPA's mobile source emissions model (MOVES) divided by the on-road vehicles registered in Massachusetts. This overestimates the per-engine emissions for certain categories because the MOVES emissions are based on vehicle miles travelled (VMT) which includes vehicles that are registered out-of-state. This affects long-haul truck per engine emissions most because there are many long-haul trucks traveling through Massachusetts. The over estimation is offset somewhat because long-haul trucks registered in Massachusetts also spend a portion of their time outside of the state. MOVES national data suggest that long-haul trucks registered in Massachusetts travel significantly less within Massachusetts than the average long-haul truck travels in all states. Further refinement of the per engine emissions would require estimating VMT specific to Massachusetts from more detailed data from the International Registration Plan (IRP) (see Chapter 3).

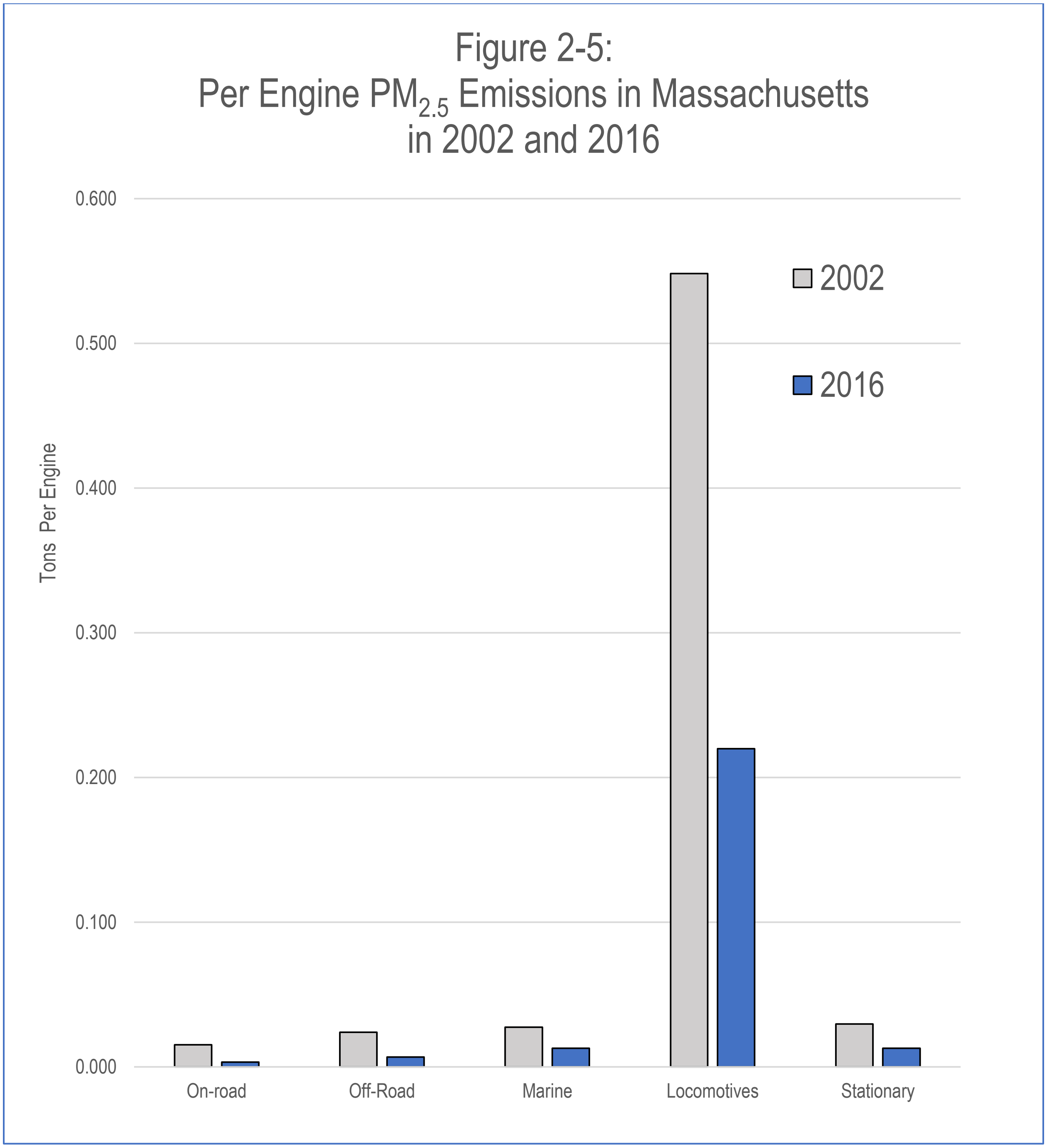

Figure 2-5 Per Engine $PM_{2.5}$ Emissions in Massachusetts in 2002 and 2016

Table 2-5 Per Engine $PM_{2.5}$ Emissions by Engine Group in Massachusetts in 2002 and 2016

Engine Group	2002 Number of Engines	2002 $PM_{2.5}$ Emissions (tons)	2002 $PM_{2.5}$ Per Engine (tons)	2016 Number of Engines	2016 $PM_{2.5}$ Emissions (tons)	2016 $PM_{2.5}$ Per Engine (tons)	Change in Per-Engine PM2.5
On-Road	121,476	1,860	0.015	164,640	497	0.003	-80%
Passenger Cars				14,981	4	0.0003	
Light Trucks				4,206	4	0.001	
Buses				11,413	11	0.001	
Single Unit Trucks**				93,490	78	0.001	
Combination Unit Trucks				40,550	401	0.010	
Land-Based, Off-Road	71,964	1,726	0.024	104,855	718	0.007	-71%
Construction Equipment	29,226	1,113	0.038	40,273	449	0.011	-71%
Commercial Equipment	22,921	198	0.009	34,457	113	0.003	-62%
Industrial Equipment	10,679	289	0.027	15,327	86	0.006	-79%
Six Off-Road Groups *	9,138	126	0.014	14,798	70	0.005	-66%
C1 and C2 Marine	6,787	187	0.028	5,797	75	0.013	-53%
Locomotives	259	142	0.550	299	66	0.221	-60%
Stationary	1,081	32	0.030	1,415	19	0.013	-55%
Total	201,567	3,947	0.020	277,006	1,375	0.005	-75%

* These include agricultural equipment, airport ground support equipment, commercial lawn and garden equipment, logging equipment, railroad equipment, and recreational equipment.
** Includes motorhomes and refuse trucks.

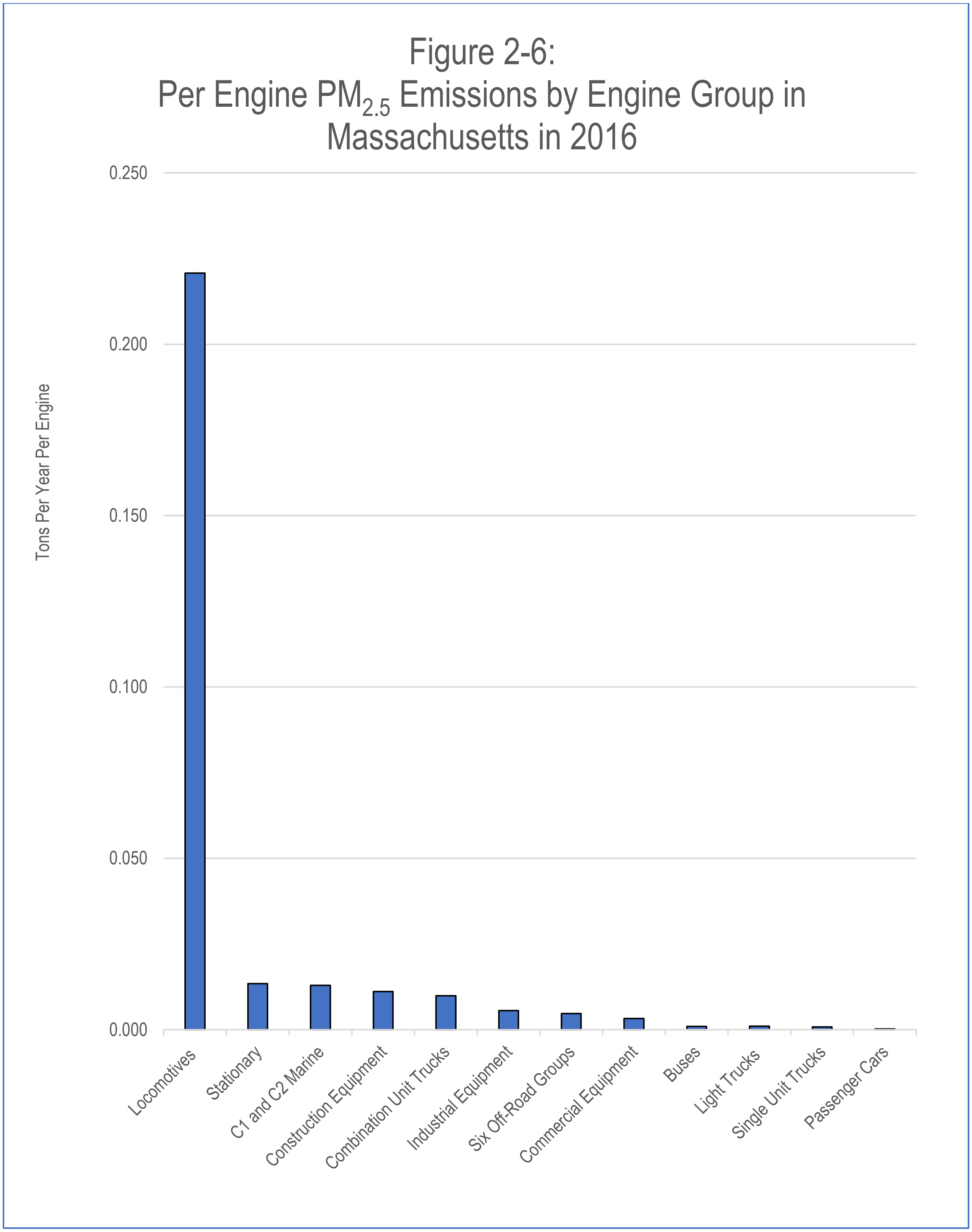

Figure 2-6 Per Engine $PM_{2.5}$ Emissions by Engine Group in Massachusetts in 2016

3.0 On-Road Diesel Engines

The on-road diesel engine sector consists of highway vehicles such as cars, pickup trucks, school and transit buses, delivery trucks, and 18-wheelers. This chapter identifies and estimates emissions from vehicles registered in Massachusetts, vehicles registered out-of-state traveling on Massachusetts roadways, school buses, transit buses, and waste collection vehicles.

3.1 Data Sources

Data for on-road diesel vehicles came from these sources.

- MassDEP and the Massachusetts Registry of Motor Vehicles (RMV) Vehicle Inspection Database (VID) (Appendix 3.6)
- Massachusetts Department of Transportation (MassDOT)
- EPA 2014 National Emissions Inventory (NEI) version 1
- International Fuel Tax Association, Inc. (IFTA)
- 2011 International Registration Plan (IRP) (provided by MassDEP)

3.2 Number of On-Road Diesel Vehicles

Based on analysis of data from the VID and older IRP data, in 2016 there were 164,640 on-road diesel vehicles registered in Massachusetts and an estimated 556,639 diesel trucks registered out–of-state. Of the 164,640 vehicles registered in Massachusetts, there were:

- 6,415 diesel school buses,
- 4,131 diesel public and private transit buses, and
- 582 diesel waste collection vehicles.

The 556,639 trucks registered out-of-state are all heavy-duty because they were based on IRP data which only includes trucks above 26,000 lbs. MassDEP assumes that these trucks operate mostly on the interstates. Based on 2015 Massachusetts interstate annual average daily traffic (AADT) from the Highway Performance Monitoring System (HPMS), combination unit trucks make up 51% of the total combination and single unit truck volumes.[1] The percent of combination unit AADT is much lower (24-31%) on the non-interstate road classes (such as other principal arterials, minor arterials, collectors, and local roads). Using the interstate road splits of 49% and 51% of the HPMS AADT for single unit and combination unit respectively, the numbers of trucks registered out-of-state in each category were estimated as:

- 272,724 single unit trucks, and
- 283,915 combination unit trucks.

3.2.1 *State-Registered On-Road Diesel Vehicles*

The Massachusetts Enhanced Emissions and Safety Test Program requires all motor vehicles registered in Massachusetts, including all on-road diesel vehicles, to undergo annual vehicle safety inspections (and emissions inspections for certain vehicles). The VID operated by MassDEP and the

[1] HPMS Public Release of Geospatial Data in Shapefile Format. Available online at https://www.fhwa.dot.gov/policyinformation/hpms/shapefiles.cfm. Massachusetts 2015 data was downloaded in September 2017.

Massachusetts RMV tracks all the data from these inspections. As discussed further in Section 3.7, a January 2016 snapshot of diesel vehicles in the Massachusetts VID was analyzed. The original database included 169,764 vehicles, but upon further analysis of the vehicle characteristics 1,710 vehicles were found to be fueled by gasoline and 3,414 more were identified as off-road vehicles. The gasoline and off-road vehicles (3% of the database) were excluded from further analysis. The remaining 164,640 on-road diesel vehicles were mapped into the categories required by EPA's MOtor Vehicle Emission Simulator (MOVES) model. Table 3-1 lists the 2016 vehicle populations categorized into broad groups to enable comparison to the 2002 inventory. Figure 3-1 illustrates the same population summary as Table 3-1. Table 3-2 lists the diesel vehicles registered in Massachusetts in 2016 summarized by MOVES source use types.

Table 3-1 Population of On-Road Diesel Vehicles in Massachusetts in 2002 and 2016

Diesel On-Road Vehicle Type	2002 Population	2016 Population	Percent Change
Registered in Massachusetts	121,476	164,640	36%
School Buses	8,497	6,415	-25%
Transit Buses	4,083	4,131	1%
Waste Collection Trucks*	1,980	582	-71%
Other: Trucks and Passenger Cars	106,916	153,512	44%
Registered Out-of-State	481,000	556,639	16%
Total	602,476	721,279	20%

SOURCE: Analysis of the 2016 VID and the MassDEP 2002 inventory

* The 2002-2016 disparity is due to differences in the two different databases. The 2002 diesel report used US Census data that did not identify vehicles by fuel so all waste vehicles were counted as diesel. Therefore this category is likely overestimated in the 2002 report. This 2016 report used a Massachusetts RMV database based on 'BodyStyle –GARBA' to identify garbage vehicles as explained in Section 3.2.5.

Table 3-2 On-Road Diesel Vehicles Registered in Massachusetts in 2016

MOVES Source Use Types	Examples of Vehicles in Class	Population
Passenger Car	Cars and smaller SUVs	14,981
Passenger and Light Commercial Trucks	Pickups with GVWR* ≤ 10,000 lbs.	4,206
Buses	Intercity travel, transit, and school buses	11,413
Single Unit Trucks	Refuse trucks, local delivery trucks, motorhomes	93,490
Combination Unit Trucks	Tractor-trailer trucks often used for interstate travel	40,550
Total		164,640

* GVWR is gross vehicle weight rating and means the value specified by the manufacturer as the loaded weight of a single vehicle. (49 CFR 579.3).

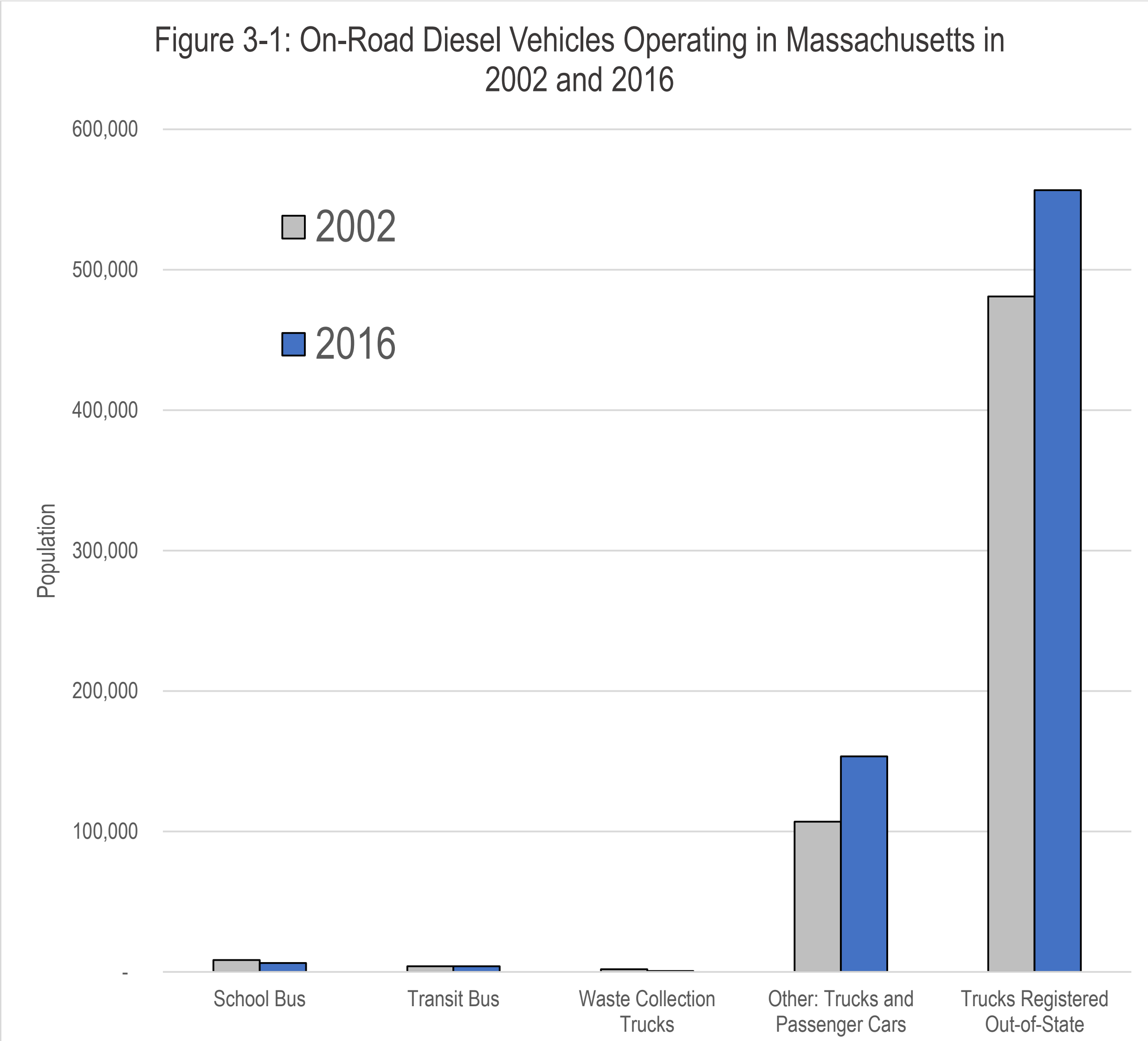

Figure 3-1 On-Road Diesel Vehicles Operating in Massachusetts in 2002 and 2016

As Table 3-2 shows, the majority of the state's diesel vehicles are single-unit (93,490) and combination-unit (40,550) trucks – nearly 134,000 vehicles together (or 81% of total diesel vehicles). According to license plate information in the VID most of these vehicles are used for commercial purposes. Diesel buses (11,413) made up nearly 7% of the registered vehicles, and the remaining diesel vehicles are cars (14,981) or passenger and light commercial trucks weighing 10,000 lbs. or less (4,206 vehicles).

3.2.2 *Out-of-State On-Road Vehicles*

The available information on the number of trucks registered out-of-state travelling on Massachusetts roads is dated. One estimate of trucks registered out-of-state is 530,888 vehicles from 2011 International Registration Plan (IRP) data. The IRP is an agreement among jurisdictions (U.S. states and Canadian provinces) which provide apportioned payments of registration fees based on the carrier's vehicle miles travelled (VMT) in the jurisdictions. The International Fuel Tax Agreement

(IFTA) is a similar program for distributing fuel tax revenues to states and provinces. Program participation is voluntary for carriers, but they do have an incentive – the alternative to IRP and IFTA registration is that a truck carrier must call ahead of an interstate trip to secure temporary travel permits from each member jurisdiction through which the truck trip would pass.

When a truck is registered under IRP and IFTA it receives decals to display on the body and an "apportioned" license plate type. The Massachusetts RMV database's 164,640 diesel vehicles includes 21,136 of vehicles with apportioned plates, 95% of which were classified as single and combination unit trucks. The other 5% are affixed to intercity buses and refuse trucks.

A carrier may register with IRP and IFTA declaring Massachusetts as its "base jurisdiction" if the vehicle travels on the state's roadways and either of the following conditions are met: (1) the vehicle is registered in-state or (2) the out-of-state registration can be made available to Massachusetts.[2] According to published IFTA records, the number of trucks registered with Massachusetts as their base jurisdiction in 2016 was 29,710 vehicles.[3] Subtracting the 21,136 apportioned plate Massachusetts vehicles from this number leaves 8,574 confirmed out-of-state vehicles operating on Massachusetts roadways in 2016. This estimate is low and incomplete, however, because it does not include trucks that are registered in other base jurisdictions and travel in Massachusetts. Furthermore, the estimate does not include any of the temporary travel permits issued by the RMV for vehicles that are not registered under IRP/IFTA. Unfortunately, this information is not readily available.

Due to the challenges of developing an inventory of the out-of-state vehicle population, a simplified estimation approach was taken. First, the 2011 IRP numbers (530,888 vehicles) were projected to 577,775 vehicles for 2016 assuming a growth of 8.8%, which is the same as the growth in number of IFTA decals issued in Massachusetts in 2016 relative to 2011.[4] Subtracting the apportioned vehicles registered in Massachusetts (21,136) from 577,775 vehicles leaves an estimate of 556,639 vehicles registered out-of-state.

It is worth noting that the total 2016 VMT from MassDOT includes travel by all vehicles regardless of where they are registered, so the PM emission inventory is consistent with real vehicle activity in the state. The uncertainty rests in how many vehicles contribute to that VMT and where they are registered.

3.2.3 *School Buses*

School buses registered in Massachusetts receive a special license plate type, and these plates were identifiable in the RMV database as the code abbreviation SBN or SBR.[5] A total of 6,415 diesel school buses were extracted from the 2016 RMV database by filtering on the field "RMV_PlateType" for these categories. Appendix 3.1 summarizes the diesel and gasoline bus populations in the RMV database according to their city or town of registration.

3.2.4 *Transit and Intercity Buses*

Non-school buses registered in Massachusetts were extracted from the RMV database based on meeting either of the two following criteria. First, if the RMV registration database field

2 http://www.mass.gov/dor/docs/dor/forms/miscform/pdfs/ifta-bklt.pdf
3 https://www.iftach.org/annualedit/viewall2016.php?jur=Massachusetts
4 IFTA decals issued by year and state. https://www.iftach.org/annualreports/ or http://www.massrmv.com/portals/30/docs/20141.pdf
5 Plate Type definitions in the RMV database. http://www.massagent.com/rpmlinks/umsappenda.pdf

"RMV_BodyStyle" was a "Bus" *and* the plate type was not a school bus (i.e., not SBN or SBR), then the vehicle was considered a non-school bus. The second criteria relaxed the restriction on body style (allowing large vans, for example) but required the field "RMV_PlateType" to be one of the bus or livery category codes that includes BUN, BUR, BUV, LVN, LVR, or LVV. Some of the livery plate vehicles however had a GVWR of less than 10,000 lbs., and these were excluded from the non-school bus category.

After the non-school buses were extracted from the 2016 registration database they were further divided into the MOVES bus categories of "Transit" or "Intercity" based on whether the license plate type was apportioned. For MOVES categorization purposes, all apportioned plate non-school buses were assumed to be Intercity Bus (867 vehicles) and non-apportioned plates were assigned to Transit Bus (4,131 vehicles) as shown in Table 3-5. Appendix 3.2 lists the intercity buses by city or town of registration.

3.2.5 *Waste Collection Vehicles*

Refuse truck populations in Massachusetts were extracted from the RMV database where the field "RMV_BodyStyle" listed the text "GARBA," which signifies a garbage truck.[6] A total of 582 vehicles were identified as diesel refuse trucks by this method.

3.3 Growth in On-Road Vehicle Travel

According to the Federal Highway Administration's Highway Statistics (VM-2 table), Massachusetts VMT increased from 53,266 million miles in 2002[7] to 60,531 million miles in 2016. The growth in VMT from 2002 to 2016 was 14%.

3.4 PM Emission Standards

To estimate emissions from a full fleet made up of new and older vehicles it is important to know the PM emission standards in effect at the time of the engine's manufacture. EPA first regulated PM 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. Heavy-duty trucks manufactured before 1988 have no PM controls and represent the highest-emitting vehicles on the road. In subsequent years EPA tightened the standard three more times for model year 1991, 1994, and 2007 engines. As Table 3-3 shows, model year 2007 on-road heavy-duty vehicles have the lowest PM standard to date (0.01 g/bhp-hr).[8] Final phase-in of the 2007 standard was on a percent-of-sales basis: 25% in 2007, 50% in 2008, 75% in 2009, and 100% in 2010. Federal PM standards for urban bus engines were first promulgated in 1988 and were more stringent than for heavy-duty diesel truck engines during the 1990s until the standards synchronized in 2007.

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[6] Body Style definitions in the RMV database. http://www.massrmv.com/Portals/30/docs/ums/userman/20847.pdf
[7] 2002 FHWA Highway Statistics. https://www.fhwa.dot.gov/policy/ohim/hs02/vm2.cfm
[8] 66 FR 5002, Jan. 18, 2001.

Table 3-3 National PM Emission Standards for On-Road Heavy-Duty Diesel Vehicles

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

SOURCE: EPA (2016b)
* g/bhp-hr = grams per brake-horsepower-hour

The standards shown in Table 3-4 apply to the following diesel vehicle types.[9]

- cars (light-duty vehicles) (LDV)
- light-duty-trucks (LDT):
  - LDT1 with a GVWR ≤ 6,000 lbs. and loaded vehicle weight (LVW)[10] ≤ 3,750 lbs.
  - LDT2 with a GVWR ≤ 6,000 lbs. and a LVW > 3,750 lbs.
  - LDT3 with a GVWR > 6,000 lbs. and ≤ 8,500 lbs. and with an adjusted loaded vehicle weight (ALVW)[11] ≤ 5,750 lbs.
  - LDT4 with a GVWR > 6,000 lbs. and ≤ 8,500 lbs. and with an ALVW > 5,750 lbs.
- medium duty passenger vehicles (MDPV) with a GVWR of 8,501-10,000 lbs.
- heavy-duty vehicles (Tier 3 only) with GVWR > 8,500 lbs or curb weight > 6,000 lbs.

EPA first regulated light-duty vehicle PM emissions for model year 1981, which later became known as the Tier 0 standards. Tier 0 remained in effect until EPA promulgated Tier 1 for model year 1994, which phased in progressively for model years 1994-1997. For model year 1999, EPA implemented the Clean Fuel Vehicles (CFV) standards. Also for model year 1999, the northeastern states voluntarily adopted California's emission standards (known as the national low emission vehicle or NLEV standards) on an earlier implementation schedule than was federally mandated. For model year 2004, EPA began the transition to Tier 2 emissions standards which phased in for model years 2004-2007. The standards also applied to MDPVs for the first time. These standards remained in effect through model year 2016.

[9] 40 CFR 86.1803-01 Definitions. https://www.ecfr.gov/cgi-bin/retrieveECFR?gp=1&SID=02e4334add3f1e394f0ebe3eeecb2caf&ty=HTML&h=L&mc=true&r=SECTION&n=se40.21.86_11803_601
Also see: United States: Cars and Light Duty Trucks. https://www.dieselnet.com/standards/us/ld_t2.php and EPA Vehicle Weight Classifications for the Emission Standards Reference Guide https://www.epa.gov/emission-standards-reference-guide/vehicle-weight-classifications-emission-standards-reference-guide

[10] LVW (loaded vehicle weight) = curb weight + 300 lb (40 CFR 86.1803-01)

[11] ALVW (adjusted loaded vehicle weight) = average of GVWR and curb weight (40 CFR 86.1803-01)

Table 3-4 National PM Emission Standards for On-Road Diesel Vehicles

Emission Standard	Model Year Standard is Effective	Vehicle Type	Emission Category	PM Standard at 50,000 miles (grams/mile)	PM Standard at Full Life[a] (grams/mile)
Tier 0	1981	LDV	--	0.20	--
		LDT1	--	--	0.26
		LDT2	--	--	0.13
		LDT3	--	--	0.26
		LDT4	--	--	0.13
Tier 1	1994	LDV	--	0.08	0.1
		LDT1	--	0.08	0.1
		LDT2	--	0.08	0.1
		LDT3	--	--	0.1
		LDT4	--	--	0.12
NLEV and Federal CFV	1999	LDV, LDT1, and LDT2	TLEV	0.08	0.08
			LEV	0.08	0.08
			ULEV	0.08	0.04
			ZEV	0	0
		LDT3 0-3750 ALVW	LEV	--	0.08
			ILEV	--	0.08
			ULEV	--	0.04
		LDT3 3751-5750 ALVW	LEV	--	0.1
			ILEV	--	0.1
			ULEV	--	0.1
		LDT4 5751-8500 ALVW	LEV	--	0.12
			ILEV	--	0.12
			ULEV	--	0.06
Tier 2	2004	LDV, LDT1, LDT2, LDT3, LDT4, and MDPV	Bin1	--	0
			Bins 2-6	--	0.01
			Bins 7-8	--	0.02
			Bin 9[b]	--	0.06
			Bin 10[b]	--	0.08
			Bin 11[b]	--	0.12
Tier 3 at 150,000 miles*	2017	LDV, LDT1, LDT2, LDT3, LDT4, MDPV, and HDV	Bin 20-160	LDV 0.01	0.003
				--	HDV 2B 0.08
				HDV 0.08	HDV-3 0.10

SOURCE: EPA (2016c, 2016d, 2016e).
[a] Full Life is 100,000 miles until Tier 2 when it became defined as 120,000 miles.
[b] Bins 9-11 expired in 2006 for LDV and LDT1/2 and in 2008 for LDT3/4.

*EPA Proposes Tier 3 Tailpipe and Evaporative Emission and Vehicle Fuel Standards
Regulatory Announcement
https://www.dieselnet.com/standards/us/ld_t3.php
Low Emission Vehicles (LEV) types:[12]
CFV – Clean Fuel Vehicle
ILEV – Inherently Low Emission Vehicle (hybrid)
NLEV – National Low Emission Vehicle
TLEV – Transitional Low Emission Vehicle
ULEV – Ultra Low Emission Vehicle
ZEV – Zero Emission Vehicle

Starting in model year 2017, EPA again tightened emission standards with the Tier 3 rule, which reduces PM emission standards to 0.003 g/mi, extends the full life to 150,000 miles, and applies to class 2b and 3 heavy-duty trucks (previously governed by heavy-duty standards). Tier 3 began in model year 2017 and will be fully phased in by model year 2025.

3.5 Diesel Fuel

For many years on-road diesel vehicles operated on diesel fuel with an average in-use sulfur level of 350 ppm. Effective 2006, EPA required the sulfur level of on-road diesel to begin decreasing to 15 ppm (known as Ultra Low Sulfur Diesel (ULSD)) to facilitate the introduction of model year 2007 vehicles whose emission control after-treatment devices require ultra-low levels of sulfur to operate properly. By October 2006, refiners and importers across the country had to ensure that at least 80% of the volume of highway diesel fuel being sold was ULSD fuel.[13] From October 2006 to December 2010 retail outlets sold either the ULSD fuel alone or in conjunction with 350 ppm-sulfur fuel. Since December 2010 retail outlets have sold ULSD as the only type of diesel fuel.

Table 3-5 shows the estimated 2016 fuel usage and fuel economy by MOVES diesel vehicle "source use type" in Massachusetts compared to MOVES national fuel economy data. Differences between Massachusetts and national average miles per gallon are likely due to differences in vehicle age distributions.

- **The third most populous vehicle category, combination unit long-haul trucks, used the most diesel fuel — over 145 million gallons**. Despite their moderate population these vehicles have relatively low fuel economy (approximately 5 miles per gallon) and travel the most miles annually, factors that together result in a high amount of fuel consumed. The next two largest users of diesel fuel were combination unit short-haul trucks (almost 82 million gallons per year) and single unit short-haul trucks (almost 30 million gallons per year).

- **Per vehicle, combination unit long-haul trucks consumed the most fuel (over 9,000 gallons per vehicle per year) – more than 2 times any other category.**

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[12] Emission Standards: USA: Cars and Light-Duty Trucks—California *https://www.dieselnet.com/standards/us/ld_ca.php*

[13] 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." Available on-line at: http://www.clean-diesel.org/highway.html.

Table 3-5 Fuel Usage for On-Road Diesel Vehicles in Massachusetts in 2016

Diesel Source Use Type	Total Engines	Diesel Fuel Consumption (gallons)	Per Vehicle (gallons)	Diesel VMT (miles)	Massachusetts MOVES Diesel Vehicle Fuel Economy (MPG)*	National MOVES Diesel Vehicle Fuel Economy, 2016 (MPG)
Passenger Cars	14,981	26,285,325	1,756	707,707,226	26.9	*29.0*
Passenger Trucks	4,015	15,398,001	3,835	233,361,473	15.2	*15.2*
Light Commercial Trucks	191	655,320	3,431	10,895,013	16.6	*15.8*
Intercity Bus	867	2,264,789	2,612	12,248,267	5.4	*5.8*
Transit Bus	4,131	3,708,119	1,402	25,393,365	6.8	*7.2*
School Bus	6,415	1,804,413	281	16,532,304	9.2	*10.2*
Refuse Truck	582	722,843	1,242	3,886,470	5.4	*5.9*
Single Unit Short-haul Truck	86,716	29,882,325	407	260,847,837	8.7	*10.1*
Single Unit Long-haul Truck	4,603	2,703,493	587	25,976,454	9.6	*10.9*
Motor Home	1,589	103,202	65	841,765	8.2	*9.3*
Combination Unit Short-haul Truck	25,043	81,868,305	3,861	432,925,261	5.3	*5.9*
Combination Unit Long-haul Truck	15,507	145,277,497	9,369	745,943,118	5.1	*5.3*
Total	164,640	310,673,630	2,128	2,476,558,553		

SOURCE: U.S. EPA MOVES2014a Onroad Model, Massachusetts Counties, Calendar Year 2016
* MPG - Miles per gallon

3.6 Model Year and Vehicle Type

Figure 3-2 shows the on-road diesel vehicles by model year that summarizes the registration data in Appendix 3.6. The model years included in the VID ranged from 1910 to 2017.

- **The two model years with the highest diesel vehicle population on the road were 2006 (10,725 vehicles) and 2015 (10,686 vehicles).** The 2006 heavy-duty models were manufactured to meet the 1994 heavy-duty PM standard of 0.1 g/bhp-hr, whereas the 2015 heavy-duty models meet the 2007 standard of 0.01 g/bhp-hr. In anticipation of the 2007 standards there was a large uptick in 2006 vehicle sales. The economic recession of 2007-2010 could also explain the reduced sales of new vehicles in Massachusetts in those years.

- **Model years 2007 and later represent almost half (48% or 78,866) of on-road diesel vehicles. Another 45% (74,096) were model year 1994 to 2006.** This means that nearly half the 2016 heavy-duty diesel vehicle fleet in Massachusetts was manufactured to meet the 1994 heavy-duty standard of 0.10 g/bhp-hr, and nearly another half of the fleet meet the cleanest 2007 heavy-duty standard of 0.01 g/bhp-hr. In 2002, 69% of all diesel vehicles registered in Massachusetts were model year 1994 or later compared to 93% by 2016. The fleet is therefore now much cleaner.

- **Only 4% of vehicles (6,058) were model years 1988 to 1993.** Approximately half of the heavy-duty vehicles in this small group were manufactured to meet the 0.25 g/bhp-hr PM emission standard effective for model years 1991 through 1993. The other half was manufactured to the 0.60 g/bhp-hr heavy-duty PM emission standard effective for model years 1988 through 1990.

- **3% of vehicles (5,620) were model years 1910 to 1987.** Vehicles in this group were manufactured before there was a PM standard in place. Due to the absence of a standard and their age in 2016, these vehicles emit the most $PM_{2.5}$ per mile traveled of the diesel vehicles registered in Massachusetts. Table 3-6 lists the pre-1988 vehicles by model year groups in 2002 and 2016. The number of registered vehicles manufactured before 1988 decreased 71% over the 14-year period.

Table 3-6 Number of Pre-1988 Diesel Vehicles by Model Year Groups in Massachusetts 2002 and 2016

Model Years	2002 Population	2016 Population
1910-1960	70	126
1961-1970	566	203
1971-1980	3,494	770
1981-1987	15,505	4,521
Total	19,635	5,620

SOURCE: MassDEP 2002 Particulate Matter Emission Inventory, MassDEP and Massachusetts RMV, 2016.

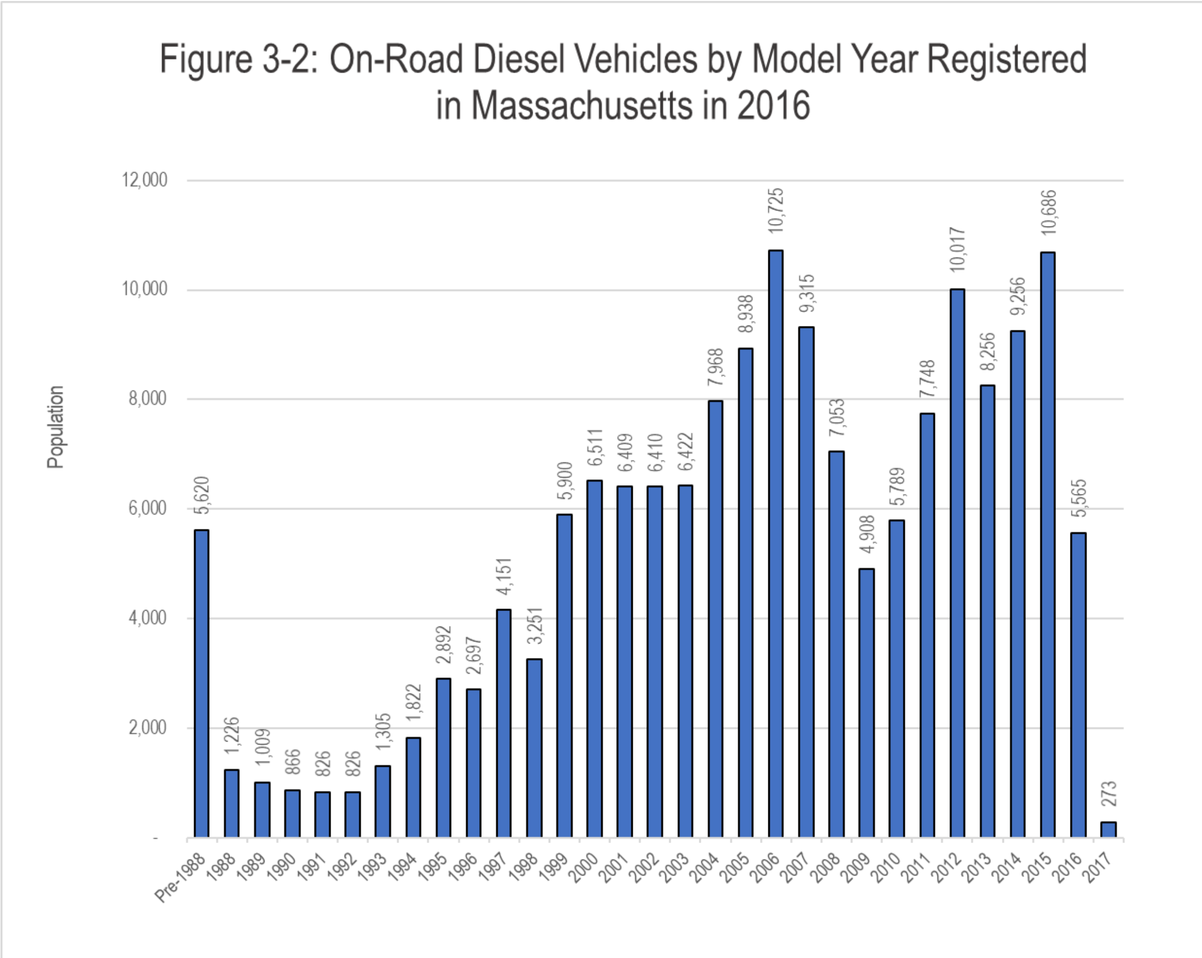

Figure 3-2 On-Road Diesel Vehicles by Model Year Registered in Massachusetts in 2016

Figures 3-3, 3-4, 3-5, and 3-6 show differences in the model year distribution for subsets of the total diesel population by groups of MOVES source type. Note that the vertical scales differ from figure to figure.

Figure 3-3 shows the population age distribution for the 19,187 light-duty diesel cars and trucks. These are the newest population of diesel vehicles. These are subject to the light-duty truck PM standards discussed previously (see Table 3-4). The vast majority (86%) of the cars and light trucks are 2004 model year and later, which was the first phase-in year for federal light-duty Tier 2 emission standards for PM. By 2009, all new light-duty vehicles were required to comply with Tier 2 standards. The next set of emission standards, Tier 3, phases in between 2017 and 2025.

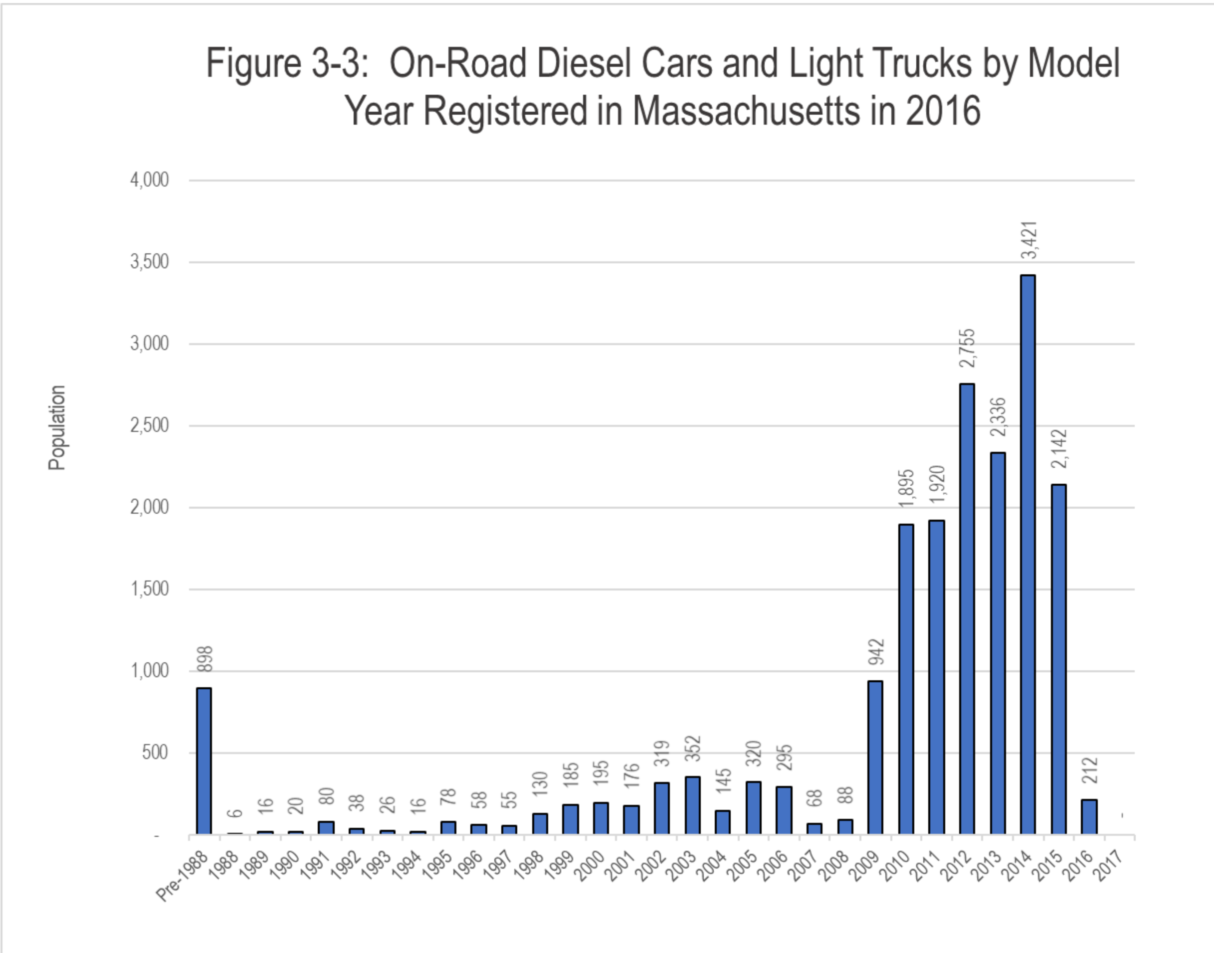

Figure 3-3 On-Road Diesel Cars and Light Trucks by Model Year Registered in Massachusetts in 2016

Figure 3-4 shows the population of 11,413 intercity, transit, and school buses by model year. Most of these vehicles (73%) are subject to the heavy-duty truck standards rather than the urban bus standards (Table 3-3) because only 36% of the diesel buses registered in Massachusetts are transit buses. Nearly all (99%) of the buses were manufactured to meet the 1994 PM standards (over 25%) or the 2007 standard (over 73%).

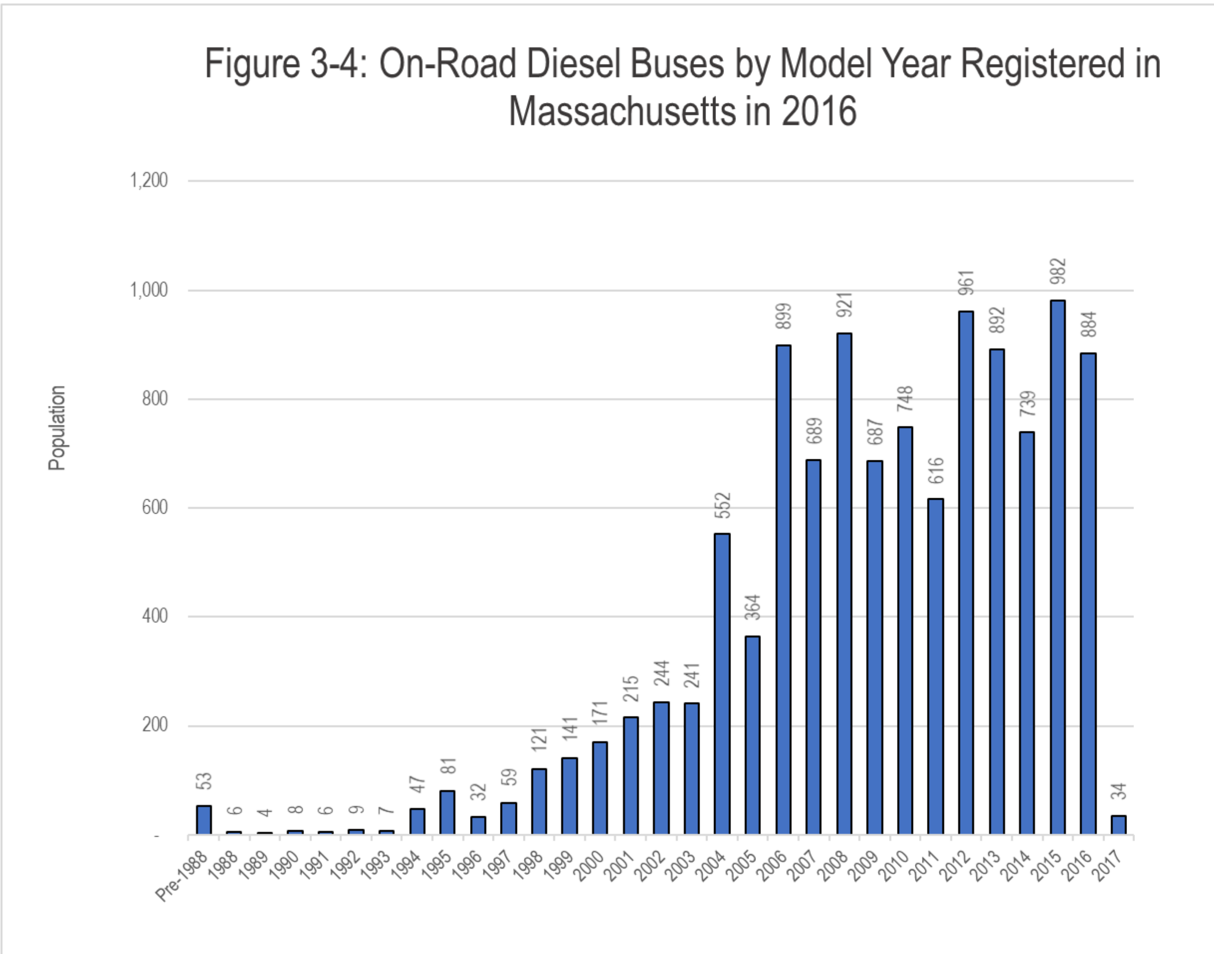

Figure 3-4 On-Road Diesel Buses by Model Year Registered in Massachusetts in 2016

Figure 3-5 shows the population of 93,490 single-unit trucks by model year that were registered in Massachusetts in 2016. These vehicles were typically older than the buses. Over 92% of these trucks meet either the 1994 (53%) or 2007 (39%) PM standards.

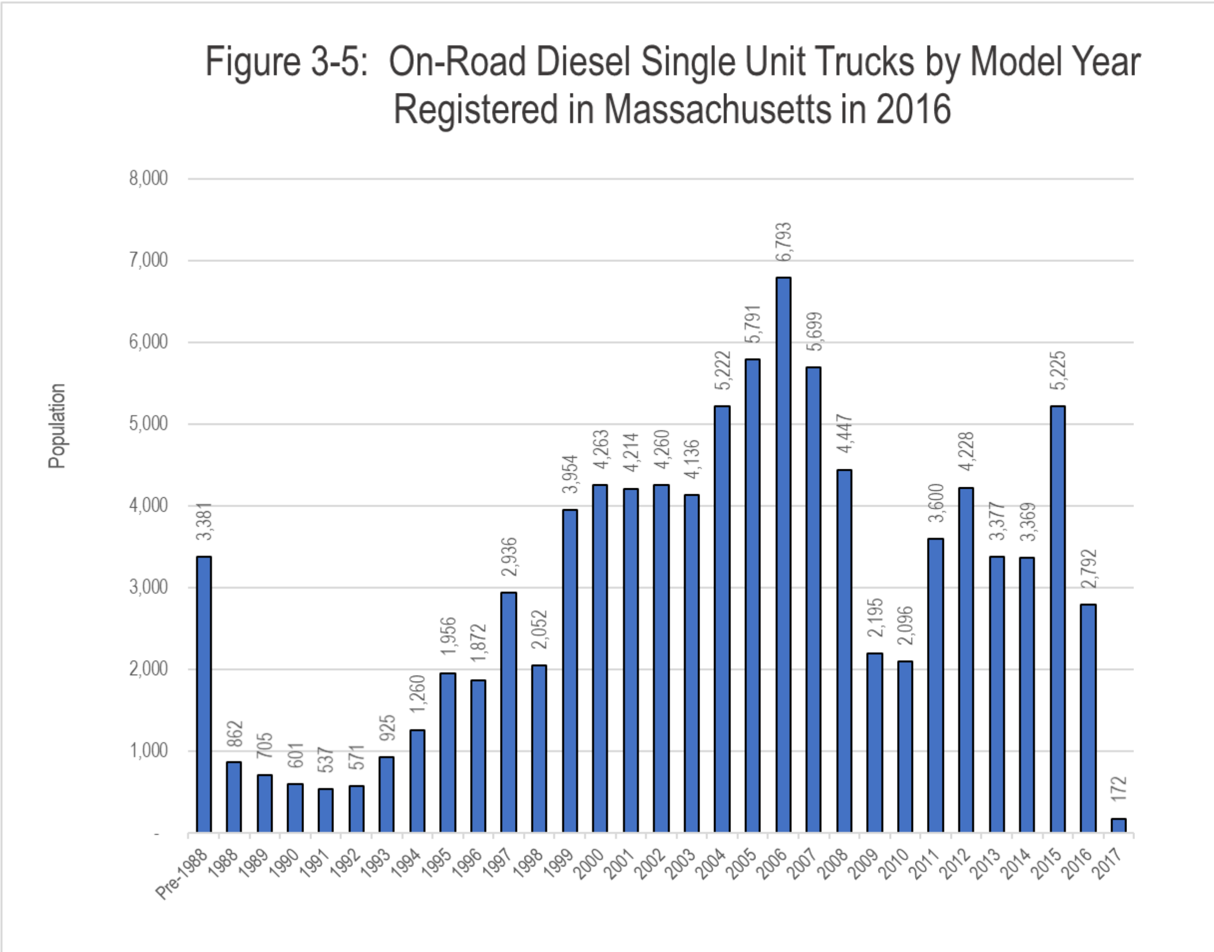

Figure 3-5 On-Road Diesel Single Unit Trucks by Model Year Registered in Massachusetts in 2016

Figure 3-6 illustrates the model years of the 40,551 diesel combination unit trucks registered in Massachusetts in 2016. These vehicles are similar in age to the single unit trucks. Of the combination trucks, almost all (93%) were manufactured to meet either the 1994 PM standards (nearly 50%) or 2007 PM standards (nearly 44%).

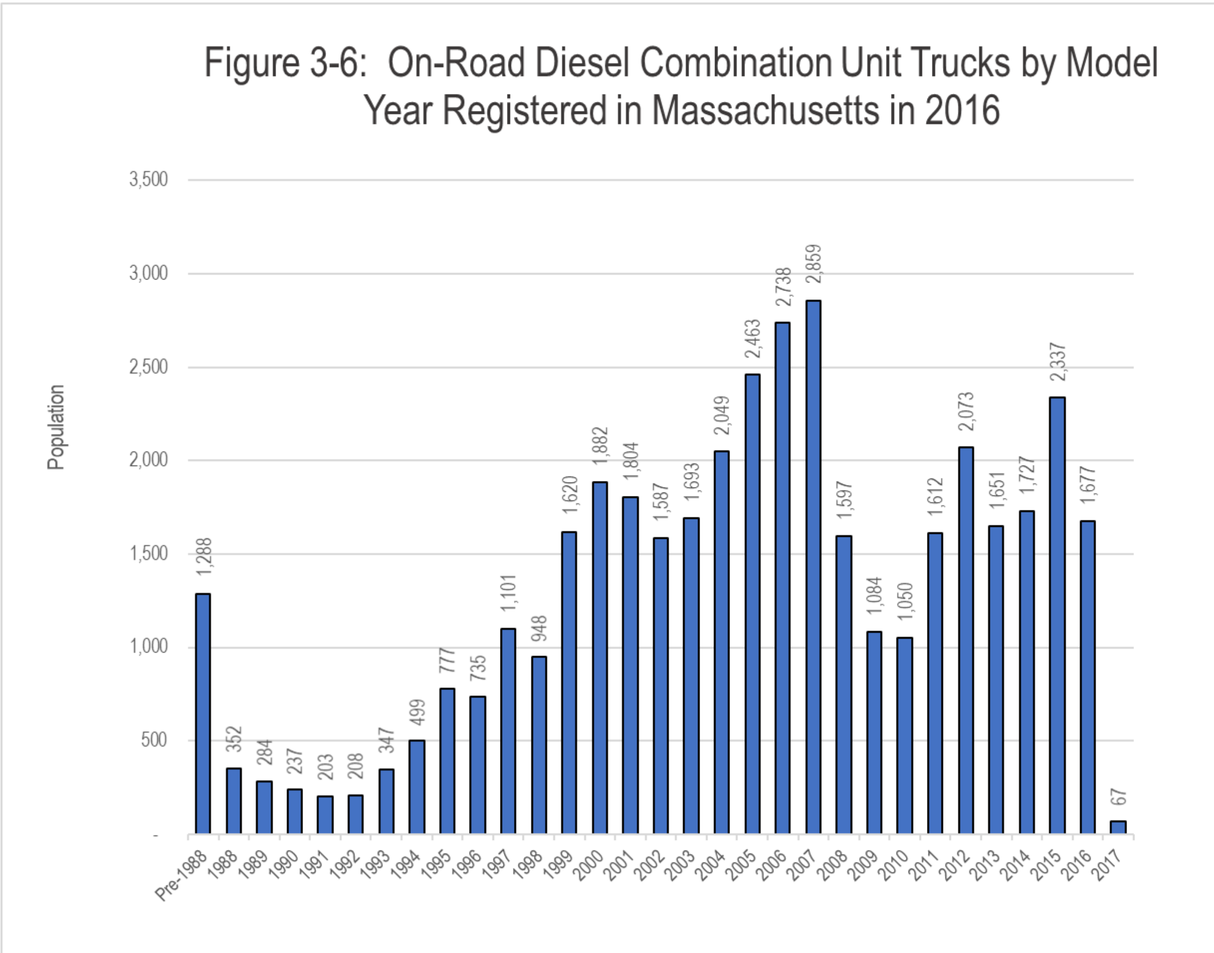

Figure 3-6 On-Road Diesel Combination Unit Trucks by Model Year Registered in Massachusetts in 2016

Table 3-7 gives the model years for all on-road diesel vehicles registered in Massachusetts in 2016 by source use type.

- **Nearly half (48%) of all registered diesel vehicles were model year 2007 and newer.** This means that nearly half the fleet meets the most stringent emission standards in place in 2016, which were the Tier 2 standards for light-duty vehicles (Table 3-4) and the 2007 heavy-duty PM emission standard (Table 3-3).

- **Diesel cars and light-duty trucks have the newest fleets (82% 2007 and later vehicles).** Out of the heavy-duty vehicles, buses had the newest fleet with 74% meeting the 2007 PM emission standard.

Table 3-7 Number of On-Road Diesel Vehicles by Model Year and Source Use Type Group Registered in Massachusetts in 2016

	Model Year					
Source Use Type	Pre-1988	1988-1990	1991-1993	1994-2006	2007-2017	Total
Passenger Cars	805	30	138	2,176	11,832	14,981
Passenger and Light Commercial Trucks	93	12	6	148	3,947	4,206
Buses	53	18	22	3,167	8,153	11,413
Single Unit Trucks*	3,381	2,167	2,032	48,709	37,200	93,490
Combination Unit Trucks	1,288	874	759	19,896	17,734	40,550
Total	5,620	3,101	2,957	74,096	78,866	164,640

* Includes refuse trucks and motor homes.
SOURCE: MassDEP and Massachusetts RMV, 2016.

3.6.1 School Buses

The 6,415 diesel school buses identified are relatively new.

- **29% (1,377 buses) of the school buses were model year 1995 to 2006** and were manufactured to meet the 1994 PM standard of 0.10 g/bhp-hr.

- **71% (5,038 buses) of the school buses were manufactured in 2007 or later** and were manufactured to meet the 2007 PM standard (0.01 g/bhp-hr).

3.6.2 Transit Vehicles

Transit buses had a similar age distribution to school buses. Of the 4,131 transit buses, nearly 65% (2,682 vehicles) were model year 2007 to 2017 and were manufactured to meet the 0.01 g/bhp-hr PM emission standard (see Table 3-8 and 3-9). Nearly 30% (1,247 vehicles) were model year 1996 to 2006 and manufactured to meet the urban bus PM emission standard of 0.05 g/bhp-hr.

Table 3-8 Diesel Transit Buses by Model Year and PM Emission Standard Registered in Massachusetts in 2016

Model Years	Number of Buses	Urban Bus $PM_{2.5}$ Standard (g/bhp-hr)
Pre-1988	52	N/A
1988-1990	17	0.60
1991-1992	13	0.25
1993	7	0.10
1994-1995	113	0.07
1996-2006	1,247	0.05
2007-2017	2,682	0.01
Total	4,131	

Due to interest in the number of buses registered by the Massachusetts Bay Transportation Authority (MBTA) and the 15 Massachusetts Regional Transit Authorities (RTAs), MassDEP conducted a query of the Vehicle Inspection Database (VID) that contains vehicle inspection records. The query approximated the eligibility criteria for funding under the VW Settlement (see https://www.mass.gov/guides/volkswagen-diesel-settlements-environmental-mitigation), to determine the number of pre-2010 diesel-fueled vehicles greater than 14,000 pounds GVWR registered by each authority that were inspected from February 2017 through March 2018. The VW Settlement limits eligibility to engine model years 2009 or older; however, the VID contains chassis model years rather than engine model years. Engine and chassis model years for a large vehicle are often the same, but sometimes differ based on production schedules. Table 3-9 summarizes the number of diesel vehicles greater than 14,000 pounds registered by each authority and inspected from February 2017 through March 2018, by chassis model year.

Table 3-9 Pre-2010 Diesel Vehicles by Authority and Model Year Registered in Massachusetts

Authority	Pre-1988	1988-1990	1991-1992	1994-1995	1996-2006	2007-2009	Total
Berkshire Regional Transit Authority					2	3	5
Brockton Area Transit Authority					18	11	29
Cape Ann Transit Authority					3	0	3
Cape Cod Regional Transit Authority					12	6	18
Franklin Regional Transit Authority					2	0	2
Greater Attleboro-Taunton Regional Transit Authority					10	5	15

Lowell Regional Transit Authority					1	20	21
MBTA	4	5	2	35	390	205	641
Merrimack Valley Regional Transit Authority					10	12	22
Metro West Regional Transit Authority					1	0	1
Montachusett Regional Transit Authority					11	10	21
Nantucket Regional Transit Authority					2	2	4
Pioneer Valley Transit Authority					31	49	80
Southeastern Regional Transit Authority				1	2	9	12
Vineyard Transit Authority					4	6	10
Worcester Regional Transit Authority					1	8	9
Total	4	5	2	36	500	346	893

3.6.3 *Waste Collection Vehicles*

Waste collection vehicles registered in Massachusetts are a considerably older fleet than other heavy-duty vehicles that serve neighborhoods (such as transit and school buses). In 2016, only about half (54%) of the 582 refuse trucks are model years 2007 and later, leaving 46% that were manufactured prior to 2007. Of these older trucks, 4% were built prior to the 1994 PM standard.

Waste collection vehicles have a unique start and stop low speed drive pattern not followed by other single-unit truck types. Furthermore, waste collection vehicles spend time at idle while loading and compacting waste. Therefore, the MOVES model contains refuse truck specific driving cycles (speed vs. time trace) (EPA, 2016a).

3.7 Vehicle Mapping into MOVES Source Use Types

January 2016 registration data from MassDEP and the RMV listed 169,764 vehicles with their unique vehicle identification number (VIN), the county of registration, and other descriptive fields (Appendix 3.6). Each vehicle was mapped to one of the 12 diesel-fueled MOVES source types. The most useful fields to help categorize the vehicles included Contractor_GVWR, Contractor_Mobile6Class, RMV_PlateType, and RMV_BodyStyle.

First, 1,710 gasoline vehicles were removed from the diesel registration database. These vehicles had a gasoline fueled Contractor_Mobile6Class and most of them were confirmed gasoline using an independent VIN decoder maintained by Eastern Research Group, Inc. Another 3,414 vehicles were classified as off-road equipment because: (1) their VINs did not decode to any on-road vehicle characteristics *and* their body style was an off-road equipment type (e.g., a crane or skid steer loader); or (2) their VIN did not decode *and* the RMV_Make field was a known manufacturer of off-road equipment (e.g., John Deere or Caterpillar). These exclusions left 164,640 diesel on-road vehicles remaining that required mapping into the 12 diesel-fueled MOVES source use types prior to estimating emissions in MOVES.

Second, all light-duty vehicles were classified as one of these source use types (with IDs): Passenger Car (21), Passenger Truck (31), or Light Commercial Truck (32). These were identified by the following criteria: (1) the field Contractor_GVWR was less than or equal to 10,000 lbs., and (2) the Contractor_Mobile6Class began with the letter "L" which includes LDDV, LDDT1, LDDT2, LDDT3, and LDDT4. LDDV were mapped to source type 21. The light-duty trucks were mapped to source types 31 or 32 depending on whether the RMV_PlateType field specified a personal plate (source type 31) or commercial plate (source type 32).

Third, buses were assigned one of the 3 MOVES bus source type IDs: Intercity Bus (41), Transit Bus (42), or School Bus (43). These were assigned based on the database fields RMV_BodyStyle and RMV_PlateType. School buses were readily identified by the RMV_PlateType because special plates are required to transport pupils in Massachusetts. The remaining non-school buses were identified by RMV_BodyStyle value of "Bus" and by separately filtering for bus plate types. Non-school buses were also extracted by filtering the RMV_PlateType on bus and livery plates, as discussed previously in Section 3.2.4. The non-school buses were split based on RMV_PlateType where buses with apportioned plates were all assigned to source type Intercity Bus (41) and non-apportioned plates were assigned Transit Bus (42).

Fourth, Refuse Trucks (source type 51) and Motor Homes (source type 54) were identified. Vehicles were assigned to source type 51 if the RMV_BodyStyle was "GARBA," signifying a garbage truck. Vehicles were assigned to source type 54 if the RMV_PlateType was camper – plate type codes "AHN," "AHV," or "AHR."

After extracting two of the single unit truck source use types (refuse trucks and motorhomes) the remainder of heavy-duty diesel trucks fell into one of four source use type categories: Single Unit Short-haul (52), Single Unit Long-haul (53), Combination Unit Short-haul (61), or Combination Unit Long-haul (62). First the short-haul trucks vs. long-haul trucks were split based on RMV_PlateType. Non-apportioned plates (primarily commercial plates) were mapped to a combined intermediate short-haul category that included 52 and 61 together. Likewise, apportioned plate types were mapped to the long-haul category of 53 and 62 together. There were no fields in the RMV database that reliably indicated whether the truck was a single-unit vs. combination-unit (i.e., tractor-trailer). Therefore split factors were used to divide these (52s from 61s; and 53s from 62s) based on EPA's source use type population posted online for version 2 of the 2014 NEI. The split factors were developed from EPA's vehicle population files that list population by source type, fuel type, and county thereby allowing Massachusetts county data to be extracted for use in developing the factors. The EPA population was a mid-year 2014 snapshot of a centrally compiled national registration database that included individual vehicle body characteristics. Source type ratios from this data set were applied to disaggregate the long-haul and short-haul groups created from the plate types.

3.8 PM Emissions from On-Road Diesel Vehicles

The MOVES on-road model (version 2014a, database movesdb20161117) was used to estimate the $PM_{2.5}$ and PM_{10} emissions from highway engines operating on diesel fuel. The runs were conducted at the model's County Domain/Scale and Inventory Calculation mode for each of the 14 counties in Massachusetts. The runs were performed for both weekdays and weekends of a winter month (January) and summer month (July), and the model outputs were manually aggregated outside of MOVES to calculate the annual inventory. The MOVES input, output, and summary files are presented in Appendices 3.3 to 3.8.

The following input parameters were used with MOVES:

- 2016 Massachusetts-specific age distributions derived from an analysis of the VID
- 2016 diesel source type populations derived from an analysis of the VID
- 2014 version 1 NEI county databases[14] for the following MOVES inputs
    - Diesel fractions (Alternative Vehicle Fuel Table (AVFT))
    - Source Type Population of vehicles fueled by gasoline, E85 and CNG, projected to 2016 using MOVES ratios of VMT
    - Stage II vapor recovery program parameters
    - Inspection and Maintenance program parameters
    - LEV base emission rates
    - VMT distributions by month, day type, and hour
    - Average speed distributions
- 2016 meteorology data prepared by MassDEP
- 2016 annual VMT and road type distribution provided by MassDOT

The exhaust $PM_{2.5}$ and PM_{10} emission inventory is summarized in Tables 3-10 and 3-11 and detailed in Appendix 3.4 for diesel-fueled and non-diesel-fueled vehicles by season (winter/summer) and as annual totals. The non-diesel category includes predominantly gasoline-fueled vehicles but also those that operate on ethanol (E85) and compressed natural gas (CNG). These non-diesel vehicles were included in Tables 3-10 and 3-11 and Appendix 3.4 for context because they make significant contributions to total exhaust PM.

The fraction of exhaust-only $PM_{2.5}$ and PM_{10} to total $PM_{2.5}$ and PM_{10} is presented for each MOVES source type in Table 3-11. The non-exhaust fraction of total PM emissions comes from brake and tire wear. For source types with a higher fraction of newer vehicles, where exhaust PM is well-controlled, the fraction of total PM coming from exhaust is smaller (see Appendix 3.5).

In past versions of MOVES (2010b and earlier) and MOBILE, exhaust PM was broken out into elemental carbon (EC), organic carbon (OC), and sulfate (SO_4). MOVES2014 and later provides more detailed components of the OC (e.g., nitrate, ammonium, and metals) required for air quality modeling (EPA, 2015). This level of detail is provided in Appendix 3.5.

[14] ftp://ftp.epa.gov/EmisInventory/2014/doc/onroad/2014v1_supportingdata/2014v1_CDBs/unseeded/

Table 3-10 Exhaust and Non-Exhaust PM Emissions from On-Road Vehicles in Massachusetts in 2016

Diesel Exhaust Only Source Use Type - Diesel	ID	$PM_{2.5}$	% of Diesel Total $PM_{2.5}$	PM_{10}	% of Diesel Total PM_{10}
Diesel Vehicles 2016					
Combination Unit Long-haul Truck	62	252.3	46%	274.2	31%
Combination Unit Short-haul Truck	61	148.2	27%	161.1	18%
Single Unit Short-haul Truck	52	71.5	13%	77.8	9%
Intercity Bus	41	5.4	1.0%	5.8	0.7%
Single Unit Long-haul Truck	53	4.9	0.9%	5.3	0.6%
Passenger Trucks	31	4.0	0.7%	4.3	0.5%
Passenger Cars	21	3.8	0.7%	4.1	0.5%
Transit Bus	42	3.1	0.6%	3.4	0.4%
School Bus	43	2.1	0.4%	2.2	0.3%
Refuse Truck	51	1.2	0.2%	1.3	0.1%
Motor Home	54	0.4	0.1%	0.5	0.1%
Light Commercial Truck	32	0.4	0.1%	0.4	0.04%
Diesel Exhaust Only - Total		497.3	92%	540.5	60%
Diesel Non-exhaust*		46.0	8%	356.3	40%
Diesel Total – Exhaust and Non-Exhaust		543.3	100%	896.9	100%
All On-Road Vehicles Exhaust 2016					
Non-Diesel Exhaust**		603.9		682.6	
Total All Vehicle Exhaust		1101.2		1223.1	
Diesel Vehicle Exhaust as % of All Vehicle Total Exhaust		45%		44%	
Diesel Vehicles 2002					
Diesel Exhaust Only		1,860		2,012	
Non-Diesel Exhaust Only		469		519	
Total All Vehicle Exhaust Only		2,329		2,531	
Diesel Vehicle Exhaust as % of All Vehicle Total Exhaust		80%		80%	
Diesel Non-Exhaust*		98		301	
Diesel Total – Exhaust and Non-Exhaust		1,958		2,313	

* brakes and tire wear, see Appendix 3.5 for analysis by source type for diesel vehicles (not available for non-diesel vehicles)

** gasoline, ethanol, CNG

The key results are as follows.

- **While diesel vehicles contributed to only 4% of the VMT, they emitted 45% of the on-road $PM_{2.5}$ exhaust emissions.**

- **Total PM_{10} emissions from on-road diesel vehicles in 2016 amounted to 897 tons (exhaust and non-exhaust).** Most of this was $PM_{2.5}$ (543 tons or 61%).

- **Exhaust emissions are the largest source of PM_{10} and almost all of the $PM_{2.5}$.** Exhaust emissions accounted for 60% of PM_{10} (541 tons) and almost all (92% or 497 tons) of the $PM_{2.5}$ for on-road diesel vehicles in 2016. In 2002, exhaust accounted for more of the total PM emissions – 80% (2,012 tons) of PM_{10} and 80% (1,860 tons) of $PM_{2.5}$. See Table 3-10 and Appendices 3.4 and 3.5.

- **Non-exhaust emissions from diesel vehicles (brake wear and tire wear) accounted for 40% (356 tons) of PM_{10} and only 8% (46 tons) of $PM_{2.5}$.** See Appendix 3.5 for details.

- **Because of the technology required to meet Tier 2 (for light-duty vehicles) and the 2007 standards (for heavy-duty), exhaust emissions are generally decreasing. Non-exhaust (e.g., brake and tire) PM_{10} emissions, however, are increasing with VMT.** See Table 3-10.

- **Seasonal PM effects were minimal for diesel-fueled vehicles.** For diesel-fueled vehicles, the winter PM emission factors were very close to the summer values. VMT, however, is seasonal. Because summer VMT was 26% higher than winter VMT, the emissions are also higher in summer by this percent. See Appendix 3.4 for details.

PM emissions in tons per day were calculated for each vehicle class. The emissions were calculated by first using MOVES for summer and winter conditions with Massachusetts VMT and other Massachusetts inputs. The outputs of MOVES were converted into composite exhaust emission rates (grams per mile) that included running exhaust, start exhaust, and extended idle exhaust. Detailed results from this analysis are presented in Appendix 3.4. The format of Appendix 3.4 follows the 2002 inventory by presenting the information as emission rates by season and calculating annual emissions by multiplying the summer rates by 183 days and the winter rates by 182 days, then summing to annual PM emissions.

Appendix 3.4 includes non-diesel vehicles as well as diesel vehicles for context, since gasoline, E85, and CNG vehicles collectively emit 55% of the exhaust $PM_{2.5.}$ However, this report focuses on $PM_{2.5}$ from diesel vehicles (information on non-diesel emissions can be found in MassDEP's emissions inventories).

Results from the MOVES runs are shown in Tables 3-10 and 3-11 and Figures 3-7 and 3-8; highlights for vehicle classes are given below.

- **Heavy-duty diesel vehicles contributed the most $PM_{2.5}$ to the diesel on-road sector totals, in both 2002 and 2016. Emissions from all vehicle types decreased substantially.[15]**

[15] The on-road emissions reported for 2002 were estimated using EPA's MOBILE6.2 model but 2016 emissions were estimated using EPA's MOVES model. While the main drivers for the emissions changes from 2002 to 2016 are the strengthening emission standards and fleet turnover, the change in model also has an effect. In an

Figure 3-8 shows the heavy-duty vehicle emissions as well as the light-duty and bus contributions. From 2002 to 2016, diesel heavy-duty (non-bus) vehicle emissions decreased 72%, diesel light-duty decreased 58%, and diesel bus $PM_{2.5}$ decreased 90%.

- **Combination unit long-haul trucks emitted the most $PM_{2.5}$ in 2016.** These vehicles accumulate the highest VMT annually per truck due to their long-haul usage patterns. In addition, combination unit long-haul trucks are the only source type in the inventory to have extended idling emissions. **Combination unit long-haul trucks contribute 51% of the $PM_{2.5}$ exhaust emissions from on-road diesel vehicles.** The next two largest contributors were combination-unit short-haul trucks (30% of diesel exhaust $PM_{2.5}$), then single unit short-haul trucks (14%). **Although single unit trucks comprise 55% of the diesel on-road engine population in 2016 (Table 3-7), they only emit 15% of the diesel $PM_{2.5}$ exhaust emissions (Table 3-11). In contrast, the combination unit trucks comprise only 25% of the population but account for 81% of the exhaust emissions.**

- **Motorhomes and Light Commercial Trucks emitted the least $PM_{2.5}$ in 2016.** Vehicles in these categories had low populations in Massachusetts. Motorhomes and Light Commercial Trucks each contributed 0.1% to the diesel on-road $PM_{2.5}$ emissions.

- **Motorhomes and Intercity Buses were the highest emitters on a per vehicle basis, but their overall $PM_{2.5}$ exhaust emissions were small compared to other vehicle classes.** Motorhomes and intercity buses had composite $PM_{2.5}$ emission factors of 0.48 and 0.40 grams per mile (see Table 3-11 and Appendix 3.4), but their VMT fractions were less than 0.01% each, making them insignificant contributors to the diesel PM inventory.

The $PM_{2.5}$ emissions contribution of vehicles registered out-of-state is unknown. This is because the MassDOT annual VMT used in the MOVES model does not distinguish between VMT from vehicles registered in Massachusetts and vehicles registered out-of-state.

Figure 3-7 shows the contribution of each MOVES source type to the total exhaust $PM_{2.5}$ emissions (excluding brake and tire), while Figure 3-8 compares the exhaust $PM_{2.5}$ from 2002 to 2016 for heavy-duty vehicles, light-duty vehicles, and buses.

EPA study the MOVES model was shown to produce somewhat lower emissions estimates than the MOBILE 6.2 model (EPA 2009). This does not materially impact the findings of this inventory.

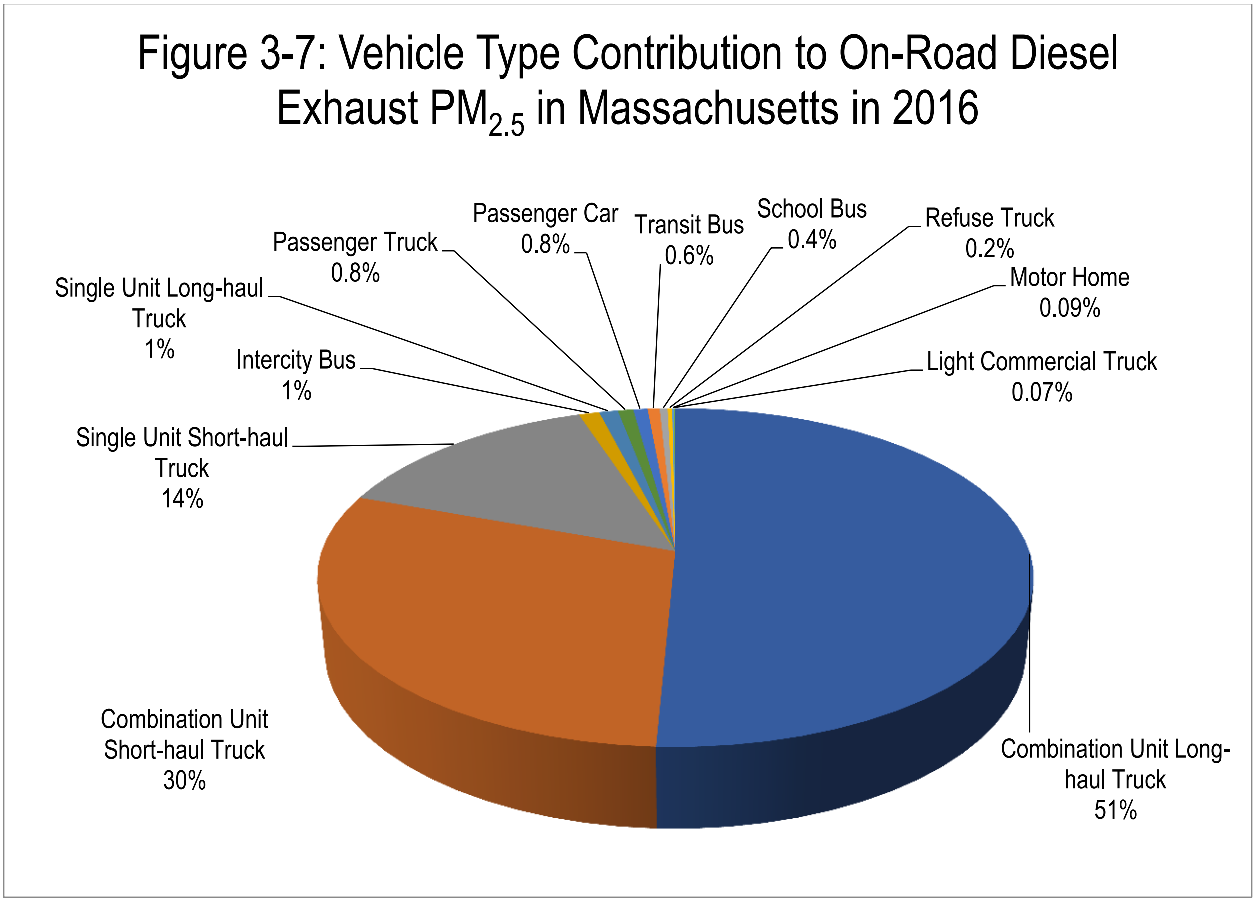

Figure 3-7 Vehicle Type Contribution to On-Road Diesel Exhaust $PM_{2.5}$ in Massachusetts in 2016

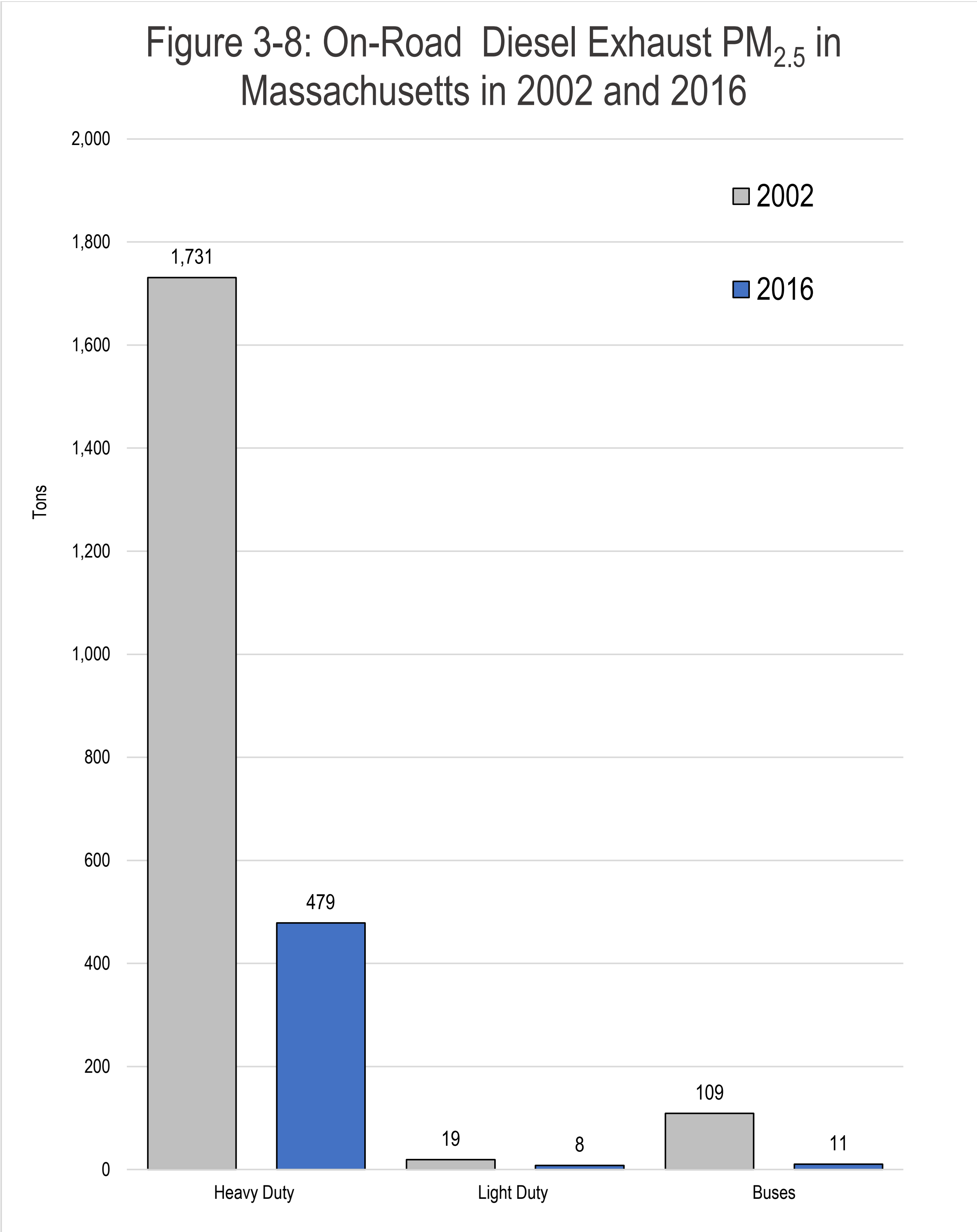

Figure 3-8 On-Road Diesel Exhaust $PM_{2.5}$ in Massachusetts in 2002 and 2016

Table 3-11 $PM_{2.5}$ and PM_{10} Exhaust PM by MOVES Source Use Type in Massachusetts 2016

				PM2.5				PM10			
Fuel Types	ID	Source Use Type	VMT Fraction	Emission Factor (g/mi)	Annual Emissions (tons)	Total Contribution (%)	Diesel Contribution (%)	Emission Factor (g/mi)	Annual Emissions (tons)	Total Contribution (%)	Diesel Contribution (%)
Diesel	21	Passenger Cars	0.012	0.005	3.8	0.3%	0.8%	0.01	4.1	0.3%	0.8%
	31	Passenger Trucks	0.004	0.02	4.0	0.4%	0.8%	0.02	4.3	0.4%	0.8%
	32	Light Commercial Truck	0.000	0.03	0.4	0.03%	0.07%	0.03	0.4	0.03%	0.07%
	41	Intercity Bus	0.000	0.40	5.4	0.5%	1.1%	0.43	5.8	0.5%	1.1%
	42	Transit Bus	0.000	0.11	3.1	0.3%	0.6%	0.12	3.4	0.3%	0.6%
	43	School Bus	0.000	0.11	2.1	0.2%	0.4%	0.12	2.2	0.2%	0.4%
	51	Refuse Truck	0.000	0.28	1.2	0.1%	0.2%	0.30	1.3	0.1%	0.2%
	52	Single Unit Short-haul Truck	0.004	0.25	71.5	6.5%	14.4%	0.27	77.8	6.4%	14.4%
	53	Single Unit Long-haul Truck	0.000	0.17	4.9	0.4%	1.0%	0.19	5.3	0.4%	1.0%
	54	Motor Home	0.000	0.48	0.4	0.04%	0.09%	0.52	0.5	0.04%	0.09%
	61	Combination Unit Short-haul Truck	0.007	0.31	148.2	13.5%	29.8%	0.34	161.1	13.2%	29.8%
	62	Combination Unit Long-haul Truck	0.013	0.31	252.3	22.9%	50.7%	0.33	274.2	22.4%	50.7%
	Diesel Subtotal		*0.042*		*497.3*	*45.2%*	*100.0%*		*540.5*	*44.2%*	*100.0%*
Gasoline, E85, and CNG	11	Motorcycle	0.005	0.02	7.6	0.7%	--	0.03	8.6	0.7%	--
	21	Passenger Cars	0.524	0.01	315.3	28.6%	--	0.01	356.5	29.1%	--
	31	Passenger Trucks	0.328	0.01	195.9	17.8%	--	0.01	221.5	18.1%	--
	32	Light Commercial Truck	0.099	0.01	77.2	7.0%	--	0.01	87.3	7.1%	--
	42	Transit Bus	0.000	0.02	0.1	0.01%	--	0.02	0.1	0.01%	--
	43	School Bus	0.000	0.08	0.02	0.001%	--	0.09	0.02	0.001%	--
	51	Refuse Truck	0.000	0.21	0.03	0.003%	--	0.24	0.03	0.003%	--
	52	Single Unit Short-haul Truck	0.002	0.05	6.5	0.6%	--	0.06	7.4	0.6%	--
	53	Single Unit Long-haul Truck	0.000	0.19	0.2	0.01%	--	0.21	0.2	0.02%	--
	54	Motor Home	0.000	0.10	0.9	0.1%	--	0.12	1.0	0.1%	--
	61	Combination Unit Short-haul Truck	0.000	0.54	0.02	0.002%	--	0.61	0.02	0.002%	--
	Non-diesel Subtotal		*0.958*		*603.9*	*54.8%*	--		*682.6*	*55.8%*	--
Total Fleet					1,101.2	100.0%			1,223.2	100.0%	

SOURCE: U.S. EPA MOVES2014a run at the County Domain/Scale, Calendar Year 2016, for Massachusetts counties, summed to the state level.

3.8 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. This diesel $PM_{2.5}$ inventory presents data on nine equipment groups in the off-road land-based diesel engine sector. Recreational marine vessels are typically included in the off-road engine sector, but for this inventory they are discussed in the marine diesel engine chapter. Examples of the equipment in each group are given below 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 Chapter 6 *Diesel Locomotive Engines*.

- **Recreational Equipment**: Diesel specialty vehicle carts – diesel recreational boats are covered in Chapter 5 *Marine Diesel Engines*.

4.1 Data Sources

The primary source of data on the number and type of off-road mobile engine equipment in Massachusetts is the EPA MOVES Nonroad model (version 2014a). MOVES Nonroad includes data from sources such as Power Systems Research (PSR, a data management company that tracks the sales and populations of all types of engines sold in the United States), the U.S. Forest Service, National Oceanic and Atmospheric Administration, U.S. Department of Agriculture, Oak Ridge National Laboratory, U.S. Energy Information Administration, U.S. Census Bureau, the California Air Resources

Board (ARB), Motorcycle Industry Council, International Snowmobile Manufacturers Association, and the National Marine Manufacturers Association (EPA, 2016b).

MOVES Nonroad defaults were used for off-road mobile sources except for local diurnal temperature profiles for summer and winter 2016 at the county level that were provided by MassDEP.[1] The large electronic Nonroad model input and output sub-files can be found in Appendix 4.3.

4.2 Number of Off-Road Land-Based Diesel Engines

EPA's MOVES Nonroad model estimates that there were 104,855 diesel-fueled off-road, land-based engines in Massachusetts in 2016. The model relies primarily on national populations of equipment prepared in 2003 by Power Systems Research (PSR) for year 2000 diesel equipment (EPA, 2010a; EPA, 2005b). The model projects these base year populations to 2016 using growth and scrappage assumptions that vary by equipment category as discussed in Section 4.3. MOVES Nonroad then allocates the national equipment population (and activity) to Massachusetts counties using geographic allocation factors (EPA, 2005a). These allocations are based on one of the following surrogates: human population and its associated income and housing data, business activity, or geographic data. These data are from the U.S. Census Bureau and other federal agencies except for construction activity and industry data on motorcycles and ATVs. Construction activity is allocated to counties based on the dollar value of construction projects adjusted for the relative cost differences for a similar project in different areas. EPA obtained these data from the construction industry.

Table 4-1 presents the number of diesel engines estimated by MOVES Nonroad for 2016 by equipment category. Figure 4-1 presents the data graphically by percentage. With 40,273 engines, the construction equipment category contained the most diesel engines in the nonroad sector in 2016 (38% of all off-road land-based diesel engines). Commercial equipment followed, with 34,457 engines (33%). The other seven categories accounted for the remaining 29%. See Appendix 4.1 for a complete list of types of engines within each off-road land-based diesel engine category.

[1] Boston max temperatures for 2016 from National Oceanic and Atmospheric Association (NOAA) - http://w2.weather.gov/climate/xmacis.php?wfo=box; Boston humidity levels for July 2016 from Weather Underground: https://www.wunderground.com/history/airport/KBOS/2016/7/31/MonthlyHistory.html?req_city=Boston&req_state=MA&req_statename=Massachusetts&reqdb.zip=02108&reqdb.magic=1&reqdb.wmo=99999

Table 4-1 Number and Percent of Off-Road Land-Based Diesel Engines in Massachusetts in 2016

Diesel Equipment Category	Number	Percent
Construction	40,273	38%
Commercial	34,457	33%
Industrial	15,327	15%
Lawn/Garden	11,559	11%
Agriculture	1,393	1%
Recreational	1,130	1%
Airport Support	563	1%
Logging	115	0.1%
Railroad	38	0.04%
Total	104,855	100%

SOURCE: U.S. EPA MOVES2014a Nonroad Model, Massachusetts Statewide, Calendar Year 2016

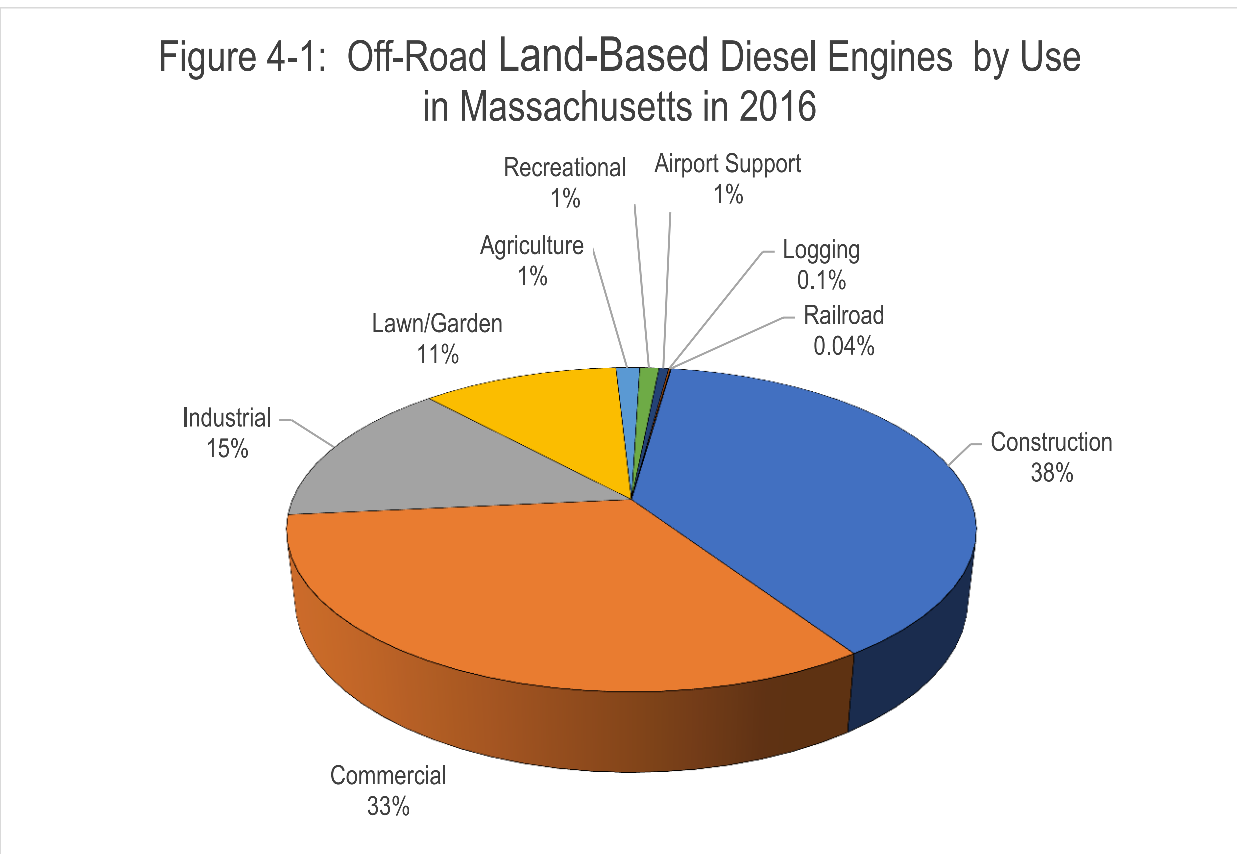

Figure 4-1 Off-Road Land-Based Diesel Engines by Use in Massachusetts in 2016

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

The MOVES Nonroad model applies growth factors to project a base year population (and associated activity) to future years by equipment category and fuel type (EPA, 2004a). Diesel equipment growth factors tend to have larger percent increases annually than equipment that operates on gasoline or natural gas. The model's growth factors are based on the PSR database equipment population growth over 1989 to 1996 and extrapolation beyond 1996 based on a linear regression of the available data years. EPA also performed several spot updates for entire populations in certain sectors (e.g., industrial) and for specific fuel types in other sectors. Table 4-2 shows the model-estimated growth in diesel off-road engines over the 15-year period of 2002 to 2016. All categories but logging equipment increased over this time from 34 to 70% (3 to 6.8% annual increase). Logging equipment population decreased by 12% for this period (0.9% annual decrease). The overall number of diesel off-road engines increased by 46% between 2002 and 2016.

Table 4-2 Growth in Massachusetts Diesel Off-Road Engine Population 2002 to 2016

Equipment Category	2002 Population	2016 Population	Percent change
Construction	29,226	40,273	38%
Commercial	22,921	34,457	50%
Industrial	10,679	15,327	44%
Lawn/Garden	6,800	11,559	70%
Agriculture	1,039	1,393	34%
Recreational	809	1,130	40%
Airport Support	334	563	68%
Logging	130	115	-12%
Railroad	26	38	48%
Total	71,964	104,855	46%

SOURCE: U.S. EPA MOVES2014a Nonroad Model, Massachusetts Statewide, Calendar Year 2016

4.4 Annual Equipment Usage

MOVES Nonroad uses annual activity not only to compute emissions in a future year but also to determine the average useful life and age distribution for engines (as discussed in Section 4.7). The activity factor in the model is expressed as annual hours of operation. MOVES Nonroad relies on a 1998 database prepared by PSR based on several yearly surveys of equipment owners that determined a mean usage rate for engines by application and fuel type (EPA, 2010b). It should be noted that, although anecdotally older equipment is used less frequently than newer equipment, EPA did not have quantifiable data for the model so MOVES Nonroad does not show differences in annual activity by age.

Tables 4-3 through 4-5 show the hours of use per year of diesel equipment in the largest equipment categories (construction, commercial, and industrial) which total 86% of the engines in the off-road land-based sector. The values in the tables are the annual hours of operation listed in the MOVES model database table 'NRSourceUseType.' More details on the MOVES Nonroad run for this 2016 inventory can be found in Section 4.8. Table 4-3 shows that in the construction subsector, off-highway trucks have the highest annual activity (1,641 hours of operation per year) followed by tractors/loaders/backhoes (1,135 hours per year); cement and mortar mixers have the least (275 hours per year).

Table 4-3 National Average Annual Hours of Operation for Construction Equipment

Equipment Type	Annual Activity (Hours/Year)
Bore/Drill Rigs	466
Cement & Mortar Mixers	275
Concrete/Industrial Saws	580
Cranes	990
Crawler Tractor/Dozers	936
Crushing/Proc. Equipment	955
Dumpers/Tenders	566
Excavators	1,092
Graders	962
Off-Highway Tractors	855
Off-highway Trucks	1,641
Other Construction Equipment	606
Pavers	821
Paving Equipment	622
Plate Compactors	484
Rollers	760
Rough Terrain Forklifts	662
Rubber Tire Loaders	761
Scrapers	914
Signal Boards/Light Plants	535
Skid Steer Loaders	818
Surfacing Equipment	561
Tampers/Rammers	460
Tractors/Loaders/Backhoes	1,135
Trenchers	593

SOURCE: U.S. EPA MOVES2014a Nonroad Model Database

Commercial equipment has a smaller range in annual activity than construction equipment – from 145 hours per year (pressure washers) to 815 hours per year (air compressors). Industrial equipment (Table 4-5) tends to have higher activity per equipment unit than commercial equipment, ranging from 384 hours per year (aerial lifts) to 1,700 hours per year (forklifts) – a range similar to the activity for construction equipment.

Table 4-4 National Average Annual Hours of Operation for Commercial Equipment

Equipment Type	Annual Activity (Hours/Year)
Air Compressors	815
Generator Sets	338
Hydro Power Units	790
Pressure Washers	145
Pumps	403
Welders	643

SOURCE: U.S. EPA MOVES2014a Nonroad Model Database

Table 4-5 National Average Annual Hours of Operation for Industrial Equipment

Equipment Type	Annual Activity (Hours/Year)
AC Refrigeration	1,341
Aerial Lifts	384
Forklifts	1,700
Other General Industrial Equipment	878
Other Material Handling Equipment	421
Other Oil Field Equipment	1,231
Sweepers/Scrubbers	1,220
Terminal Tractors	1,257

SOURCE: U.S. EPA MOVES2014a Nonroad Model Database

4.5 Registered Off-Road Vehicles

Massachusetts law requires that a registration plate be affixed to an off-road vehicle if the vehicle will be used on a public roadway[2] or if the vehicle is a recreational off-highway vehicle.[3] These off-road vehicles, though not subject to emissions tests, must undergo an annual safety inspection.[4] The Massachusetts vehicle inspection database (VID) tracks the data from the safety inspections and provides the same descriptions as for vehicles designed for use on roads.

Mass DEP obtained a dataset with a total of 151,119 diesel-fueled vehicles registered with the Massachusetts Registry of Motor Vehicles (RMV) as of January 2016. The RMV dataset showed that most vehicles are on-road. The dataset has one record for each vehicle with a unique vehicle

[2] M.G.L. c. 90 Section 6
[3] M.G.L. c. 90B Section 22
[4] M.G.L. c.90 Section 7A and 540 CMR 4.00

identification number (VIN), the city or town of registration, county of registration, vehicle make, model, model year, body style, plate type, and a MassDEP contractor's assessment of the vehicle type, make, model, model year, trim name, body type, engine displacement, gross vehicle weight, and MOBILE6 vehicle class.

As explained in the On-Road section 3.2.1, of the VINs that did not decode to an on-road vehicle type (5,114 vehicles, 3.4%), 3,414 were assessed to be likely off-road vehicles based on their body style and/or vehicle make (the other 1,700 vehicles were identified as gasoline vehicles). The majority (98%) of these off-road vehicles has a commercial license plate type; the other 2% were passenger plates.

The 3,414 registered vehicles that were identified as off-road vehicles include tractors, all-terrain vehicles (ATVs), skid steer loaders, and mobile construction equipment that travels on a public roadway to arrive at a work site (e.g., cranes and dump trucks). The registration data does not contain all off-road land-based equipment in Massachusetts because not all off-road equipment is required to be registered. Therefore the registration data cannot be reconciled with the MOVES Nonroad population estimates. Nonetheless, the registered off-road equipment is presented here to aid in understanding the Massachusetts diesel vehicle population. Table 4-6 lists the off-road land-based diesel equipment by categories that were identifiable from the RMV file's body style or model name fields. Figure 4-2 presents the data graphically by percentage. The 752 "unknown" vehicles were not identifiable but were included in the list of registered off-road vehicles nonetheless, because their VINs did not decode to an on-road vehicle type and the RMV make was one of the following known off-road equipment manufacturers: BOBCAT, BOMBA, CASE, CAT, CATAP, CATE, CATEP, CATER, DEE, DEER, DEERE, JOHN, JOHND, JON, KAWA, KOMA, KOMAS, KOMAT, or KUBOT.

Table 4-6 Off-Road Vehicles Registered in Massachusetts in 2016

Equipment Type	Number Registered
Backhoe	934
Crane	32
Dump Truck	314
Excavator	9
Forklift	3
Grader	2
Loader	910
Mixer	15
Plow	10
RTV	8
Skid Steer Loader	73
Tractor	352
Unknown	752
Total	3,414

SOURCE: MassDEP and Massachusetts Registry of Motor Vehicles (RMV), 2016. See Appendix 4.3.

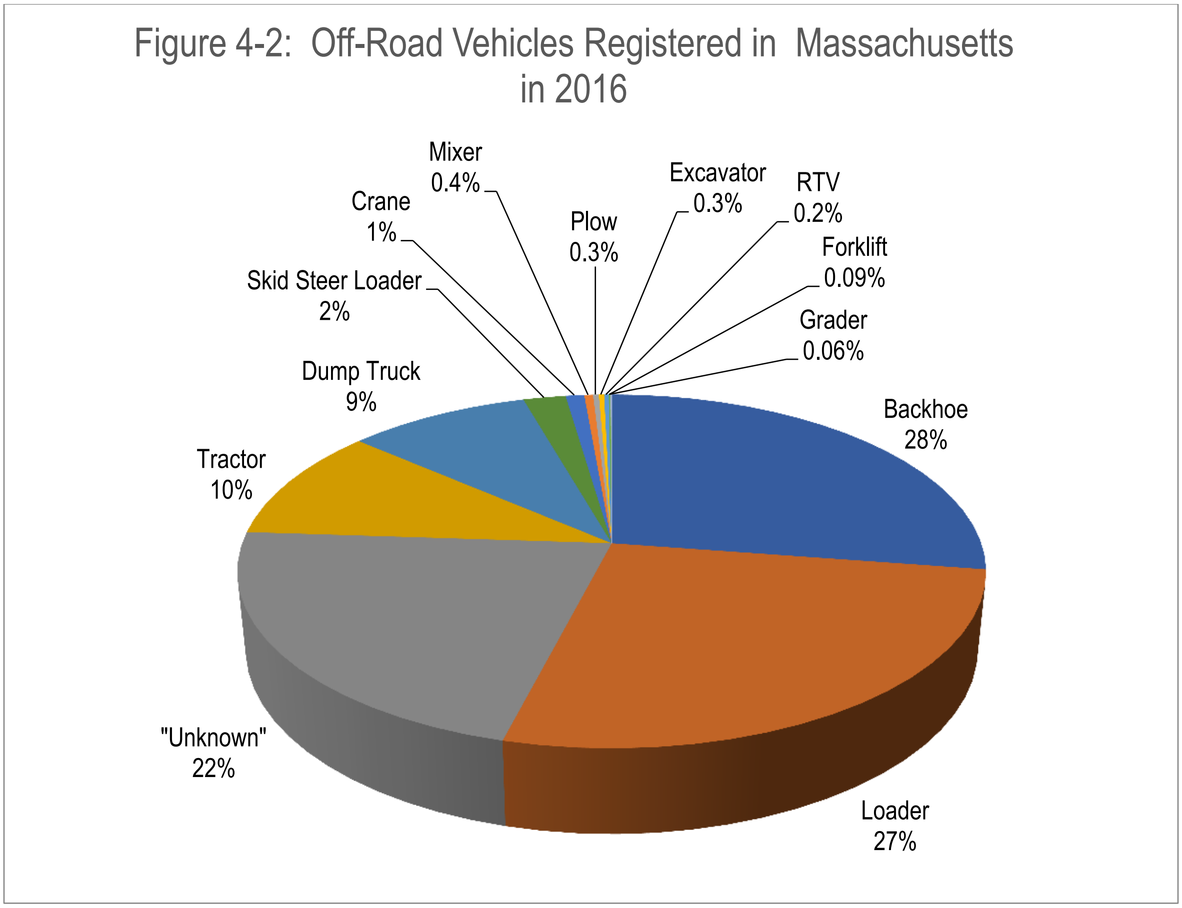

Figure 4-2 Off-Road Diesel Vehicles Registered in Massachusetts in 2016

4.6 PM 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. The combined effect of new engine and low sulfur fuel standards has led to an emissions reduction from diesel off-road vehicles of more than an order of magnitude for both PM and NO_X between 1990 and today.

4.6.1 PM 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 175 horsepower (hp) or more (such as bulldozers). These were phased in from 1996 to 2000 (EPA, 1998).

Four years later, EPA established Tier 1 standards for engines under 50 hp (such as lawn tractors) which were phased in from 1999 to 2000. EPA also established increasingly more stringent Tier 2 standards for all engine sizes and Tier 3 standards for other off-road diesel engines 50 hp and more (EPA, 1998). Tier 2 standards were effective for model year 2001 to 2006 engines, and Tier 3 standards were to be effective for model year 2006 to 2008 engines with 50 to 750 hp. However, Tier 3 standards were never adopted. In 2004 EPA established Tier 4 emission standards for all sizes of off-road engines, phased in from 2008 to 2015.[5] The standards, which reduce PM by over 90%, are largely achieved with the use of exhaust after-treatment technologies. Table 4-7 summarizes the PM emission standards for off-road diesel engines in units of grams per brake horsepower-hour (g/bhp-hr).

Due to the phase in of more stringent emissions standards over time and fleet turnover, the average per engine $PM_{2.5}$ emission factor is lower in 2016 than in the past. Table 4-8 summarizes the diesel off-road land-based equipment populations in 2002 and 2016. According to the model year distributions in MOVES Nonroad, in 2002 over half the fleet (63%) was pre-Tier 1; by 2016 over half meets Tier 4 standards (54%). Note that these are default projections from a model; the actual numbers are unknown.

4.6.2 Diesel Fuel

Diesel fuel for off-road land-based engines was required to have substantially lower sulfur levels under a 2004 EPA rule.[6] 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. Under the same rule the level was reduced to 15 ppm in June 2010, the current sulfur level of on-road ultra-low sulfur diesel (ULSD) fuel (EPA, 2004b). EPA required the use of ULSD to help achieve the Tier 4 emission standards for off-road land-based engines, which require after-treatment technology that is contaminated by high sulfur levels.

Fuel consumption by sector is determined by the operational power level (horsepower and load factor) and activity (hours per year) of equipment. Table 4-9 shows that the fuel consumption per unit "Average Per Unit (Gallons/Year)" tracks closely with the annual hp-hours per equipment column furthest to the right. This measure of annual activity was calculated as the product of annual hours, hp, and load factor, then summed to the equipment level. Heavier equipment and higher operating load both increase fuel consumption.

Table 4-9 shows EPA's estimate of Massachusetts diesel fuel usage by diesel equipment category; highlights are below.

- **The largest engine category, construction equipment, used the most diesel fuel in 2016—over 107 million gallons**. The next largest users of diesel fuel were industrial equipment engines (over 33 million gallons) and commercial equipment engines (over 17 million gallons).

- **On a per engine basis, logging engines consumed the most fuel (8,019 gallons per year).** Airport equipment also consumed a high average amount of fuel per engine (4,189 gallons per engine per year). The per-unit consumption of airport equipment was more than 50% higher than construction equipment, the category with the next highest rate. Logging equipment per unit fuel consumption was triple that of construction equipment.

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5 69 FR 38958, June 29, 2004. Available online: https://www.gpo.gov/fdsys/pkg/FR-1994-06-17/html/94-13956.htm.

6 69 FR 38958, June 29, 2004. Available online at: https://www.gpo.gov/fdsys/pkg/FR-2004-06-29/pdf/04-11293.pdf.

*Table 4-7 Tier 1, 2 and 4 PM Emission Standards for Off-Road Diesel Engines**

Engine Power	Tier	Effective Model Year	PM (g/bhp-hr)
<11 hp	1	2000	0.75
	2	2005	0.60
	4	2008	0.30
$\geq$11 hp to <25 hp	1	2000	0.60
	2	2005	0.60
	4	2008	0.30
$\geq$25 hp to <50 hp	1	1999	0.60
	2	2004	0.45
	$4_{interim}$	2008	0.22
	4_{final}	2013	0.02
$\geq$50 hp to <75 hp	1	-	-
	2	2004	0.30
	4	2013	0.02
$\geq$75 hp to <100 hp	1	-	-
	2	2004	0.30
	4	2012	0.01
$\geq$100 hp to <175 hp	1	-	-
	2	2003	0.22
	4	2012	0.01
$\geq$175 hp to <300 hp	1	1996	0.40
	2	2003	0.15
	4	2011	0.01
$\geq$300 hp to <600 hp	1	1996	0.40
	2	2001	0.15
	4	2011	0.02
$\geq$600 hp to <750 hp	1	1996	0.40
	2	2002	0.15
	4	2011	0.01
$\geq$750 hp	1	2000	0.40
	2	2006	0.15
	$4_{interim}$	2011	0.07
All engines except generator sets	4_{final}	2015	0.03
Generator sets	4_{final}	2015	0.02

SOURCE: EPA (2016a).

* -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.

Table 4-8 Comparison of Population Distributions of Off-Road Diesel Vehicles in Massachusetts by Emission Standards 2002 to 2016

Emission Standard	2002 Population	Percent	2016 Population	Percent
Pre - Tier 1	45,435	63%	10,449	10%
Tier 1	26,245	36%	14,238	14%
Tier 2	284	<0.5%	23,083	22%
Tier 4	--	--	57,085	54%
Total	*71,964*		*104,855*	

SOURCE: U.S. EPA MOVES2014a Nonroad Model, Massachusetts Statewide, Calendar Years 2002 and 2016.

Table 4-9 Fuel Usage of Off-Road Land-Based Diesel Equipment in Massachusetts in 2016

Diesel Equipment Category	Number of Engines	Diesel Fuel Consumption (gallons/year)	Average Per Unit (gallons/year)	Annual hp-hours Per Unit, including Load Factor (hp-hours)
Agriculture	1,393	2,677,462	1,922	35,378
Airport Support	563	2,357,363	4,189	78,002
Commercial	34,457	17,805,650	517	8,914
Construction	40,273	107,346,214	2,665	48,023
Industrial	15,327	33,751,205	2,202	38,957
Lawn/Garden	11,559	7,772,303	672	11,952
Logging	115	920,575	8,019	150,415
Railroad	38	66,495	1,741	27,690
Recreational	1,130	405,496	359	5,557
Total	*104,855*	*173,102,763*		

SOURCE: U.S. EPA MOVES2014a Nonroad Model, Massachusetts Statewide, Calendar Year 2016

4.7 Average Age and Useful Life

The off-road equipment age distribution determines the mix of emission standards for the engines operating in any year and thus has a large impact on the emission inventory. MOVES Nonroad uses equipment age distributions for the base year (2000 for diesel equipment) from engine population data and calculates future years by stepping through each year between the base and future year projecting growth in sales and scrappage of the older model years. Annual growth rates are from PSR (EPA, 2004a) and discussed previously in Section 4.3. Scrappage of equipment means permanent retirement from the fleet resulting from aging or equipment failure (i.e., no longer contributing to emissions or consuming fuel). MOVES Nonroad uses a scrappage curve to determine removal of equipment as a function of age that accounts for hours of use and load factor. It is based on PSR's Partslink database (EPA, 2005b).

The expected lifetime of off-road engines varies with engine type (e.g., compression vs. spark ignition) and power level. Compression ignition (diesel-fueled) engines with higher power ratings and larger displacement tend to last longer than non-diesel, smaller engines. MOVES Nonroad uses expected life estimates (termed "median life") based on the California ARB's OFFROAD model, which EPA increased based on the results of a supplemental report prepared by Energy and Environmental Analysis.[7] For MOVES Nonroad, EPA set median life at full load for diesel engines at 2,500, 4,667, or 7,000 hours for engines with hp ratings of less than 50, 50 to 300, and greater than 300, respectively (EPA, 2010b). The model effectively assumes a non-trivial number of old units still in service that may remain in service for many years in the future as shown in the tables below. For example, pressure washers have a median life of 64 years. Tables 4-10 through 4-12 list the average age in 2016 of engines in each equipment type and their median lifetime in the three largest diesel off-road categories – construction (Table 4-10), commercial (Table 4-11), and industrial (Table 4-12). The median lifetime in years for individual equipment types was derived by dividing the median life in hours at full load by the load factor and annual operating hours.

Table 4-10 Average Age and Lifetime of Off-Road Construction Equipment in Massachusetts in 2016 *(years)*

Equipment Type	Average Age	Median Lifetime
Bore/Drill Rigs	11	24
Cement & Mortar Mixers	11	34
Concrete/Industrial Saws	5	10
Cranes	6	12
Crawler Tractor/Dozers	5	10
Crushing/Proc. Equipment	6	11
Dumpers/Tenders	11	28
Excavators	4	7
Graders	4	8
Off-Highway Tractors	7	13
Off-highway Trucks	4	7
Other Construction Equipment	8	13
Pavers	5	9
Paving Equipment	5	10
Plate Compactors	6	12
Rollers	5	8
Rough Terrain Forklifts	6	10
Rubber Tire Loaders	6	11
Scrapers	6	11

7 http://government-contractors.insidegov.com/l/374071/Energy-and-Environmental-Analysis-Inc.

Equipment Type	Average Age	Median Lifetime
Signal Boards/Light Plants	6	15
Skid Steer Loaders	10	19
Surfacing Equipment	6	14
Tampers/Rammers	6	13
Tractors/Loaders/Backhoes	10	15
Trenchers	6	12

SOURCE: U.S. EPA MOVES2014a Nonroad Model, Massachusetts Statewide, Calendar Year 2016

Table 4-11 Average Age and Lifetime of Off-Road Commercial Equipment in Massachusetts in 2016 *(years)*

Equipment Type	Average Age	Median Lifetime
Air Compressors	6	11
Generator Sets	10	33
Hydro Power Units	6	12
Pressure Washers	12	64
Pumps	9	27
Welders	10	30

SOURCE: U.S. EPA MOVES2014a Nonroad Model, Massachusetts Statewide, Calendar Year 2016

Table 4-12 Average Age and Lifetime of Off-Road Industrial Equipment in Massachusetts in 2016 *(years)*

Equipment Type	Average Age	Median Lifetime
AC Refrigeration	3	5
Aerial Lifts	12	41
Forklifts	2	4
Other General Industrial Equipment	6	11
Other Material Handling Equipment	12	50
Sweepers/Scrubbers	4	7
Terminal Tractors	3	6

SOURCE: U.S. EPA MOVES2014a Nonroad Model, Massachusetts Statewide, Calendar Year 2016

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

The MOVES Nonroad model (version 2014a, database movesdb20161117) was used to estimate the PM emissions from Massachusetts off-road land-based diesel engines. MOVES Nonroad calculates emissions from over 300 types of off-road equipment/engines based on national data from PSR and other sources. For consistency with the diesel on-road sector MOVES Nonroad was run with the same winter and summer month diurnal temperatures by county (although there is no seasonal effect on off-road diesel $PM_{2.5}$ emissions) (see Chapter 3). Other than meteorological data, MOVES Nonroad was run with default data. Table 4-13 summarizes the run specifications input into MOVES Nonroad to generate the emissions inventory. The large electronic Nonroad model input and output sub-files can be found in Appendix 4.3.

Tables 4-14 and 4-15 summarize PM emissions by the nine diesel equipment categories and by county in 2016. These collectively emitted 718 tons of diesel $PM_{2.5}$. Figure 4-3 shows the diesel $PM_{2.5}$ emissions for the nine off-road equipment groups in this sector. Figure 4-4 shows the number of tons of $PM_{2.5}$ in 2002 and 2016. Appendices 4.1 and 4.2 provide the PM emissions for specific types of equipment within each category. Highlights of the results are below.

- **Emissions decreased 58% since 2002 despite a Nonroad model projected increase of 46% in the Massachusetts diesel off-road equipment population.**[8] The reduction in emissions is due to turnover as the fleet transitions to cleaner technology that is enabled by ULSD fuel and older, higher-emitting engines retire from the fleet. Advanced Tier 4 control technologies used in combination with ULSD fuel resulted in PM emission reductions greater than 90% compared to uncontrolled nonroad engines. According to the MOVES Nonroad model, over half the off-road diesel engines in 2016 meet Tier 4 emission standards. In the future, $PM_{2.5}$ emission trends can be expected to level off and then increase proportionally to growth in equipment population and fuel consumption once the remaining engines become Tier 4.

- **With 63% (449 tons) 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 2016**. Construction and mining equipment engines emitted four times more $PM_{2.5}$ than commercial equipment engines (113 tons) and over five times more $PM_{2.5}$ than industrial equipment (86 tons), the next two highest emitting groups.

- **The other six equipment groups collectively emitted 70 tons of diesel $PM_{2.5}$**. Together they represented only 10% of the diesel $PM_{2.5}$ emissions for the off-road sector.

- **The top three contributors to PM emissions (construction, commercial, and industrial equipment) were responsible for 94% of the emissions reduction from 2002 to 2016.** The remaining six categories together were responsible for the other 6% reduction in $PM_{2.5}$.

- **$PM_{2.5}$ represented nearly all (97%) of diesel PM_{10} in 2016** (Appendix 4.2).

[8] Note that the off-highway emissions reported in 2002 were estimated using EPA's Nonroad 2005 model.

Table 4-13 MOVES Nonroad Model Settings for MassDEP 2016 Diesel PM Inventory

MOVES Graphical User Interface ***Panel Name*** and Option Name	User Selection(s)
Scale Panel	
Model	Nonroad
Domain/Scale	National
Calculation Type	Inventory
Time Spans Panel	
Time Aggregation Level	Day
Years	2016
Months	January, July
Days	Weekdays, Weekend
Geographic Panel	
Region	County
States	Massachusetts
Counties	(all 14)
Nonroad Vehicle Equipment	
Fuels	Nonroad Diesel Fuel
Sectors	all except Pleasure Craft
Pollutants and Processes	
Pollutants	VOC, CO, NOX, PM2.5, PM10, SO2, CO2
Processes	all
Manage Input Datasets	
Database	nr_massdep2016_in*
General Output	
Database	nr_massdep2016_out
Units for Mass, Energy, Distance	grams, joules, miles
Output Emissions Detail	
Time	24-Hour Day
Location	County
Other checkbox selections	Emission Process, SCC, Sector, Engine Tech, HP Class

*The input database contained the `zoneMonthHour` table filled with county temperatures and relative humidity as provided for the on-road Inventory (see Chapter 3)

Table 4-14 $PM_{2.5}$ Emissions from Diesel Off-Road Equipment by Type in Massachusetts in 2002 and 2016 *(tons)*

Diesel Equipment Category	2002 $PM_{2.5}$	2016 $PM_{2.5}$	Percent of 2016 $PM_{2.5}$	Percent change
Construction & Mining	1,112.89	449.18	63%	-60%
Commercial	197.96	112.85	16%	-43%
Industrial	288.64	85.86	12%	-70%
Lawn/Garden	59.62	40.83	6%	-32%
Agriculture	33.26	14.41	2%	-57%
Airport Support	16.33	7.90	1%	-52%
Recreational	6.21	4.36	0.6%	-30%
Logging	9.69	1.72	0.2%	-82%
Railroad	1.02	0.59	0.08%	-42%
Total	1,725.65	717.71		-58%

Table 4-15 $PM_{2.5}$ Emissions from Diesel Off-Road Equipment in Massachusetts by County in 2002 and 2016 *(tons)*

County	2002 $PM_{2.5}$	2016 $PM_{2.5}$	Percent of 2016 $PM_{2.5}$	Percent change
Barnstable	138.6	33.24	5%	-76%
Berkshire	58.1	16.89	2%	-71%
Bristol	119.0	52.23	7%	-56%
Dukes	29.6	3.94	1%	-87%
Essex	171.8	69.48	10%	-60%
Franklin	51.0	11.02	2%	-78%
Hampden	82.9	35.72	5%	-57%
Hampshire	38.3	15.92	2%	-58%
Middlesex	331.4	159.24	22%	-52%
Nantucket	24.2	5.65	1%	-77%
Norfolk	151.3	70.37	10%	-53%
Plymouth	156.5	58.80	8%	-62%
Suffolk	149.9	82.04	11%	-45%
Worcester	222.9	103.17	14%	-54%
Total	1,725.5	717.71		-58%

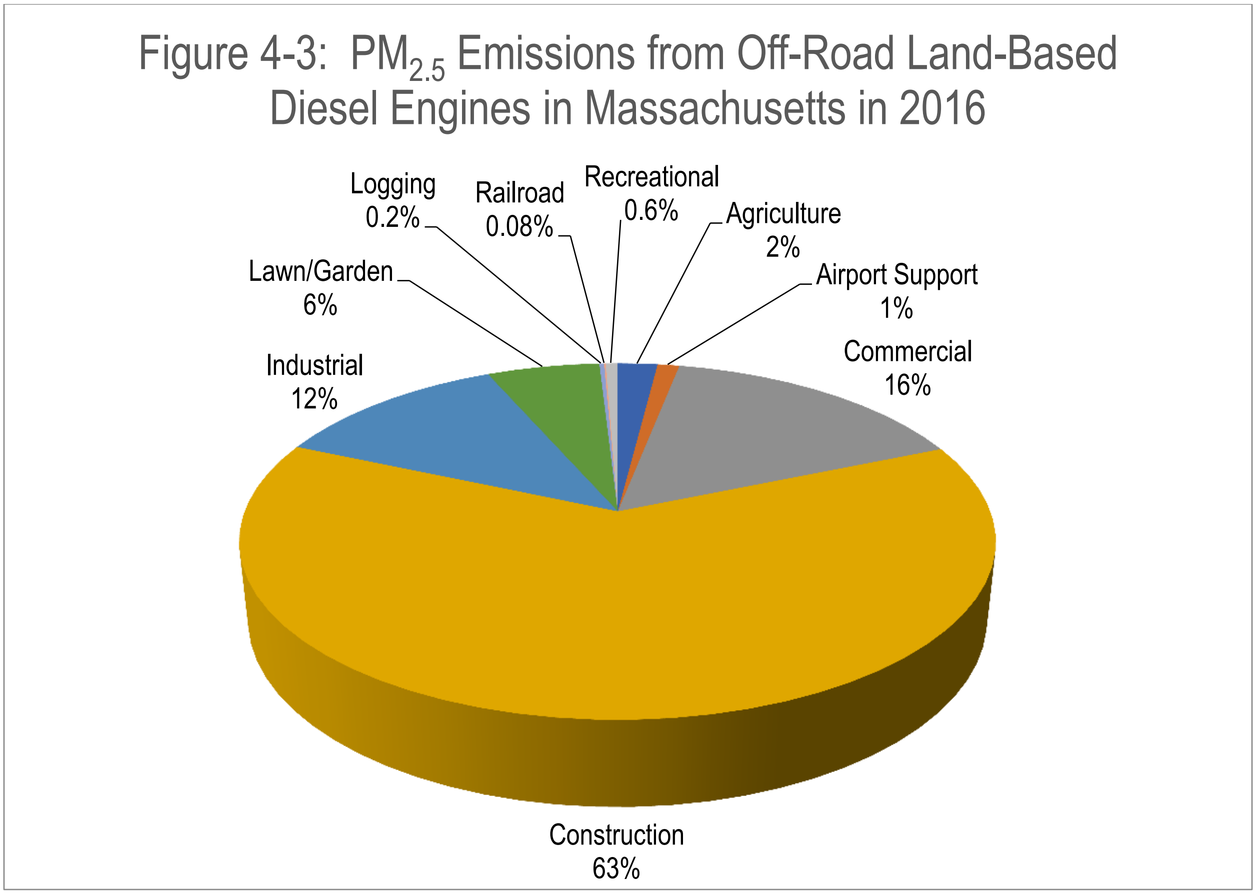
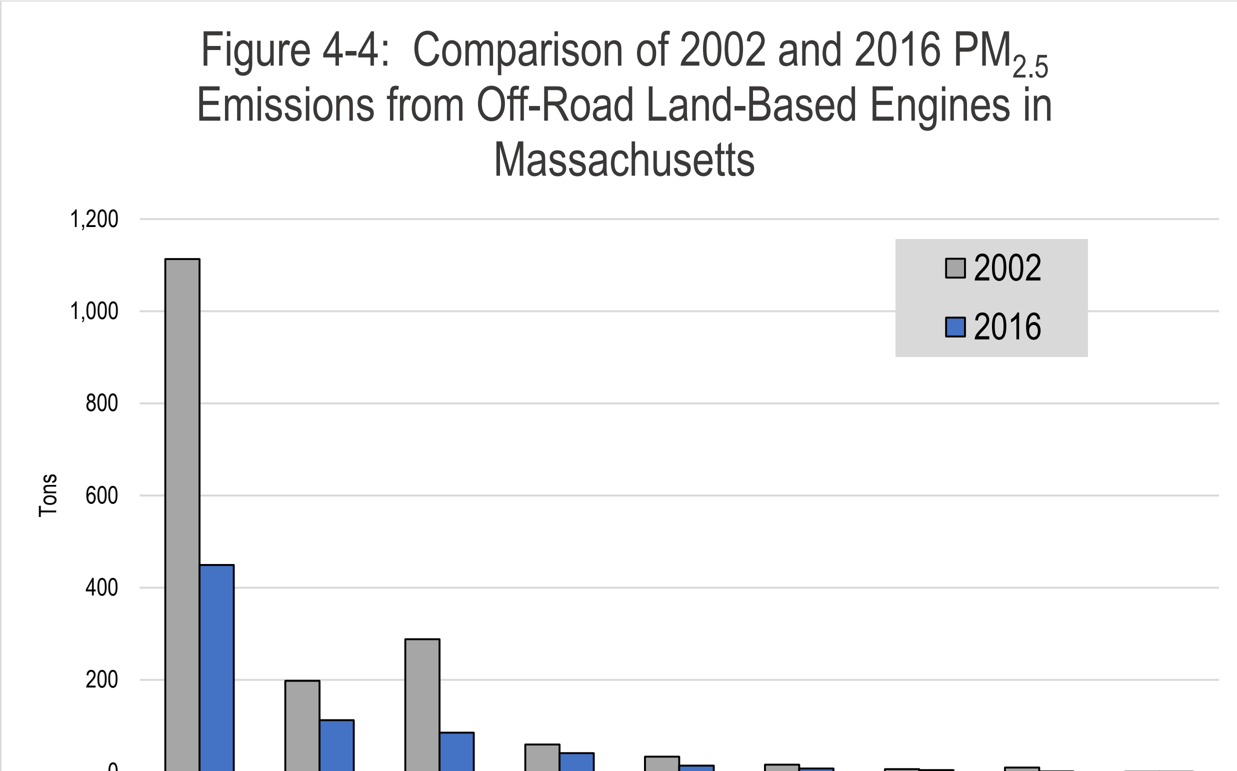


Figure 4-3 $PM_{2.5}$ Emissions from Off-Road Land-Based Diesel Engines in Massachusetts in 2016



	Construction	Commercial	Industrial	Lawn/ Garden	Agriculture	Airport Support	Recreational	Logging	Railroad
2002	1,113	198	289	60	33	16	6	10	1
2016	449	113	86	41	14	8	4	2	0.6

Figure 4-4 Comparison of 2002 and 2016 $PM_{2.5}$ Emissions from Off-Road Land-Based Engines in Massachusetts

4.9 References for Off-Road Land-Based Engines

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U.S. EPA, 2016a. Nonroad Compression-Ignition Engines: Exhaust Emission Standards. Office of Transportation and Air Quality. EPA-420-B-16-22. March 2016. Available online at: https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100OA05.pdf.

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5.0 Marine Diesel Engines

The marine diesel engine sector includes 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 (where available), emissions standards, and PM emissions.

5.1 Data Sources

Massachusetts Office of Law Enforcement (OLE), Massachusetts Division of Marine Fisheries (DMF), and the U.S. Army Corps of Engineers (USACE) provided data on the owners of marine diesel vessels in 2017. Ownership data are for fishing vessels weighing less than five tons, ferries, livery, government, and recreational vessels. See Appendices 5.1 to 5.3.

The following agencies maintain data on marine vessels that were used in this inventory.

- The DMF keeps records on the vessels of commercial fishermen that are required to obtain a permit from DMF to off-load their fish at Massachusetts docks.
- The OLE requires any motor-powered boats that operate on public waterways in Massachusetts to register their vessels with the agency. Most of these are recreational vessels.
- The U.S. Coast Guard (USCG) provided a roster of their boats and cutters along with home port and annual underway hours for 2014.
- The U.S. Department of Transportation Bureau of Transportation Statistics' National Census of Ferry Operators includes data on ferry vessels and the trips they make.
- The most recent EPA National Emissions Inventory (NEI) includes emissions for vessels for 2014.
- The USACE has information on dredging activities and domestic vessel trips.

5.2 EPA Marine Engine Categories

EPA regulates the emission standards of marine vessel engines[1] according to several broad categories (see Table 5-1). Category 1(C1) diesel marine engines are most similar to land-based off-road diesel engines in terms of the power and size of their engines. Category 2 (C2) diesel marine engines are similar to locomotive engines in power and size. Category 3 (C3) are the largest marine engines that propel the largest ocean-going vessels.

[1] *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 5-1 EPA Marine Engine Categories

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

SOURCE: U.S. EPA, Office of Transportation and Air Quality. *Regulatory Update: Overview of EPA's Emission Standards for Marine Engines*. EPA420-F-04-031, August 2004.[2]

C1 and C2 vessels—those vessels with engine displacement of less than 30 liters per cylinder—operate on diesel or distillate fuel oil. C1 and C2 vessels must use ultra-low sulfur non-road fuels (15 ppm fuel sulfur content). To comply with this fuel standard heavier residual fuels that have sulfur concentrations over 1000 ppm cannot be used or blended with distillate fuels.

C3 vessels have engines with displacements greater than or equal to 30 liters per cylinder and generally use residual oil (RO – a heavier non-diesel fuel), or a blend of marine diesel oil (MDO – a heavy distillate fuel with small amounts of residual fuel). Since these vessels tend to operate outside the state moving international cargo they are not included in this inventory. In contrast, C1 and C2 powered vessels are more likely to spend time in state waters.

Often the data sources used in this inventory do not specifically cite whether an engine is C1, C2, or C3. MassDEP therefore assigned the engine category based on the type of marine vessel (e.g., a tugboat is assigned a C2 engine). Marine vessel types included in this report are recreational, fishing, Coast Guard, dredging, ferries, state police, and commercial marine vessels.

5.3 PM Emission Standards and Fuel

In 1999, EPA set emission standards for marine engines for the first time. The emission standards were revised multiple times, most recently with the 2009 Category 3 Engine Rule. That rule introduced Tier 2 and 3 standards. The rules tighten emission standards for existing large marine diesel engines when they are remanufactured, set Tier 3 standards for newly-built marine diesel engines, and set Tier 4 standards for newly-built locomotives and marine diesel engines. Tier 4 standards reflect the

[2] EPA OTAQ Regulatory Update: https://nepis.epa.gov/Exe/tiff2png.cgi/P1002K40.PNG?-r+75+-g+7+D%3A%5CZYFILES%5CINDEX%20DATA%5C00THRU05%5CTIFF%5C00001264%5CP1002K40.TIF

application of high-efficiency aftertreatment technology. These standards are presented in Tables 5-2 through 5-7.[3]

Table 5-2 Tier 2 Marine Emission Standards

Category	Displacement (D) (dm^3 per cylinder)	PM (g/kWh)	Model Year
1	Power ≥ 37 kW D < 0.9	0.40	2005
	0.9 ≤ D < 1.2	0.30	2004
	1.2 ≤ D < 2.5	0.20	2004
	2.5 ≤ D < 5.0	0.20	2007[a]
2	5.0 ≤ D < 15	0.27	2007[a]
	15 ≤ D < 20 Power < 3300 kW	0.50	2007[a]
	15 ≤ D < 20 Power ≥ 3300 kW	0.50	2007[a]
	20 ≤ D < 25	0.50	2007[a]
	25 ≤ D < 30	0.50	2007[a]

Source: 40 CFR 94.8 Exhaust Emission Standards Table A-1
a - Tier 1 certification requirement starts in 2004

[3] *Code of Federal Regulations,* Control of Emissions from New and In-Use Nonroad Compression-Ignition Engines, Title 40, Part 89.

Table 5-3 Tier 3 Standards for Marine Diesel Category 1 Commercial Standard Power Density (≤ 35 kW/dm³) Engines

Power (P) (kW)	Displacement (dm^3 per cylinder (D)	PM (g/kWh)	Model Year
P < 19	D < 0.9	0.40	2009
19 ≤ P < 75	D < 0.9[a]	0.30	2009
		0.30[b]	2014
75 ≤ P < 3700	D < 0.9	0.14	2012
	0.9 ≤ D < 1.2	0.12	2013
	1.2 ≤ D < 2.5	0.11[c]	2014
	2.5 ≤ D < 3.5	0.11[c]	2013
	3.5 ≤ D < 7	0.11[c]	2012

Source: 40 CFR 1042
a - < 75 kW engines ≥ 0.9 dm^3/cylinder are subject to the corresponding 75-3700 kW standards.
b - Option: 0.20 g/kWh PM & 5.8 g/kWh NOx+HC in 2014.
c - This standard level drops to 0.10 g/kWh in 2018 for < 600 kW engines.

Table 5-4 Tier 3 Standards for Marine Diesel Category 1 Commercial High Power Density (> 35 kW/dm³) Engines And All Diesel Recreational Engines

Power (P) (kW)	Displacement (D) (dm^3 per cylinder)	PM (g/kWh)	Model Year
P < 19	D < 0.9	0.40	2009
19 ≤ P < 75	D < 0.9[a]	0.30	2009
		0.30[b]	2014
75 ≤ P < 3700	D < 0.9	0.15	2012
	0.9 ≤ D < 1.2	0.14	2013
	1.2 ≤ D < 2.5	0.12	2014
	2.5 ≤ D < 3.5	0.12	2013
	3.5 ≤ D < 7	0.11	2012

Source: 40 CFR 1042
a - < 75 kW engines ≥ 0.9 dm^3/cylinder are subject to the corresponding 75-3700 kW standards.
b - Option: 0.20 g/kWh PM & 5.8 g/kWh NOx+HC in 2014.

Table 5-5 Tier 3 Standards for Marine Diesel Category 2 Engines‡

Power (P) (kW)	Displacement (D) (dm^3 per cylinder)	PM (g/kWh)	Model Year
P < 3700	7 ≤ D < 15	0.14	2013
	15 ≤ D < 20	0.27[a]	2014
	20 ≤ D < 25	0.27	2014
	25 ≤ D < 30	0.27	2014

Source: 40 CFR 1042
‡ Option: Tier 3 PM/NOx+HC at 0.14/7.8 g/kWh in 2012, and Tier 4 in 2015.
a - 0.34 g/kWh for engines below 3300 kW.

Table 5-6 Tier 4 Standards for Marine Diesel Category 1 and 2 Engines

Power (P) (kW)	Displacement (D) (dm^3 per cylinder)	PM (g/kWh)	Model Year
P > 3700	<15.0	0.12[a]	2014[c]
	all	0.06	2016[b,c]
2000 ≤ P ≤ 3700	all	0.04	2014[c,d]
1400 ≤ P < 2000	all	0.04	2016[c]
600 ≤ P < 1400	all	0.04	2017[d]

Source: 40 CFR 1042
a - 0.25 g/kWh for engines with 15-30 dm^3/cylinder displacement.
b - Optional compliance start dates can be used within these model years.
c - Option for Cat. 2: Tier 3 PM/NOx+HC at 0.14/7.8 g/kWh in 2012, and Tier 4 in 2015.
d - The Tier 3 PM standards continue to apply for these engines in model years 2014 and 2015 only.

Table 5-7 Recreational Marine Diesel Engines Standards

Displacement (D) (dm3 per cylinder)	PM (g/kWh)	Model Year
0.5 ≤ D < 0.9	0.40	2007
0.9 ≤ D < 1.2	0.30	2006
1.2 ≤ D < 2.5	0.20	2006
D ≥ 2.5	0.20	2009

Source: 40 CFR 94.8 Exhaust Emission Standards Table A-1

5.4 Activity and Methodology

Activity in terms of loaded kilowatt-hours was calculated by multiplying the engine's kilowatt rating by the expected engine load and the estimated hours of operation as shown below.

$$A = MCR \times LF \times HR$$

Where:

A	=	Activity (kW-hrs)
MCR	=	Engine's kilowatt rating
LF	=	Propulsion operating load factor
HR	=	Estimated hours of operation

Engine operating loads are often expressed as fractions of an engine's Maximum Continuous Rating (MCR) ranging from 0 (when the engine is not operating) to 0.83 (optimal cruising) (EPA 2009). Most published operating load data are for large vessels equipped with C3 engines. Data on vessels equipped with C1 or C2 engines are from port studies and generally do not include bay or coastal operations. Neither the C3 or port load factors would accurately represent C1/C2 vessel operations for this inventory.

Recent emission inventories developed for Bureau of Ocean Energy Management (BOEM)[4] and Texas Commission on Environmental Quality (TCEQ) using Automatic Identification Systems (AIS) data that quantifies vessel speed every couple of seconds indicate that operating loads within coastal waters can vary significantly for C1 and C2 vessel from less than 0.3 to 0.9. For this report C1 and C2 operating load was assumed to be 0.6 unless otherwise noted (such as for dredging which has high engine operating loads). Activity in kilowatt-hours was multiplied by EPA's Tier-based emission factors shown in Table 5-8 to estimate emissions. The emissions were allocated to individual counties.

[4] https://www.boem.gov/

Table 5-8 EPA Emission Factors by Tier Level for C1/C2 Marine Engines (g/kw-hr)[5]

Tier	$PM_{2.5}$	PM_{10}
0	0.3104	0.32
1	0.3104	0.32
2	0.3104	0.32
3	0.1067	0.11

Source: U.S. EPA, 2008

The approach outlined above was used to estimate PM emissions from all marine vessel types.

5.4.1 Recreational Marine Diesel Vessels

State law requires the registration of any boat that is powered by a motor and operated on public waterways in Massachusetts. Registration is necessary even if the motor is not the primary means of propulsion for that boat. According to the Massachusetts Office of Law Enforcement (OLE), there were 2,217 boats in use fueled by diesel in 2016 (Appendix 5.1 summarized in Table 5-9).[6] The OLE registration data classifies the vessels by length. Most were Class 2 vessels,[7] which are 26 to 40 feet in length. Private citizens owned the bulk of the vessels. Approximately 85% were recreational with the remaining 15% commercial/institutional vessels, such as fishing charters, harbor tours, yacht clubs, and the Massachusetts Maritime Academy.

Recreational vessels are summarized in Table 5-9 by registration class (i.e., vessel size). The 2016 population in Table 5-9 is smaller than the 2002 population. This may be because the original 2002 estimates of recreational vessels appear to include non-recreational vessels from the USCG. For this report we have adjusted the 2002 recreational vessel count to correct this problem by using only the OLE database for both years.

The following is the adjustment for recreational vessels for 2002 given in Table 5-9 below. Table 5-4 of the 2002 report has a total of 7,280 recreational vessels with 1,948 from OLE and 5,332 from USCG. Because the USCG covered all vessels including gasoline, residual oil, recreational, fishing, and others for 2016, and this database is not available for 2002, it is assumed that the USCG database is duplicative of the OLE and DMF vessel counts and therefore not counted in this 2016 analysis. This leaves a recreational count of 1,948 diesel vessels for 2002. However, in Appendix L (OLE) of the 2002 report the actual recreational count is 2,601 diesel vessels (see Table 5.9 below). The 2002 report does not give a $PM_{2.5}$ emissions breakdown for recreational vessel emissions, but gives total dockside and underway emissions of 201.5 (136.7 + 64.8) tons that includes recreational vessels. From Table 5-20 of the 2002 report, MassDEP derived a recreational $PM_{2.5}$ emission factor of 55.36 lb/vessel (underway 136.7 tons+ dockside 64.8 tons = 201.5 tons/7,280 vessels). As shown in Table 5-10 below the adjusted recreational vessel $PM_{2.5}$ emissions for 2002 are 71.99 tons (2,601 x 55.36 lb/vessel). Tables 5-9 and 5-

5 U.S. EPA/OTAQ, Regulatory Impact Analysis: Control of Emissions of Air Pollution from Locomotive Engines and Marine Compression Ignition Engines Less than 30 Liters Per Cylinder, March 2008.

6 Massachusetts Office of Law Enforcement (OLE) "2016 Data from the Massachusetts OLE – All Marine Vessels"

7 Not to be confused with the C2 engine designation which means Category 2.

10 thus provide a 2002 and 2016 comparison of recreational vessel counts and its emissions from the same source - OLE.

Table 5-9 Number of Recreational Marine Diesel Vessels in Massachusetts by Registration Class 2002 and 2016

Boat Registration Class	2002 Count*	2016 Count	% Change
Class A <16 ft	23	20	-13%
Class 1: 16-26 ft	592	505	-15%
Class 2: 26-40 ft	1770	1,465	-17%
Class 3: 40+ ft	266	227	-15%
Total	2,601	2,217	-15%

*Adjusted – see text.

Activity for 2016 was calculated by applying the following MOVES-NONROAD assumptions to the power ratings available in the registration data: (1) each recreational vessel operated 476 hours per year and (2) operated at a load factor of 35%. The final loaded activity data were in units of kilowatt-hours (kWh).[8]

The 2016 PM emissions were calculated by applying the EPA emission factors from MOVES-NONROAD in Appendix 4.1 to the kilowatt-hours. The activity data and emission factors from MOVES-NONROAD were available by engine model year. Results are presented by county in Table 5-10 and Figure 5-1 below.

As shown in Table 5-9, there was a decrease in engine counts from 2002 to 2016. According to the USCG boating registration information for the U.S., registrations peaked in 2005 and have been steadily declining in the years since. The most popular type of boats used for recreational boating in the U.S. are the outboard motor boats that are usually small watercraft with a motor attached to the outside of vessel. While they are the most common type of boat in use, the number of outboard boats sold annually in the U.S. has declined significantly since 2000. Between 2000 and 2013, the average unit price increased markedly from an average of $9,188 in 2000 to $21,964 in 2013, which likely contributed to the declining sales volume and registrations during those years.[9]

[8] U.S. Environmental Protection Agency, Office of Transportation and Air Quality, 2010. Median Life, Annual Activity, and Load Factor Values for Nonroad Engine Emissions Modeling. EPA-420-R-10-016, NR-005d. https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P10081RV.pdf.

[9] Statista – the Portal for Statistics – Immediate access to over one million statistics and facts. https://www.statista.com/ Statistic, 2017. Number of Registered Recreational Boating Vessels in the U.S. from 1980 to 2016 (in millions). Accessed Aug 2017. https://www.statista.com/statistics/240634/registered-recreational-boating-vessels-in-the-us/.

***Table 5-10 PM Emissions from Recreational Marine Diesel Vessels in Massachusetts by County 2002 and 2016** (tons)*

NAME	2002 $PM_{2.5}$	2002 PM_{10}	2016 $PM_{2.5}$	2016 PM_{10}
Barnstable	14.74	16.02	3.86	3.98
Berkshire	0.08	0.09	0.02	0.02
Bristol	5.50	5.98	1.44	1.49
Dukes	3.90	4.24	1.02	1.05
Essex	16.14	17.54	4.23	4.36
Franklin	0.06	0.07	0.02	0.02
Hampden	0.26	0.28	0.07	0.07
Hampshire	0.10	0.11	0.03	0.03
Middlesex	5.69	6.18	1.49	1.54
Nantucket	1.09	1.19	0.29	0.30
Norfolk	5.57	6.06	1.46	1.51
Plymouth	10.53	11.44	2.76	2.84
Suffolk	4.80	5.21	1.26	1.30
Worcester	1.27	1.38	0.33	0.34
Outside Massachusetts	2.26	2.45	0.59	0.61
Total	71.99	78.24	18.86	19.45

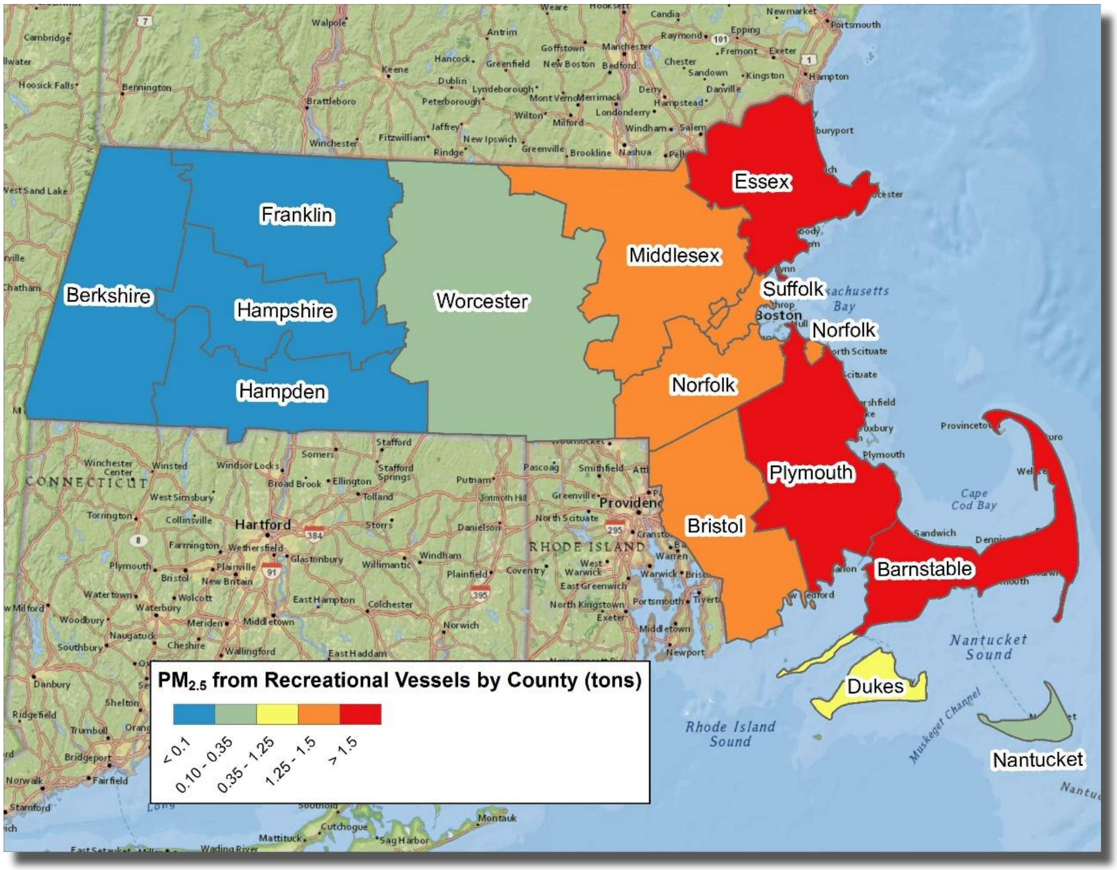

Figure 5-1 PM$_{2.5}$ Emissions from Diesel Recreational Marine Vessels in Massachusetts by County 2016

5.4.2 Commercial Marine Diesel Vessels (CMV)

Commercial marine diesel vessels include tugs and towboats, bulk carriers, passenger and cargo vessels, and excursion vessels. For these vessel types the U.S. Army Corps of Engineers maintains a Waterborne Commerce (WBC) dataset that provides vessel-specific information (including date of manufacture and power rating) for shipping routes that pass through the state. This data set is confidential data and only available to federal agencies. For the 2014 NEI, EPA made a formal data request to USACE for their latest year of data. USACE only provided EPA an aggregated version of the vessel activity data for Massachusetts to protect confidential business information.

Table 5-11 shows the number of vessels that traveled to or from ports in Massachusetts in 2013, the latest WBC data available at the time of the 2014 EPA NEI development. This report assumes that the commercial vessel fleet and activity remain relatively constant year-to-year and therefore 2013 WBC data were likely to be similar to 2016.

Table 5-11 Number of Commercial Marine Vessels by Vessel Type in Massachusetts in 2013

Vessel Type	Count
Bulk Carrier	1
Combination Passenger and Cargo	1
Excursion / Sightseeing Vessel	1
Tug	49
Total	52

To calculate the activity data in terms of kWh, the trip miles, number of trips, and average max speed were applied to the power ratings for each vessel. The WBC data included the power rating, trip miles, and the number of trips along each vessel route. Of the 52 vessels, one tug boat had a missing power rating. The average power rating of the other 48 tug boats was used (3,500 hp) to address the missing data.

The average max speeds by vessel type were available from the EPA's 2014 National Emissions Inventory (NEI) as shown below in Table 5-12. The vessel speed (knots) was multiplied by the segment length (nautical miles) to get duration in hours to transit the route. This value was multiplied by the number of trips to get total hours. It should be noted that actual vessel speed is not available in WBC, so average max speed was used.

Table 5-12 National Average Maximum Speed by Commercial Marine Vessel Type*

Vessel Type	Average Max Speed (knots)
Bulk Carrier	10.09
Combination Passenger and Cargo	11.88
Excursion / Sightseeing Vessel	6.83
Tug	8.54

*U.S. EPA 2014 National Emission Inventory

The PM emissions were calculated by applying the emission factors from Table 5-2 and an assumed load (60%) to the activity data. The load was the average of the Category 2 harbor craft underway load factor and Long Beach Port tugboat load factors from EPA's 2009 Port Guidance. The WBC data included engine manufacturing year which allowed the appropriate tier level emission factor to be applied. The resulting emissions are shown in Table 5-13. The high emissions for combination passenger and cargo are due to the very high activity in which the WBC data shows hundreds of short 9-mile trips, so the operating hours are very high.

Table 5-13 Commercial Marine Diesel PM Emissions by Vessel Type in Massachusetts 2016 *(tons)*

Vessel Type	$PM_{2.5}$	PM_{10}
Bulk Carrier	0.064	0.066
Combination Passenger and Cargo	7.274	7.499
Excursion / Sightseeing Vessel	0.003	0.003
Tug	4.128	4.255
Total	11.468	11.823

5.4.3 *Fishing Vessels*

The Massachusetts Division of Marine Fisheries (DMF) provided the number of permits issued for in-state and out-of-state commercial fishing vessels (Appendix 5.2). The 2017 list includes information about the owners, vessel name, vessel length, home port, and permit type for 5,695 vessels. Table 5-14 shows the number of vessels by permit type included in the roster of fishing vessels.

The proportion of fishing vessels with diesel engines is not known. MassDEP consulted with the Gloucester Fisheries Commission and Massachusetts Lobstermen's Association for assistance in estimating the proportion of fishing vessels with diesel engines.[10] Based on these conversations, MassDEP confirmed that vessels less than 16 feet were not generally equipped with diesel engines, and that overall diesel engines powered 3,431 vessels or over 60% of the entire fishing fleet.

Table 5-14 Number of Fishing Vessels by Permit Type in Massachusetts 2017

Vessel Size	2002	2017	Change 2002-2017
Commercial Fishing 16-25 ft	1,146	1,135	-1%
Commercial Fishing 26-39 ft	1,526	1,239	-19%
Commercial Fishing 40-59 ft	675	525	-22%
Commercial Fishing >60 ft	614	532	-13%
Total	3,961	3,431	-13%

Source: Massachusetts Division of Marine Fisheries, 2017- Appendix 5.2.

[10] Personal communication with MassDEP (Kenneth Santlal): Gloucester Fisheries Commission, Al Cottone, Director; Massachusetts Lobstermen's Association, Beth Casoni, Director.

To estimate 2016 activity for these fishing vessels, power ratings were multiplied by operating hours. The roster of fishing vessels did not include power ratings or typical operating hours. Therefore the average annual operating hours and power ratings for fishing vessels from a study by the Port of Los Angeles (Port of Los Angeles, 2015) were used to approximate activity for fishing vessels in Massachusetts as shown in Table 5-15.

Table 5-15 Average Engine Power and Annual Operation Hours for Fishing Vessels in the Port of Los Angeles 2015

Vessel Category	Propulsion Engine		Auxiliary Engine	
	Engine Power (kW)	Annual Operating Hours	Engine Power (kW)	Annual Operating Hours
Commercial Fishing	157	885	19	767

Source: Port of Los Angeles, 2015.

The PM emissions were calculated by applying the emission factors from Table 5-2 and the assumed load to the activity data. The fishing vessel roster did not include vessel manufacturing year so the emission factor tier was assumed to be Tier 0 (uncontrolled). The engine operating load was assumed to be 27% for the main engines and 43% for the auxiliary engines based on the California Air Resources Board's *Emissions Estimation Methodology for Commercial Harbor Craft Operating in California* (ARB, 2012). Emissions for each commercial fishing vessel were assigned to the county where the vessel's home base is located as shown in Figure 5-2. County-level total emissions are shown in Table 5-16.

Similar to recreational vessels, MassDEP adjusted the fishing vessel count for 2002. Appendix M of the 2002 report from DMF has a total of 6,431 registered fishing vessels but only 2,310 were counted by MassDEP as diesel based on a cut-off of 5 tons. However, for 2017 MassDEP used a different method to estimate diesel vessels: a cut-off size of 16 feet and above. MassDEP, using the DMF 2017 database, counted a total of 3,431 diesel vessels equal to or larger than 16 feet out of 5,695 fishing vessels, as summarized by size in Table 5.14. MassDEP applied this same 2016 counting method for the DMF 2002 database and out of a fishing vessel total of 6,431, 3,961 vessels were counted as diesel. MassDEP recalculated fishing vessel $PM_{2.5}$ emissions for 2002 by using the total emissions in Table 5-20 of the 2002 report divided by the number of vessels to get an emission factor to apply to the revised 2002 vessel total (222.4 tons $PM_{2.5}$/10,286 vessels = 43.24 lbs/vessel x 3,961 vessels = 85.64 tons). The same approach was used for PM_{10} and the results are listed in Table 5-16.

***Table 5-16 PM Emissions from Commercial Fishing in Massachusetts by County for 2002 and 2016** (tons)*

County	2002 $PM_{2.5}$	2002 PM_{10}	2016 $PM_{2.5}$	2016 PM_{10}
Barnstable	3.85	3.9	8.13	8.38
Bristol	2.89	2.92	6.46	6.66
Other counties	-	-	13.07	13.48
Dukes	25.02	27.4	0.85	0.88
Essex	2.89	2.92	6.30	6.50
Nantucket	8.66	8.80	0.63	0.65
Norfolk	0.96	0.98	0.51	0.52
Plymouth	-	-	3.35	3.45
Suffolk	41.37	45.93	1.48	1.53
Total	85.64	92.86	40.78	42.05

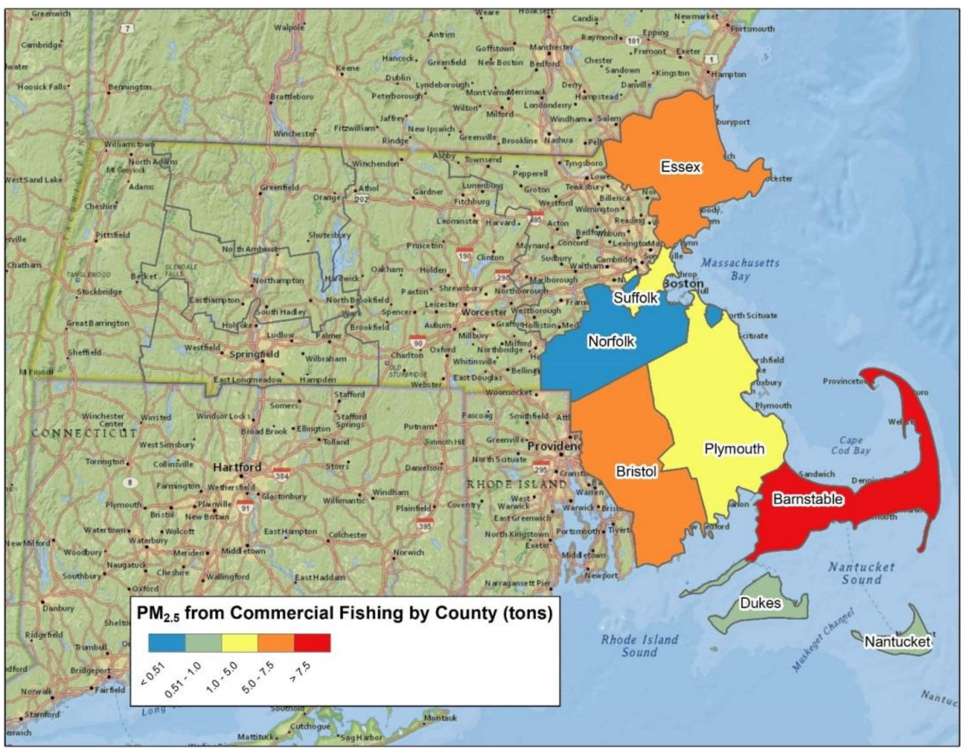

Figure 5-2 $PM_{2.5}$ Emissions from Commercial Fishing Vessels in Massachusetts 2016

5.4.4 *Dredging*

The U.S. Army Corps of Engineers maintains a database of dredging contracts which notes the location where dredging occurred, the start and stop dates for each project, the type of dredging vessel used, and the name of the vessel (U.S. Army Corps of Engineers (2017)).[11] In 2016 there was one dredging project in Massachusetts. The job "Cohassett, MA" in Plymouth County ran from May 2 through May 19 and used the dredger named Currituck built in 1974. According to the U.S. Army Corps of Engineers website the Currituck is a seagoing, shallow draft special purpose dredge with steel construction, full diesel with twin outboard propulsion units, and an engine rating of 900 hp.

To estimate the activity hours, it was assumed that during the project time frame the dredger was operating 24 hours per day. The project hours were applied to the power rating to get activity in terms of kWh (U.S. Army Corps of Engineers 2016).

PM emissions were calculated by applying the emission factors from Table 5-2 and the assumed engine operating load (90%) as found in DOI ITM 2009[12] to the activity data. Emissions are shown in Table 5-17.

Table 5-17 PM Emissions from Dredging Vessels in Massachusetts 2016 *(tons)*

Vessel Type	$PM_{2.5}$	PM_{10}
Dredging	0.0843	0.0869

5.4.5 Ferries

The US Department of Transportation, Bureau of Transportation Statistics maintains the National Census of Ferry Operators. This database includes routes, terminal locations, ferry trip count, trip duration, vessel speed, the year the ferry was built, and the power rating of the engine. The latest available version of the database is for 2014 which showed that there were 7 ferries in operation that year. It was assumed that ferry activities were the same for 2016. The ferry data count was supplemented by data from a MassDOT[13] report and the New England Ferry schedule website[14] for a total of 32 ferries. There was no ferry total for 2002 so it was assumed to be the same as 2016.

A few assumptions were required to fill gaps. Two vessels lacked an engine horsepower rating, so 3,300 hp was used as it was the average of the hp rating for the other ferry engines. One trip did not have an average trip time, so trip time was calculated from distance traveled and vessel speed. To calculate activity, the average trip time in hours was multiplied by the number of trips in the year and the vessel's kilowatt rating to obtain kilowatt-hours. An engine operating load factor of 42% was used per EPA guidance (EPA 2009).[15] Emission factors from Table 5-2 were used to calculate emissions for ferries.

[11] http://www.navigationdatacenter.us/dredge/pdf/dredgerpts/coefy.xlsx
[12] US Department of Interior, Minerals Management Services.
International Tanker Management. http://www.tankermanager.com/about-itm
[13] Massachusetts Department of Transportation Office of Transportation Planning "Passenger Ferry Transportation in Massachusetts." October 2012.
https://www.massdot.state.ma.us/Portals/17/docs/ferry/FerryTransportationinMassachusett10-4-12.pdf
[14] http://www.visit-massachusetts.com/state/ferries/
[15] U.S. Environmental Protection Agency. Current Methodologies in Preparing Mobile Source Port-Related Emission Inventories, Final Report, April 2009. https://archive.epa.gov/sectors/web/pdf/ports-emission-inv-april09.pdf

Where both the route origin and destination were in Massachusetts the emissions for the route were split evenly between the origin and destination counties. Where the route began or ended in a neighboring state all emissions were associated with the Massachusetts County. Note that this may slightly overestimate the portion of those trips that are within state waters. However, there were 4 routes in the database that did not have trip counts and as a result ferry emission estimates may be underestimated overall.

Table 5-18 Ferries Operating in Massachusetts in 2016

BOSTON	Provincetown	1	
	Hull-Hingham	2	
	Harbor Islands	2	
	Winthrop	1	
	Salem	1	
MARTHA'S VINEYARD	Falmouth	1	
	Woods Hole	2	
	New Bedford	1	
	Nantucket	1	
	Hyannis	4	
	Quonset-Kingston RI	5	Out of state
	NJ/NY	1	Out of state
NANTUCKET	Harwichport	1	
	Woods Hole	1	
	New Bedford	1	
	Hyannis	4	
	NJ/NYC	1	Out of state
PROVINCETOWN	Gloucester	1	
	Plymouth	1	
TOTAL		32	

Table 5-19 PM Emissions from Diesel Ferries in Massachusetts by County in 2016 *(tons)*

County	$PM_{2.5}$	PM_{10}
Barnstable	0.0370	0.2834
Bristol	0.0027	0.0210
Dukes	0.0389	0.2983
Nantucket	0.0301	0.2309
Plymouth	0.0005	0.0037
Total	0.1092	0.8374

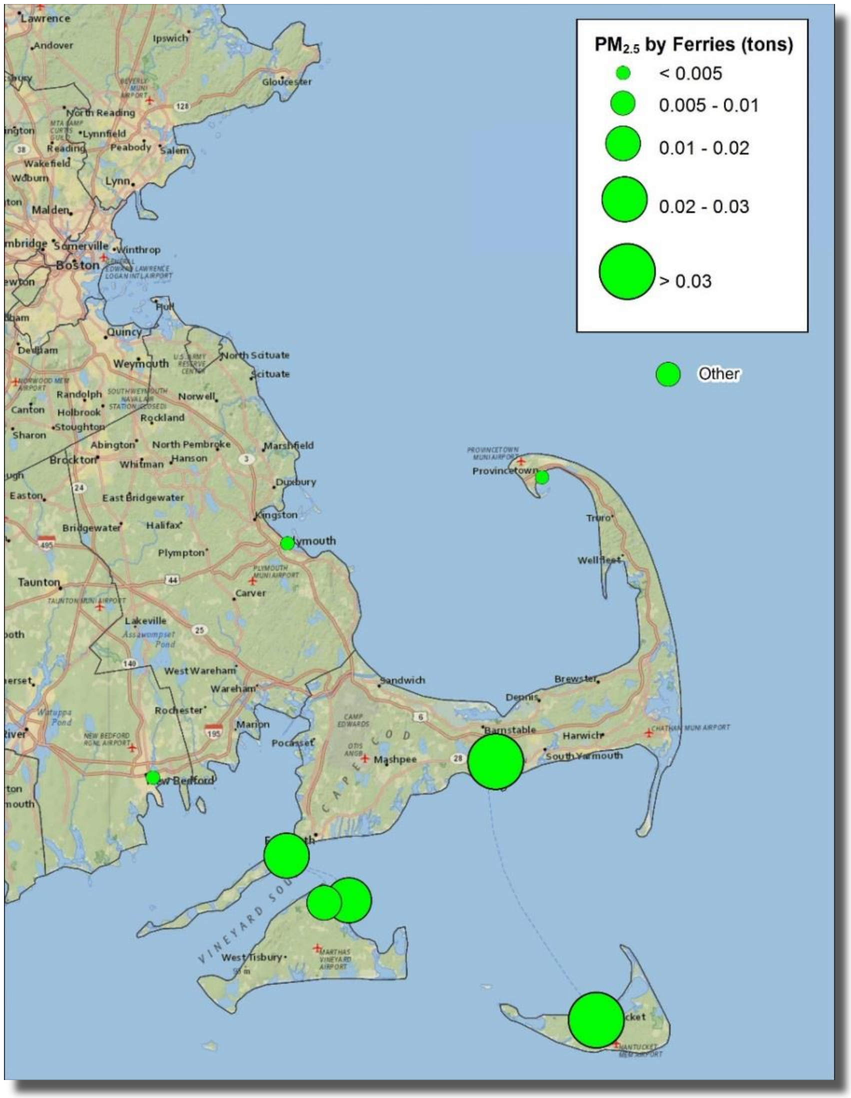

Figure 5-3 PM$_{2.5}$ Emissions from Marine Diesel Ferries in Massachusetts in 2016

5.4.6 Military

While data on U.S. Navy vessels and operations are not available due to national security concerns, U.S. Coast Guard (USCG) vessel data are available. USCG provided EPA with a comprehensive list of their cutters and boats for use in the 2014 NEI (summarized in Table 5-20).[16] Their data included engine ratings and estimated hours of operation by USCG home port (see Appendix 5.3). NEI vessel mapping (i.e., shape) files[17] in each region were identified, and activity was allocated to individual shapes as a fraction of the total area. Emissions were calculated for activity in NEI shapes located in Massachusetts state waters using the emission factors in Table 5-2. Emissions were summed to

[16] U.S. Coast Guard/External Coordination Division (CG-823), 2015a. Vessel Fleet Roster (email correspondence with Robert Mason).

[17] US EPA National Emissions Inventory 2011. https://www.epa.gov/air-emissions-inventories/2014-national-emissions-inventory-nei-data

the vessels' home ports. The final emissions by port are summarized in Table 5-21 and shown in Figure 5-4.

Table 5-20 USCG Vessels by Type

USCG Vessel Type	Count
Cutters	12
Boats	42
Total	54

Table 5-21 PM Emissions from USCG Vessels in Massachusetts by Home Port 2016 *(tons)*

Home Port	$PM_{2.5}$	PM_{10}
Boston	1.6394	1.6901
Cape Cod	0.0054	0.0055
Chatham	0.0518	0.0534
Gloucester	0.2524	0.2602
Menemsha	0.0274	0.0283
New Bedford	0.3654	0.3767
Outside MA	0.1882	0.1940
Point Allerton	0.0271	0.0279
Provincetown	0.0023	0.0024
Spencer	0.0002	0.0002
Woods Hole	0.8848	0.9121
Total	3.4444	3.5509

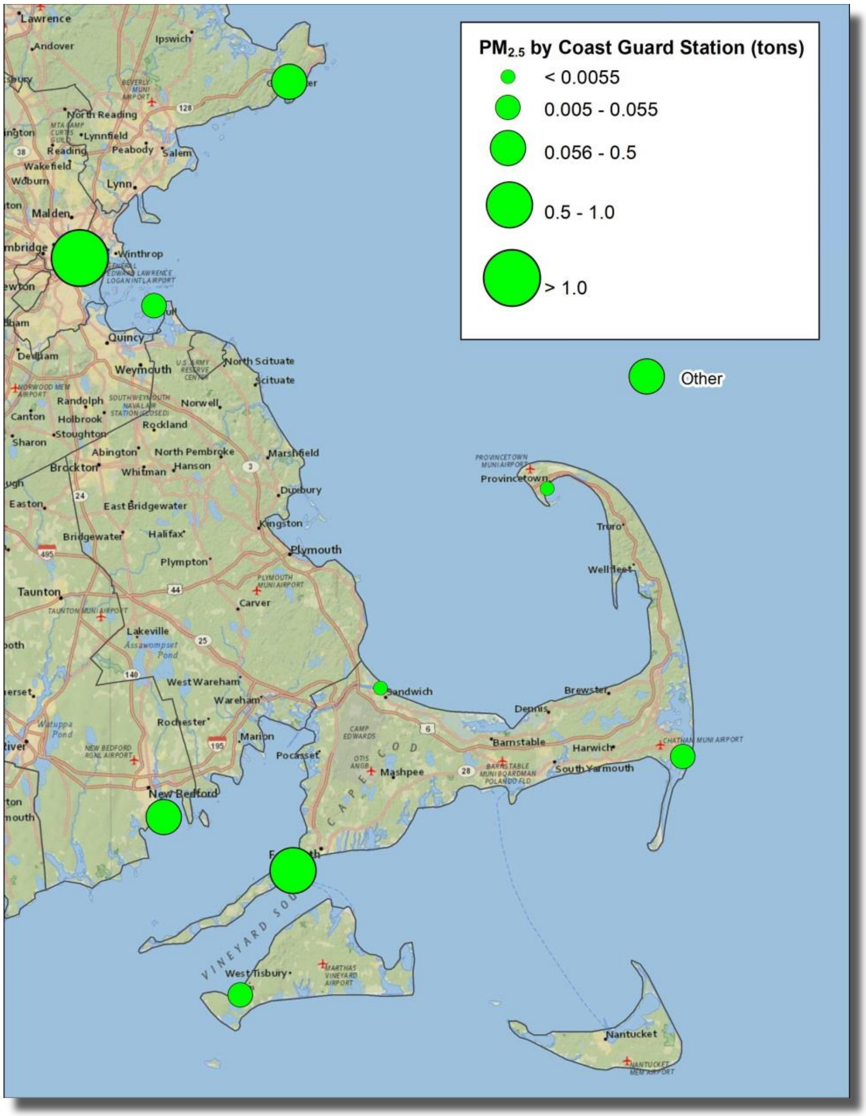

Figure 5-4 $PM_{2.5}$ Emissions from Diesel USCG Vessels in Massachusetts Waters 2016

5.4.7 Police

The Massachusetts State Police's Marine Unit and the Boston Harbor Police operate a variety of vessels for law enforcement, marine security, and search and rescue operations. The State Police Marine Unit provided the vessel counts listed in the Table 5-22. There was a decline from 19 vessels in 2002 to 10 vessels in 2016.

Table 5-22 Number of Vessels by Type in the Massachusetts State Police Marine Unit 2016

Vessel Types	Number of Vessels	Fuel Type
27' to 31' Defender Class; SAFE (Secure All-around Flotation Equipped) Boat vessels	6	Diesel
37' and 44' Catamaran diesel / water jet propulsion Moose Boats	2	Diesel
Several 41' Coast Guard Utility Boats	2	Diesel

It was assumed that each diesel fueled police vessel operated 341 hours per year because this was the average for government vessels in the 2015 Port of Los Angeles study (Port of Los Angeles, 2015). Online research was conducted to obtain an appropriate power rating for each vessel; the power ratings, sources, and comparable vessels are listed in the Table 5-23 below. Activity data were calculated by applying the power rating to the 341 operating hours and an assumed engine load factor of 60% (see Sections 5.4 and 5.4.2 on C1 and C2 vessels for load factor details).

Table 5-23 Massachusetts State Police Vessels and Comparable Propulsion Power Ratings

Vessels	kW	Source
27' to 31' Defender Class; SAFE (Secure All-around Flotation Equipped) Boat vessels	336	Defender-class boat, Wikipedia[18]
37' and 44' Catamaran diesel / water jet propulsion Moose Boats	716	Moose Boats M2 Fleet[19]
Several 41' Coast Guard Utility Boats	507	USCG[20]

The Boston Harbor Police activity data in kilowatt-hours were available from NESCAUM (2006) for the 2002 inventory when 9 vessels were in operation. It was assumed that a government vessel operated 341 hours per year because this was the average for government vessels in the 2015 Port of Los Angeles study (Port of Los Angeles, 2016). As no new information was available to update these activity data it was assumed that police activity was the same in 2016 as in 2002.

The PM emissions were calculated by applying emission factors from Table 5-2 and the same assumed load of 60% (EPA, 1994) to the activity data. The list of police vessels did not include vessel manufacture year so the uncontrolled emission factors (Tier 0) were used. Emissions for police vessels are presented in Table 5-23.

[18] https://en.wikipedia.org/wiki/Defender-class_boat#cite_note-uscg.mil-6
[19] http://www.mooseboats.com/what_we_build_m2_law_enforcement.html
[20] https://www.uscg.mil/datasheet/41utb.asp

***Table 5-24 PM Emissions for Police vessels in Massachusetts 2016** (tons)*

Source	$PM_{2.5}$	PM_{10}
Boston Harbor Police	0.12	0.12
Mass State Police	0.11	0.11
Total	0.23	0.24

5.5 Summary of Marine Diesel Vessel Population and Emissions

Both diesel marine vessel population and PM emissions for 2016 have declined substantially since 2002. For 2016, MassDEP counted a total of 5,797 individual diesel marine vessels operating in the state of Massachusetts, which emitted 75 tons of $PM_{2.5}$. As explained above in the recreational and fishing vessel sections, MassDEP adjusted the vessel population in the 2002 report from a total of 10,286 to 6,787 because of double counting of the USCG recreational vessel counts with OLE data and an under-counting of DMF fishing vessels. Table 5-25 is a summary of the vessel counts and Table 5-26 is a summary of the PM emissions for 2002 and 2016.

Key findings are below.

- **The vast majority of diesel marine vessels are fishing vessels**, which represent 59% of the population. Recreational vessels represent another 38% of the population and together with fishing vessels account for 97% of all diesel marine vessels.
- **The number of diesel marine vessels declined by 15% from 2002 to 2016.**
- **Overall $PM_{2.5}$ emissions declined by 60% from 2002 to 2016** due to several factors:
    - Vessel registration declined between 2002 and 2016 as boat prices have more than doubled between 2000 and 2013.
    - New PM standards were introduced for C1 and C2 engines.
    - The introduction of ultra-low sulfur diesel (ULSD) substantially reduced sulfate PM emissions.
- **The number of vessels does not always correlate with total emissions from each vessel type.** For example, recreational vessels are 38% of all diesel marine vessels in Massachusetts but only contribute 25% of the statewide diesel $PM_{2.5}$. Fishing vessels in 2016 accounted for 59% of the marine vessel fleet and 54% of the $PM_{2.5}$ emissions.
- **Commercial marine vessels, on the other hand, constituted less than 1% of the engine population but 16% of its emissions**. This is because CMVs have an average power rating of approximately 8,500 kW, whereas recreational vessels have much smaller engines with an average of only 100 kW.
- **Even though USCG and police vessels constitute less than 1% of the diesel fleet, they contribute 5% of $PM_{2.5}$**, as shown in Table 5-26 and Figures 5-5 and 5-6. This higher contribution is due to larger engines and more hours of activity. For example, USCG vessels operate year-round as opposed to seasonal recreation and fishing vessels. Also,

the average engine rating for a Coast Guard boat is 614 kW and a cutter is 3860 kW compared to the average for recreational vessels of 100 kW and fishing vessels of 157 kW.

- **Essex and Barnstable counties together contribute over one-third of diesel marine engine $PM_{2.5}$ emissions in Massachusetts** as shown in Figure 5-7. This was as expected given the marine activity in Cape Cod and Massachusetts Bay.

Table 5-25 Diesel Marine Vessel Count for Massachusetts 2002 - 2016

Vessel Type	2002 Count	2016 Count	Change 2002 to 2016
Recreational	2,601	2,217	-15%
Commercial -Tugs, Dredge	109	53	-51%
Ferries	32	32	0%
Fishing	3,961	3,431	-13%
USCG & Police	84	64	-24%
Total	6,787	5,797	-15%

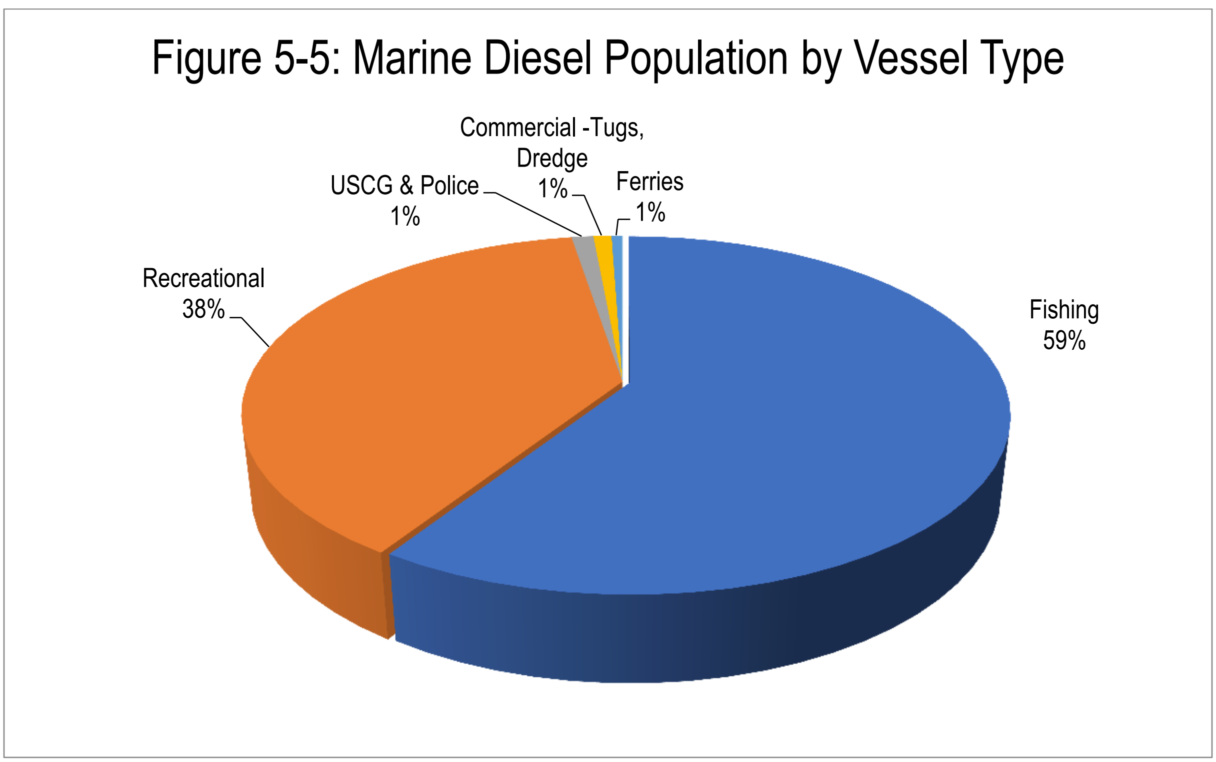

Figure 5-5 Marine Diesel Vessel Population in Massachusetts 2016

***Table 5-26 PM Emissions from Marine Diesel Vessels in Massachusetts in 2002 and 2016** (tons)*

Vessel Type	2002 $PM_{2.5}$	2002 PM_{10}	2016 $PM_{2.5}$	2016 PM_{10}	2016 Percent $PM_{2.5}$	$PM_{2.5}$ Change 2002-2016
Fishing	85.64	92.86	40.78	42.05	54%	-52%
Recreational	71.99	78.24	18.86	19.45	25%	-74%
USCG & Police	5.90	6.30	3.67	3.79	5%	-38%
Commercial – Tugs, Dredging	23.75	24.49	11.55	11.91	15%	-51%
Ferries	0.11	0.84	0.11	0.84	0.1%	0%
Total	187.39	202.73	74.97	78.04		-60%

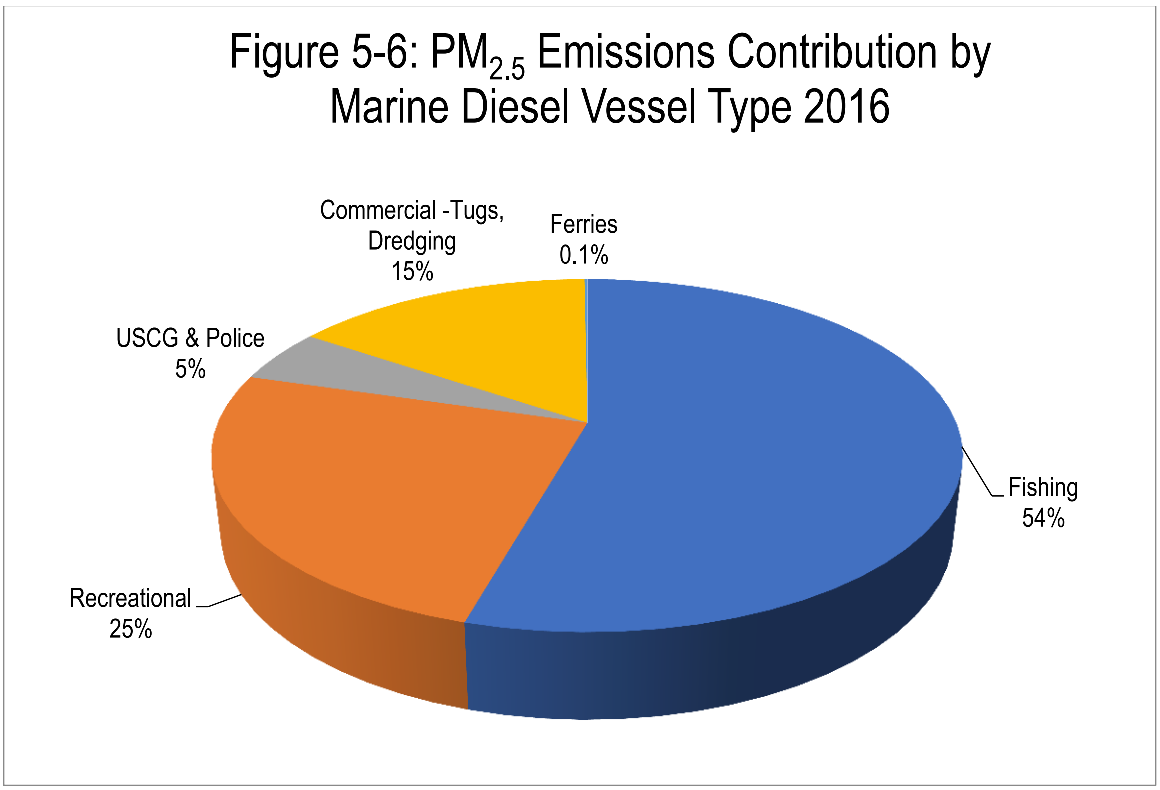

Figure 5-6 $PM_{2.5}$ Emissions Contribution by Vessel Type in Massachusetts 2016

Table 5-27 $PM_{2.5}$ Emissions from Marine Diesel Vessels in Massachusetts by County 2016 (tons)

NAME	Recreational	Fishing	USCG, Ferries, Police, Commercial	Total	Percent of Total
Barnstable	3.86	8.13	3.08	15.07	20%
Berkshire	0.02	0	0.01	0.03	0.04%
Bristol	1.44	6.46	2.03	9.93	13%
Dukes	1.02	0.85	0.48	2.35	3%
Essex	4.23	6.3	2.71	13.24	18%
Franklin	0.02	0	0.00	0.02	0.02%
Hampden	0.07	0	0.02	0.09	0.1%
Hampshire	0.03	0	0.01	0.04	0.05%
Middlesex	1.49	0	0.38	1.87	3%
Nantucket	0.29	0.63	0.24	1.16	2%
Norfolk	1.46	0.51	0.51	2.48	3%
Plymouth	2.76	3.35	1.57	7.68	10%
Suffolk	1.26	1.48	0.70	3.44	5%
Worcester	0.33	0	0.09	0.42	0.6%
Outside MA	0.59	13.07	3.51	17.17	23%
Total	18.86	40.78	15.33	74.97	

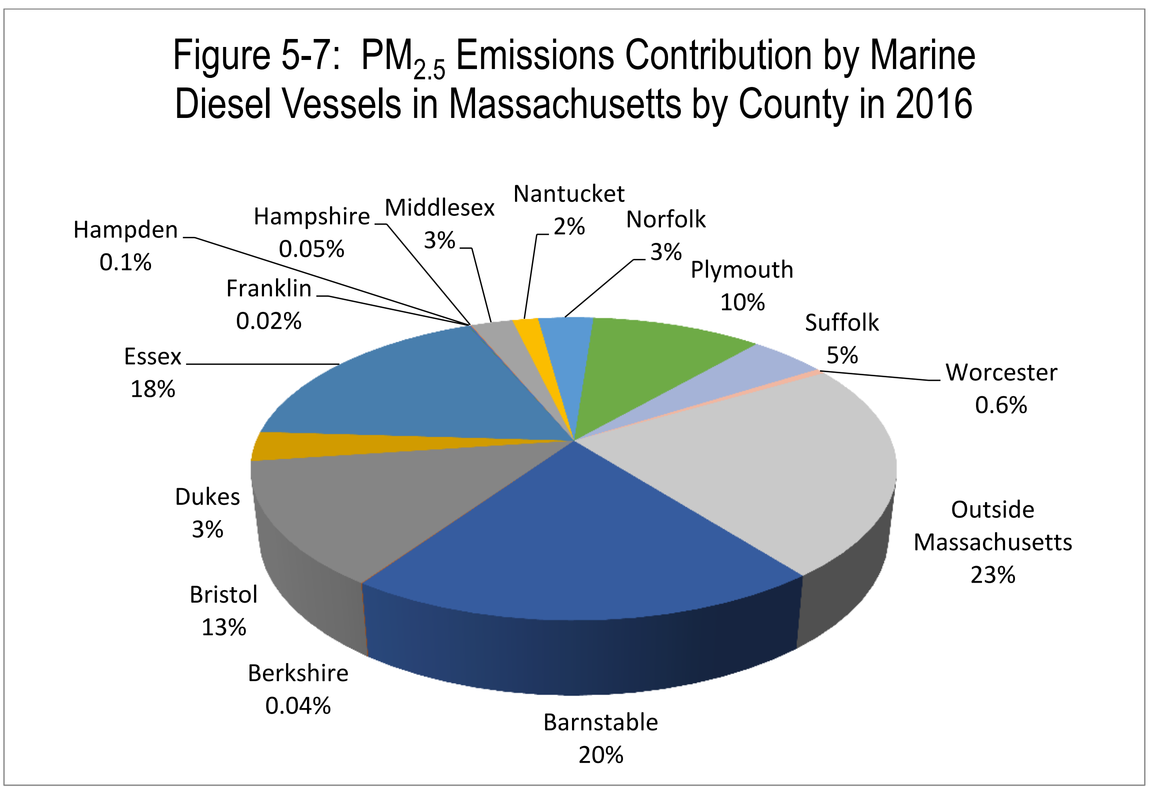

Figure 5-7 $PM_{2.5}$ Emissions Contribution by Massachusetts County 2016

5.6 References for Marine Diesel Engines

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6.0 Diesel Locomotive Engines

Railroad locomotives are primarily electric or diesel-electric powered. Electric locomotives are powered by electricity generated at stationary power plants. These electric 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, passenger locomotives, and commuter trains.

6.1 Data Sources

The Massachusetts Bay Transportation Authority (MBTA), EPA, and local rail companies provided data that MassDEP used to estimate locomotive emissions. No new Amtrak data were received, so MassDEP used Amtrak data from the *Massachusetts 2002 Baseline Emission Inventory of: Volatile Organic Compounds, Nitrogen Oxides, Carbon Monoxide, Sulfur Dioxide, Particulate Matter and Ammonia.*[1] The Northern New England Intercity Rail Initiative's (NNEIRI) *Draft Purpose and Need Statement*[2] supplied a ridership growth rate to adjust the Amtrak emission estimates to 2016 levels.

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 where possible (Table 6-1). Note that the distinctions between types are not clear because in some cases, rail companies use their line-haul engines to serve as switchyard engines.

Railroads are classified in three ways by the Federal government's Surface Transportation Board (STB) based on annual operating revenues: [3]

- A Class I railroad is a railroad with operating revenues of $447.6 million or more. The Class I railroads are the nationwide, long distance, line-haul railroads which carry the bulk of railroad commerce – they account for over 90% of the ton-miles of freight hauled annually.[4]
- A Class II or regional railroad is a non-Class I, line-haul railroad with revenues of at least $35.8 million.
- A Class III or local railroad is neither a Class I nor a Class II regional railroad with revenue less than $35.8 million that is engaged primarily in line-haul service.

[1] 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.

[2] Northern New England Intercity Rail Initiative (NNEIRI). Draft Purpose and Need Statement. April 2014. Available online at: http://www.massdot.state.ma.us/Portals/39/Docs/PurposeNeed.pdf

[3] Surface Transportation Board (49 CFR 1201). 2017. (see: https://www.stb.gov/stb/faqs.html)

[4] Office of Mobile Sources Office of Air and Radiation U.S. Environmental Protection Agency. Locomotive Emission Standards Regulatory Support Document. April 1998 [EPA-420-R-98-101] https://nepis.epa.gov/Exe/ZyPDF.cgi/P100F9QT.PDF?Dockey=P100F9QT.PDF

EPA classifies locomotive emissions using the STB categories plus passenger rail types as shown below for the 2014 National Emissions Inventory.[5]

SCC	Description
2285002006	Mobile Sources; Railroad Equipment; Diesel; Line Haul Locomotives: Class I Operations
2285002007	Mobile Sources; Railroad Equipment; Diesel; Line Haul Locomotives: Class II / III Operations
2285002008	Mobile Sources; Railroad Equipment; Diesel; Line Haul Locomotives: Passenger Trains (Amtrak)
2285002009	Mobile Sources; Railroad Equipment; Diesel; Line Haul Locomotives: Commuter Lines
2285002010	Mobile Sources; Railroad Equipment; Diesel; Yard Locomotives
2285002015	Internal Combustion Engines; Railroad Equipment; Diesel; Yard Locomotives

In 2002, 13 railroad companies provided engine count data for the baseline inventory effort. For 2016, only five companies submitted engine count data. To estimate the total number of engines operating in Massachusetts, online research was conducted to identify individual rail companies that operated in Massachusetts in 2016.[6,7] Engine counts for 2002 were used where 2016 data were unavailable. When engine counts were not available in either year one engine was assumed per company. 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. There was a 14% increase in the number of locomotive engines between 2002 and 2016.

Table 6-1 Number of Diesel Locomotive Engines in Massachusetts in 2002 and 2016

Railroad Company	2002 Engine Count	2016 Engine Count
Amtrak	10	10
Bay Colony Railroad Corporation	13	3
Berkshire Scenic Railway	**	1*
Cape Cod Central RR	3	3
Connecticut Southern Railroad	**	1*
CSX	66	66
East Brookfield & Spencer	**	3
Fore River Transportation Corp.	4	2
Grafton & Upton Railroad Company	2	2
Housatonic Railroad	3	11
Massachusetts Central	3	5
Massachusetts Coastal	**	1*

5 EPA. 2014 National Emissions Inventory, version 1, Technical Support Document. December 2016 (Table 4-117: Locomotives SCCs, descriptions and EPA estimation status). https://www.epa.gov/air-emissions-inventories/2014-national-emissions-inventory-nei-technical-support-document-tsd

6 American Short Line and Regional Railroad Association, 2017. Railroad Member Search. http://www.aslrra.org/. Accessed 27 August 2017.

7 List of Massachusetts railroads, 2017. Wikipedia. https://en.wikipedia.org/wiki/List_of_Massachusetts_railroads. Accessed 27 August 2017.

Railroad Company	2002 Engine Count	2016 Engine Count
MBTA***	83	118
New England Central Railroad, Inc.	11	11
Pan AM Railways	50	50
Pan AM Southern	**	1*
Pioneer Valley Railroad Co., Inc.	7	7
Providence & Worcester Railroad Co.	4	4
Total Engine Count	259	299

* Engine count data unavailable, so one engine was assumed.
** Not included in 2002 inventory.
***Operated by Keolis Commuter Services since 2014

6.3 PM Emission Standards and Fuel

In 1998, EPA set 3 tiers of emission standards for locomotives for the first time. These were based on the original date the locomotive was manufactured (Tier 0, 1, 2).[8] EPA revised the standards in 2009 to add standards for remanufactured Tier 0, 1, and 2 locomotives (Tier 0+, 1+, and 2+) and new standards for new locomotives. For newly built locomotives EPA established Tier 3 standards (based on engine design improvements) and Tier 4 standards (based on the application of the high-efficiency catalytic after treatment technologies for on-road diesel engines).[9]

The 2009 standards for existing locomotives apply to engines originally manufactured after 1973 but prior to 2011 that are remanufactured (rebuilt) after 2009. This is a key point since locomotive replacement rates are very low. EPA's technical support for the standards indicated that in Class I railroads locomotives are typically rebuilt every 4 to 8 years and the fleet turnover time is 40 years.[10] Similar data for Class II/III railroads are not available, but EPA noted that Class I railroads account for nearly all of the new locomotives sold, and so the industry-wide replacement rate would be even lower than represented by the Class I data. Similarly the remanufacture rate for Class II/III railroads may be lower. The standards required recertification for engines at the time of rebuilding. The standards for remanufactured locomotives were phased in as certified remanufacture kits became available.

The original (1998) and current (2009) standards are presented in Tables 6-2 by tier for line-haul and switch engines.[11] The standards are set for total PM – they are not broken down by PM_{10} and $PM_{2.5}$.

[8] EPA, 40 CFR Parts 85, 89 and 92 Emission Standards for Locomotives and Locomotive Engines, Final rulemaking. (63 FR 18978) April 16, 1998. https://www.gpo.gov/fdsys/pkg/FR-1998-04-16/pdf/98-7769.pdf

[9] EPA. 40 CFR Parts 9, 85, 86, 89, 92, 94, 1033, 1039, 1042, 1065, and 1068, Control of Emissions of Air Pollution From Locomotive Engines and Marine Compression-Ignition Engines Less Than 30 Liters per Cylinder; Republication, Final rule. (73 FR 37096) June 30, 2008.

[10] Office of Mobile Sources Office of Air and Radiation U.S. Environmental Protection Agency. Locomotive Emission Standards Regulatory Support Document. April 1998 [EPA-420-R-98-101]. https://nepis.epa.gov/Exe/ZyPDF.cgi/P100F9QT.PDF?Dockey=P100F9QT.PDF

[11] EPA. Regulatory Impact Analysis: Control of Emissions of Air Pollution from Locomotive Engines and Marine Compression Ignition Engines Less than 30 Liters Per Cylinder [EPA420-R-08-001] March 2008.

***Table 6-2 EPA Total PM Emission Standards for Locomotives** (g/bhp·hr)*

Standards apply to	Take effect in year	PM Line-haul	PM Switch
Tier 0 (1998)[1]	2002[3]	0.60	0.72
Tier 1 (1998)	2002	0.45	0.54
Tier 2 (1998)	2005	0.20	0.24
Remanufactured Tier 0[1]	2008 as available, 2010 required[2]	0.22	0.26
Remanufactured Tier 1	2008 as available, 2010 required[2]	0.22	0.26
Remanufactured Tier 2	2008 as available, 2013 required[2]	0.10	0.13
Tier 3	2012 (2011 switch)	0.1	0.10
Tier 4	2015	0.03	0.03

g/bhp·hr = grams per brake-horsepower-hour
[1] 1993-2001 locomotives that were not equipped with an intake air coolant system are subject to Tier 0 rather than Tier 1 standards.
[2] As early as 2008 if approved engine upgrade kits become available.
[3] Manufactured from 1973-2002; manufactured prior to 1973 but remanufactured after 2002.
Sources:
EPA. 40 CFR Parts 85, 89 and 92 Emission Standards for Locomotives and Locomotive Engines, Final rulemaking. (63 FR 18978) April 16, 1998. https://www.gpo.gov/fdsys/pkg/FR-1998-04-16/pdf/98-7769.pdf
EPA. 40 CFR Parts 9, 85, 86, 89, 92, 94, 1033, 1039, 1042, 1065, and 1068, Control of Emissions of Air Pollution From Locomotive Engines and Marine Compression-Ignition Engines Less Than 30 Liters per Cylinder; Republication, Final rule. (73 FR 37096) June 30, 2008.

In developing the impact analysis to support the 2009 emission standards EPA created emission factors to aid in projecting the benefits of the new rule.[12] These factors, originally in grams per brake-horsepower-hour (g/bhp-hr), were converted to g/gal by multiplying the original emission rates by a conversion factor relating the fuel consumption (gal/hr) and the usable power (bhp) of the engine (see Table 6-3). EPA provided the emission factors for PM_{10}, but also gave a conversion factor to $PM_{2.5}$ of 0.97 (indicating that nearly all of the PM from a locomotive is $PM_{2.5}$). These factors, presented in Table 6-4, were used to calculate locomotive emissions for Massachusetts.

***Table 6-3 Conversion Factors** (bhp-hr/gal)*

Locomotive Application	Conversion Factor (bhp-hr/gal)
Large Line-Haul and Passenger	20.8
Small Line-Haul	18.2
Switching	15.2

[12] U.S. EPA, Office of Transportation and Air Quality, Emission Factors for Locomotives, EPA-420-F-09-025, April 2009. https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100500B.pdf

Table 6-4 Locomotive Emission Factors *(g/gal)*

	Line-Haul		Switch	
	$PM_{2.5}$*	PM_{10}	$PM_{2.5}$*	PM_{10}
Uncontrolled	6.5	6.7	6.5	6.7
Tier 0	6.5	6.7	6.5	6.7
Tier 0+	4.0	4.2	3.4	3.5
Tier 1	6.5	6.7	6.3	6.5
Tier 1+	4.0	4.2	3.4	3.5
Tier 2	3.6	3.7	2.8	2.9
Tier 2+	1.6	1.7	1.6	1.7
Tier 3	1.6	1.7	1.2	1.2
Tier 4	0.3	0.3	0.2	0.2

+Indicates that these are the revised standards in 40 CFR Part 1033
* $PM_{2.5}$ emissions estimated at 0.97 times PM_{10} emissions.
Source: U.S. EPA, Office of Transportation and Air Quality, Emission Factors for Locomotives, EPA-420-F-09-025, April 2009.
https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100500B.pdf

6.4 PM Emissions of Diesel Locomotive Engines

6.4.1 *Class I Railroads*

Class I PM emissions data were pulled from EPA's 2014 National Emissions Inventory (NEI). The 2014 NEI data included FIPS county code,[13] but did not include activity data. EPA worked with ERTAC[14] in 2008 to develop emission estimates. Each railroad provided fleet mix information so that ERTAC could calculate weighted emission factors based on the fraction of locomotives at each EPA tier level. Emissions were calculated by applying weighted emission factors to fuel consumption data.[15] These data were grown for later emissions inventories, but changing fleet mix was not taken into consideration. Therefore, for this effort a 48% reduction was applied to account for changes to regulations and associated fleet changes based on emission factors listed in Table 6 of the EPA's *Locomotive Emission Factors.*[16]

[13] The FIPS county code is a five-digit Federal Information Processing Standards (FIPS) code which uniquely identifies counties and county equivalents in the United States, certain U.S. possessions, and certain freely associated states.

[14] The Eastern Regional Technical Advisory Committee is a consortium of states and their Multi-Jurisdictional Oganizations (MJOs) for providing technical driven process for developing and improving specialized sections of emission inventories on a national basis. http://www.ertac.us/

[15] U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, 2014 National Emission Inventory, 2016 https://www.epa.gov/air-emissions-inventories/2014-national-emissions-inventory-nei-documentation

[16] U.S. EPA, Office of Transportation and Air Quality, Emission Factors for Locomotives, EPA-420-F-09-025, April 2009. https://www.epa.gov/moves/emissions-models-and-other-methods-produce-emission-inventories

Class I engine counts of 66 engines (40 line haul + 26 switchers) were provided by CSX in 2002, but no new data were available for this effort (Table 6-3). CSX was selected as a growth surrogate for all Class I railroads because CSX is the primary Class I rail line in Massachusetts.

Emissions from the 2014 NEI were adjusted to 2016 levels using a fraction derived from comparing fuel usage from CSX's U.S. Department of Transportation (DOT) Federal Railroad Administration (FRA) R-1 reports between 2014 and 2016.[17] Fuel usage for CSX in 2016 decreased to 86.2% of the 2014 usage so 2014 NEI emissions were reduced by multiplying them by 0.862. Emissions were further reduced by 48% to account for changes to regulations and associated fleet changes based on the difference between the factors used for the 2002 inventory and the emission factors listed in Table 6 of the EPA's *Locomotive Emission Factors*.[18] Emissions by county are summarized in Table 6-5.

Table 6-5 Class I Railroad PM Emissions in Massachusetts by County in 2016 *(tons)*

County	$PM_{2.5}$	PM_{10}
Berkshire	3.13	3.41
Bristol	0.18	0.20
Hampden	4.11	4.47
Hampshire	0.44	0.48
Middlesex	0.51	0.55
Norfolk	0.25	0.27
Plymouth	0.003	0.003
Suffolk	0.05	0.05
Worcester	3.01	3.27
2016 Total	11.69	12.71
2002 Total	32.6	59.6

6.4.2 Class II/III Railroads

Bay Colony, Fore River, Mass Central, and Housatonic rail lines provided fuel consumption data and locomotive counts to MassDEP. Brookfield/Spencer Rail only provided locomotive counts. Fuel consumption for Brookfield/Spencer Rail was estimated using the average fuel use per locomotive from the other railroads. The data were allocated to counties based on track mileage for each county for each railroad. Table 6-6 summarizes the locomotive counts and fuel use.

[17] U.S. Department of Transportation Federal Railroad Administration, 2016 R-1 Data, p. 84, Downloaded June 8, 2017. Available online at: https://www.csx.com/index.cfm/investors/annual-materials/

[18] U.S. EPA, Office of Transportation and Air Quality, Emission Factors for Locomotives, EPA-420-F-09-025, April 2009.

Table 6-6 Class II/III railroad activity data for Massachusetts in 2016*

Company	Number of Locomotives	County	Fuel Consumption (gallons)
Bay Colony	3	Barnstable	1,075
		Bristol	260
		Middlesex	72
		Norfolk	882
		Plymouth	1,620
		Suffolk	100
Housatonic Rail Road	11		7,000
Fore River	3	Norfolk	2,000
East Brookfield/Spencer Rail	3	Worcester	10,788
Mass Central	5	Hampden	13,217
		Hampshire	8,218
		Worcester	12,110

* These activity data only include activity for rail companies that provided data.

To estimate emissions for Class II/III railroads EPA's switch emission factors were applied to the fuel consumption data. Because manufacturing/remanufacturing dates were unavailable, tier levels for the Class II/III fleets could not be determined. We assumed that these engines were older and have not undergone a retrofit since regulations came into effect. Therefore, Tier 0+ emission factors were used from Table 6-4.

MassDEP compared the emissions estimates from the 5 (of 18) companies that provided fuel consumption data with what was included in the 2014 NEI. The NEI estimates were higher and therefore presumably accounted for Class II/III rail companies that did not respond to the MassDEP request. Therefore the NEI data were used to more accurately estimate Massachusetts emissions for Class II/III railroads. Emissions from the 2014 NEI were adjusted to 2016 levels using fuel usage from CSX's U.S. Department of Transportation (DOT) Federal Railroad Administration (FRA) R-1 reports between 2014 and 2016 as a surrogate for Class II/III rail activity.[19] Fuel usage for CSX decreased to 86.2% of the 2014 usage, so 2014 NEI emissions were reduced by multiplying them by 0.862. The final emissions for Class II/III railroads are listed in Table 6-7.

[19] U.S. Department of Transportation Federal Railroad Administration, 2016 R-1 Data, p. 84, Downloaded June 8, 2017. Available online at: https://www.csx.com/index.cfm/investors/annual-materials/

***Table 6-7 Class II/III Railroad PM Emissions in Massachusetts by County in 2016** (tons)*

County	$PM_{2.5}$	PM_{10}
Barnstable	0.79	0.86
Berkshire	0.90	0.98
Bristol	0.90	0.98
Essex	1.20	1.31
Franklin	1.46	1.59
Hampden	1.03	1.12
Hampshire	0.58	0.64
Middlesex	2.11	2.29
Norfolk	0.68	0.74
Plymouth	0.97	1.05
Suffolk	0.16	0.17
Worcester	2.63	2.86
2016 Total	13.40	14.57
2002 Total	29.5	32.7

6.4.3 Commuter Railroads

Commuter rail data were provided by MBTA[20] and are presented in Appendices 6.1 and 6.2. MBTA provided 2016 fuel consumption that was allocated to counties based on daily train stops[21] and engine counts by year of manufacture and rebuild. Table 6-8 summarizes the fuel consumption allocated to each county and Table 6-9 lists the engine counts by year.

[20] Massachusetts Bay Transportation Authority (MBTA) E-mail to Kenneth Santlal from Mimi Lannin June 19, 2017.

[21] MBTA Schedules & Maps Commuter Rail (http://www.mbta.com/schedules_and_maps/rail/lines/)

Table 6-8 MBTA Fuel Consumption in 2016

FIPS	County	Diesel (gallons)
25005	Bristol	303,681
25009	Essex	1,986,577
25017	Middlesex	2,790,065
25021	Norfolk	2,201,684
25023	Plymouth	771,855
25025	Suffolk	2,385,157
25027	Worcester	1,448,809
Total		11,887,827

Table 6-9   MBTA Locomotive Counts by Year of Manufacture and Rebuild in 2016

Year of Manufacture	Year of Rebuild	Number of Locomotives
1974	1997	25
1978	1989	13
1980	1989	4
1988	2002	25
1991	2004	12
1954		1
1971		1
2009		2
2009		2
2013		33
Total		118

To estimate emissions for Commuter Lines EPA emission factors from Table 6-4 were multiplied by the fuel consumption data. Because engine counts by manufacturing dates were available, factors from Table 6-4 were weighted by engine counts listed in Table 6-9. EPA's switch engine emission factors were used for commuter and short haul operations. Despite the increase in locomotives since 2002 there was an overall decrease in emissions due to the inclusion of new engines and engine rebuilds. The commuter rail emissions are summarized in the Table 6-10.

Table 6-10 Commuter Rail PM Emissions in Massachusetts by County in 2016 *(tons)*

County	$PM_{2.5}$	PM_{10}
Bristol	0.94	0.97
Essex	6.17	6.33
Middlesex	8.66	8.89
Norfolk	6.84	7.02
Plymouth	2.40	2.46
Suffolk	7.41	7.60
Worcester	4.50	4.62
2016 Total	36.91	37.88
2002 Total	75.1	83.4

6.4.4 *Amtrak*

No new Amtrak engine or activity data were available for 2016, so we used Amtrak diesel data from MassDEP's *Massachusetts 2002 Baseline Emission Inventory of: Volatile Organic Compounds, Nitrogen Oxides, Carbon Monoxide, Sulfur Dioxide, Particulate Matter and Ammonia.*[22] A ridership growth rate from the Northern New England Intercity Rail Initiative's (NNEIRI) *Draft Purpose and Need Statement*[23] was applied to the Amtrak diesel consumption rate (698,485 gallons) to estimate 2016 levels (860,682 gallons). The growth rate weighted by ridership in the Pioneer Valley (Springfield, Massachusetts and Hartford, CT) was 23%.

To estimate emissions for Amtrak EPA's emission factors from Table 6-4 were applied to the fuel consumption data. Because manufacturing dates were unavailable tier levels for the Amtrak fleet could not be determined. MassDEP assumed that older engines were updated prior to the 2009 regulations. Therefore the Tier 0+ emission factors were used. Despite an increase in activity from 2002, the emissions ultimately decreased due to engine updates prior to the 2009 regulatory changes. Table 6-11 summarizes the emission estimates.

[22] 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. http://www.mass.gov/eea/agencies/massdep/air/reports/emissions-inventories.html

[23] Northern New England Intercity Rail Initiative (NNEIRI). Draft Purpose and Need Statement. April 2014. http://www.massdot.state.ma.us/Portals/39/Docs/PurposeNeed.pdf

***Table 6-11 Amtrak PM Emissions in Massachusetts in 2002 and 2016** (tons)*

Year	$PM_{2.5}$	PM_{10}
2016	3.79	3.98
2002	5.2	5.8

6.4.5 PM Emissions Summary

MassDEP estimates that railroad locomotives emitted 66 tons of $PM_{2.5}$ in 2016. Table 6-12 summarizes 2002 and 2016 emissions by class, and Table 6-13 summarizes emissions by county. These emission estimates include both line haul and switch engine emissions. Key findings are below.

- **MBTA passenger trains emitted more diesel $PM_{2.5}$ (37 tons) than all other rail lines combined** due to MBTA having a larger fleet than the other categories. MBTA locomotives account for almost 40% of the locomotive fleet. Commuter line emissions were 55% of the total emissions from locomotives. Figure 6-3 shows the breakout of emissions between each rail class.

- **Class II/III locomotives were the next highest $PM_{2.5}$ emitters** with 13 tons of $PM_{2.5}$.

- **Middlesex and Worcester Counties had the highest locomotive emissions** with 11 tons and 10 tons of $PM_{2.5}$, respectively. This is expected, as these counties have the highest rail line mileage, accounting for approximately 40% of all rail lines in the state.

- **Barnstable County had the lowest locomotive emissions** with 1 ton of $PM_{2.5}$. This is also expected, as Barnstable has the shortest rail line mileage in the state, accounting for only 4% of all rail lines in the state. Note that Dukes and Nantucket counties have no rail lines.

- **Compared to 2002, the emissions of $PM_{2.5}$ from Class I and Class II/III locomotives decreased by 64% and 55%, respectively.** The reasons for this decrease include the decrease in diesel fuel consumption for the rail industry, the introduction of new regulations in 2009, and fleet turnover. This reduction is consistent with the national consumption of diesel fuel by rail locomotives which decreased by 30% from 2002 to 2016.[24]

- **Compared to 2002 the emissions of $PM_{2.5}$ from commuter lines and Amtrak decreased by 51% and 27%, respectively.** This decrease is due to the introduction of new regulations and fleet turnover.

[24] CSX Transportation, Inc., Class I Railroad Annual Report, pp. 91, December 27, 2002. Downloaded: September 5, 2017. Available online at: http://library.corporate-ir.net/library/92/929/92932/items/270286/R-1%202002.pdf

Table 6-12 $PM_{2.5}$ and PM_{10} Emissions from Locomotives in Massachusetts in 2002 and 2016 *(tons)*

	2002 Estimates		2016 Estimates		
	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}	% Change $PM_{2.5}$
Class I	32.6	59.6	11.69	12.71	-64%
Class II/III	29.5	32.7	13.40	14.57	-55%
Commuter Lines	75.1	83.4	36.91	37.88	-51%
Amtrak	5.2	5.8	3.79	3.98	-27%
Total	142.4	181.5	65.80	69.14	-54%

Table 6-13 PM Emissions from Locomotives in Massachusetts by County in 2016 *(tons)*

County	$PM_{2.5}$	PM_{10}
Barnstable	0.79	0.86
Berkshire	4.03	4.38
Bristol	2.03	2.15
Essex	7.37	7.64
Franklin	1.46	1.59
Hampden	8.93	8.57
Hampshire	1.02	1.11
Middlesex	11.28	11.74
Norfolk	7.77	8.03
Plymouth	3.36	3.51
Suffolk	7.61	7.82
Worcester	10.13	10.74
Total	65.80	69.14

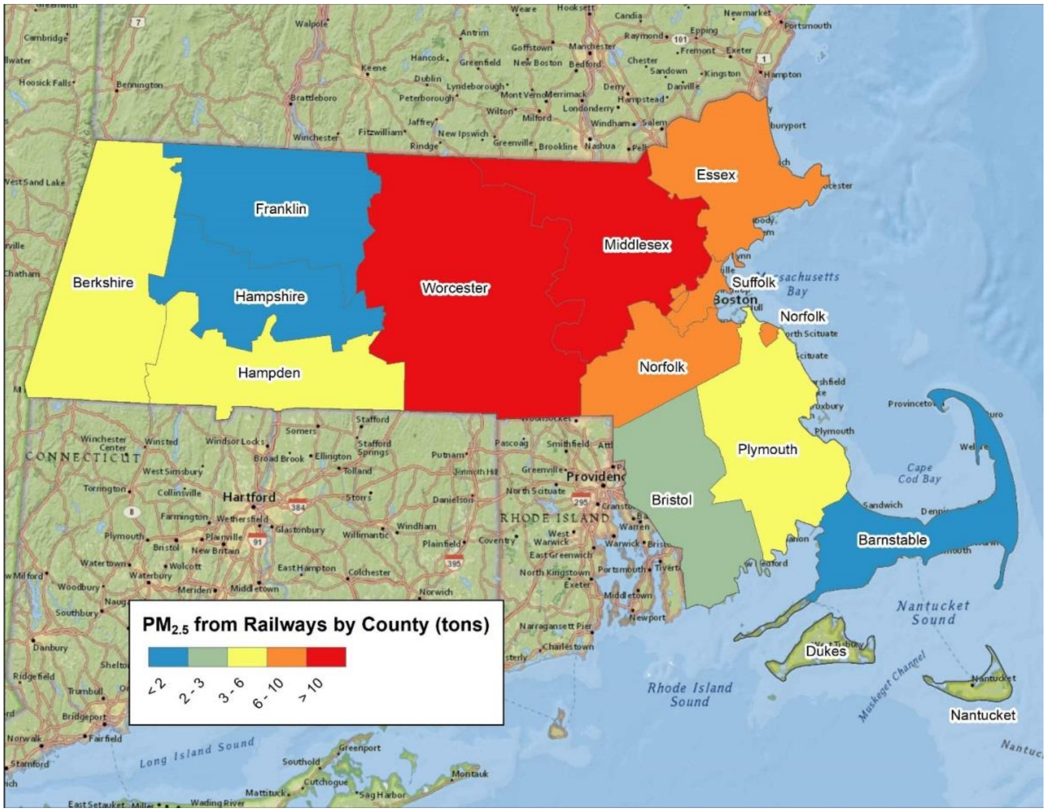

Figure 6-1 $PM_{2.5}$ Emissions from Railroads in Massachusetts by County in 2016

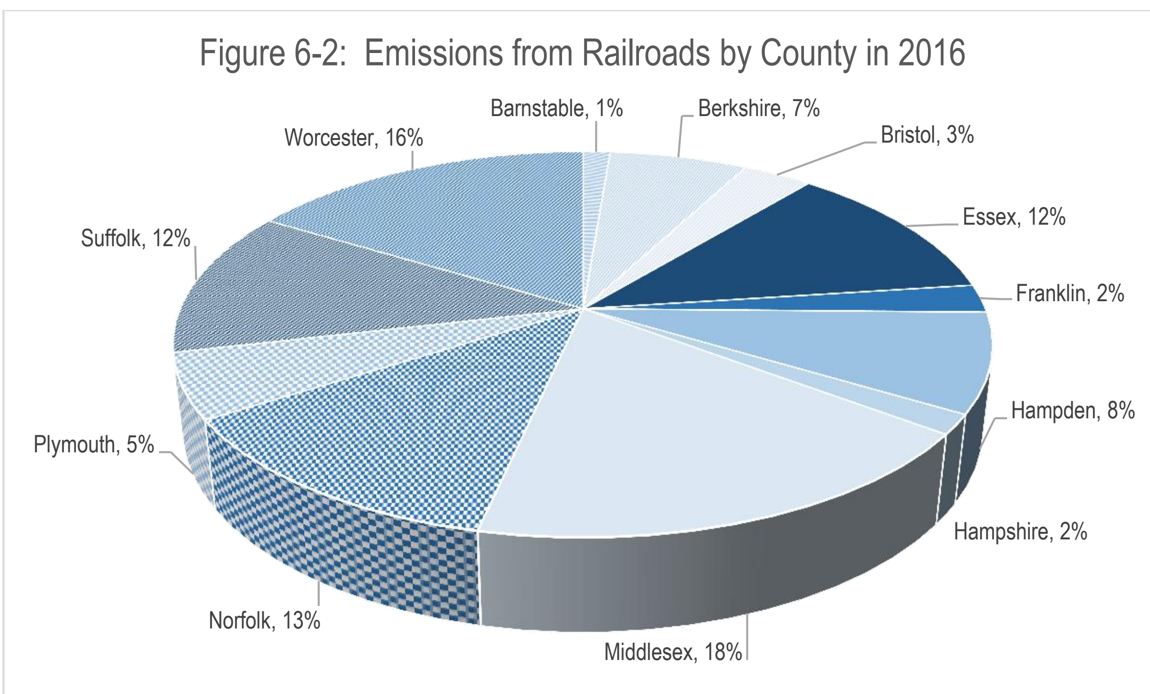

Figure 6-2 Proportion of $PM_{2.5}$ Emissions in Massachusetts by County in 2016

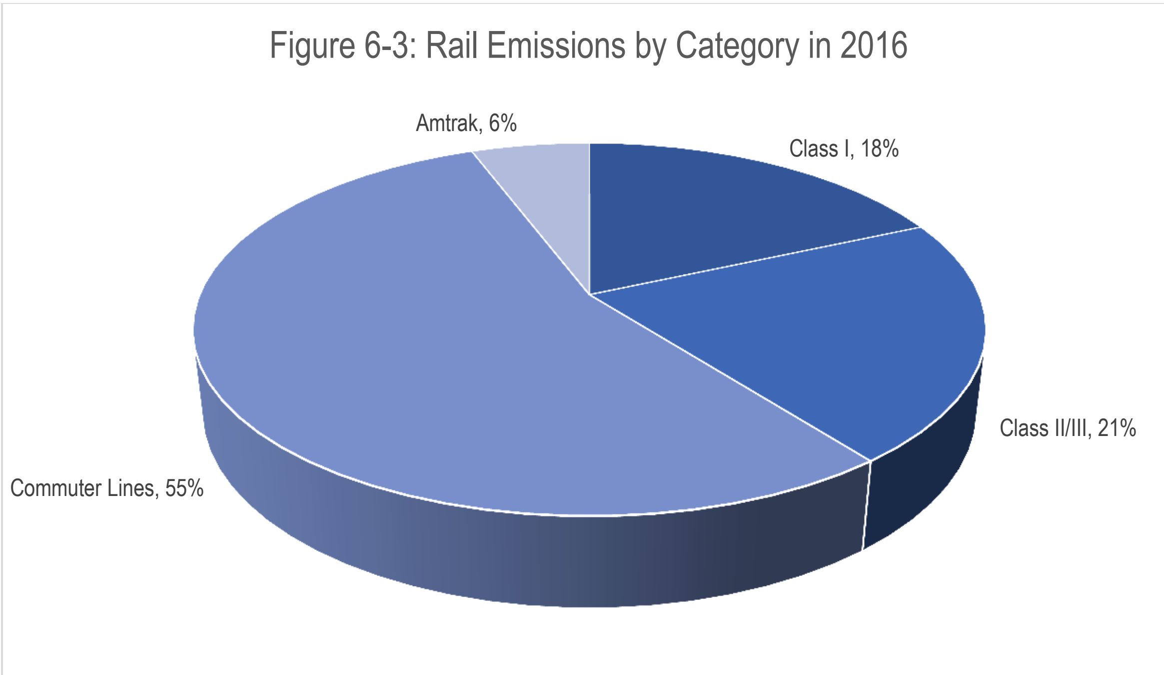

Figure 6-3 Proportion of $PM_{2.5}$ Emissions from Locomotives by Rail Class and Type in Massachusetts in 2016

6.5 References for Locomotive Diesel Engines

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7.0 Stationary Diesel Engines

Stationary diesel engines are engines and turbines that are used at power, chemical, and manufacturing plants to generate electricity and to run pumps and compressors. They are also used by a wide variety of facilities 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

Stationary sources for the purpose of this inventory are those that submit emissions data to MassDEP under 310 CMR 7.12, referred to as Source Registration. These are factories, power plants, and institutions that have large emission units or the potential to emit more than specific threshold amounts of certain pollutants. Facilities submit reports either annually (for higher emitting facilities) or triennially (for smaller sources). There are about 300 annual filers and 2,000 triennial filers. The latest emissions reporting year available for this report was 2015. For triennial filers, however, the latest available report was used, which may be earlier than 2015 (reports queried ranged from 2011 – 2015). This dataset provided the number of stationary emission units combusting diesel fuel in Massachusetts and their $PM_{2.5}$ emissions as reported by the facilities. A “diesel” unit was defined for this report as an internal combustion reciprocating engine or turbine where the facility reported diesel for at least one of its fuels except where the reported sulfur content of that fuel exceeded 15 ppm.

7.2 Number of Stationary Diesel Engines

MassDEP’s 2015 Source Registration data contains 1,415 stationary emission units combusting diesel fuel. The types of emission units combusting diesel were turbines, reciprocating engines, co-generating turbines, and co-generating reciprocating engines. This number may be underestimated due to errors by facilities in reporting the sulfur content of their fuel (e.g., where an facility indicates diesel but then reports a sulfur content higher than diesel fuel).

Nearly all of the units (1,364 of 1,415) reported at least some (>0.0001 tons) $PM_{2.5}$ emissions for calendar year 2015 (or the latest year for which there is reporting). The remaining 51 reported no emissions from diesel fuel combustion (they may have had emissions for other fuels, but those are not included in this inventory). Appendix 7.1 contains a list of the individual emissions units identified for this inventory, their fuel use, $PM_{2.5}$ emissions, age, and the year they last reported.

7.3 Growth in the Number of Stationary Diesel Engines

The number of registered stationary diesel engines/turbines increased from 1,081 engines in 2002 to 1,415 in 2015 – an increase of 31%. This growth may be underestimated due to: (1) previously mentioned misreporting of diesel fuel use as a higher sulfur fuel, and (2) inclusion in the 2002 inventory of units that were not burning diesel fuel.

7.4 Ownership

Appendix 7.1 lists the facilities and North American Industry Classification System (NAICS) codes for the stationary diesel engines currently operating in Massachusetts. The largest ownership categories are hospitals (18%, NAICS 622110), colleges, universities, and professional schools (17%, NAICS 611310), and fossil fuel electric power generators (5%, NAICS 221112).

7.5 PM Emission Standards and Fuel

7.5.1 *PM Emission Standards*

PM emission standards for stationary diesel engines 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 under 310 CMR 7.26(43) as an alternative to BACT for stationary engines with rated power output equal to or greater than 50 kW that are constructed, substantially reconstructed, or altered on or after March 23, 2006. MassDEP's standards are shown in Table 7-1. MassDEP has not received any certifications for liquid fuel engines under 310 CMR 7.26(43); all existing non-exempt units have been installed under 310 CMR 7.02 (i.e., subject to case-by case BACT).

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

Installation Date	Filterable PM (Liquid Fuel Only)
On and after 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). Note standards for filterable PM not $PM_{2.5}$.

In addition, EPA promulgated New Source Performance Standards (NSPS) for stationary diesel engines in July 2006.[1] Beginning in model year 2007, the NSPS aligned the PM emission standards for stationary diesel engines with those for non-road mobile engines (see section 4.6 for those standards).

7.5.2 *Diesel Fuel*

Starting in 2007, 310 CMR 7.05 required most stationary engines and turbines to begin using fuel oil with the same sulfur content as on-road diesel fuel. After 2010 this meant the use of 15 ppm ultra-low sulfur diesel (ULSD) fuel consistent with the federal requirements for on-road ULSD. These units are included in this 2016 inventory. Other units not covered by this provision will be required to begin burning ULSD in mid-2018 (these units are not included in this 2016 inventory).

7.6 Age

The average age of the stationary diesel units is 19 years. Table 7-2 presents the age of diesel engines and turbines in the Massachusetts stationary source inventory.

7.7 PM Emissions of Stationary Diesel Engines

Some of the PM emissions presented here were calculated by the facilities and entered into their Source Registration reports. Some of the emissions were calculated by MassDEP's on-line Source

[1] 40 CFR, Chapter 1, Part 60.

Registration forms based on the equipment type and fuel use entered by the facilities in their reports. The facility chose which calculation method they preferred. The automated calculations were based on EPA emission factors from WebFIRE[2] and EPA SCCs[3] identified by the facilities. MassDEP's on-line forms factor in each unit's control equipment (if any) and its reported effectiveness when calculating emissions.

Although 1,415 stationary engines reported diesel use in their last Source Registration report the $PM_{2.5}$ emissions from these sources were not large: 19 tons. Stationary diesel engines and turbines emitted less than 1% of the diesel $PM_{2.5}$ in the state.

Table 7-2 is a summary of the most recent reported diesel fuel use and $PM_{2.5}$ emissions by engine and turbine types (generally 2015). A more detailed listing of individual engines and turbines is in Appendix 7.1.

Key finding: though the 1379 engines used less fuel than the 36 turbines, the engines have higher filterable $PM_{2.5}$ emission factors, and therefore **the engines were responsible for 77% of the filterable $PM_{2.5}$ emissions**.

Table 7-2 Stationary Diesel Engines and Turbines with Fuel Use, Filterable $PM_{2.5}$ Emissions, and Average Age in Massachusetts 2015*

Stationary Unit Burning Diesel Fuel	Units	Units %	Diesel Use (gal)	Diesel Use %	$PM_{2.5}$ Emissions** (tons)	$PM_{2.5}$ Emissions %	Average Age (yrs)
Engine	1379	97%	11,788,000	4%	14	77%	19
Turbine	36	3%	258,094,000	96%	4	23%	26
Total	1415		269,882,000		19		19

* Years for each unit are the latest reported, mostly 2015 but some are 2011-2014.
** filterable $PM_{2.5}$ only

7.8 References for Stationary Diesel Engines

Massachusetts Department of Environmental Protection (MassDEP). *Massachusetts 2011 Baseline Emission Inventory of: Volatile Organic Compounds, Nitrogen Oxides, Carbon Monoxide, Sulfur Dioxide, Particulate Matter and Ammonia*. June 2017.

MassDEP. Source Registration data. 2011-2015.

[2] WebFIRE is the EPA's online database that contains emissions factors for criteria and hazardous air pollutants (HAP) for industrial and non-industrial processes. https://cfpub.epa.gov/webfire/

[3] The U.S. EPA uses Source Classification Codes (SCCs) to classify different types of activities that generate emissions. Each SCC represents a unique source category-specific process or function that emits air pollutants. The SCCs are used as a primary identifying data element in EPA's WebFIRE (where SCCs are used to link emissions factors to an emission process), the National Emissions Inventory (NEI), and other EPA databases. https://ofmpub.epa.gov/sccwebservices/sccsearch/

U.S. EPA. “Regulatory Announcement: New Emission Standards for Nonroad Diesel Engines.” EPA420-F-98-034. August 1998 and 2006 update: http://www.assocpower.com/eqdata/tech/US-EPA-Tier-Chart_2004-2017.php September 27, 2006