FINAL REPORT

Scoping Study to Evaluate the Emissions of Harbor Craft Operating in Boston Harbor and Potential Control Options

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Prepared by NESCAUM

1. INTRODUCTION

1.1. Overview

Diesel-powered marine vessels emit high levels of ozone precursors, particulate matter, and other hazardous air pollutants associated with long-term and acute public health effects, and much of the marine activity occurs in close proximity to densely populated areas. Diesel engines typically are used in commercial applications because they are more fuel efficient, durable, and powerful than gasoline engines; however, most were not required to meet an emissions standard when they were manufactured. Although more stringent federal standards will go into effect for newly manufactured engines over the next decade, nationwide tens of thousands of in-use commercial diesel engines and millions of pleasure craft diesel engines will continue to emit large amounts of pollution for the foreseeable future, absent further control measures. In addition, marine vessels are under-regulated relative to other mobile sources of air pollution. Consequently, a variety of cost-effective emissions control measures could achieve significant reductions in this sector.

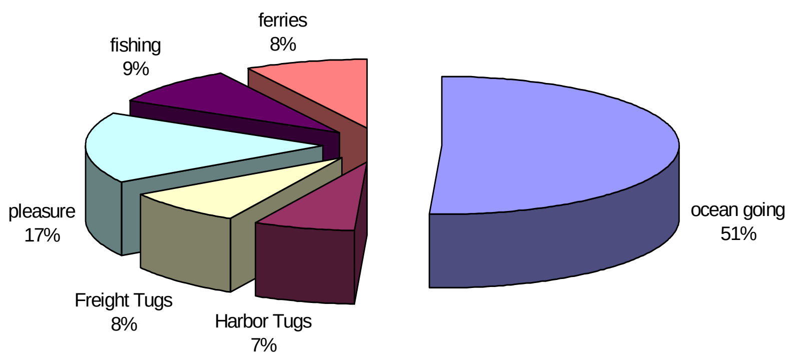
The marine fleet in Boston Harbor includes a broad range of recreational and commercial vessels that are powered primarily by diesel engines. To better characterize pollutants emanating from the harbor's commercial fleet, NESCAUM developed a preliminary inventory of emissions from passenger ferries, tour boats, tugboats, military craft, and other vessels, which are collectively known as "harbor craft." In 2005, there were 93 harbor craft in Boston Harbor. The inventory does not include either fishing or recreational vehicles. NESCAUM also developed recommendations and a menu of control options for reducing emissions from these sources, as well as a set of potential partnerships and outreach strategies. This report summarizes the findings of the scoping study and provides preliminary information to the Massachusetts Department of Environmental Protection for its consideration of emissions reduction strategies.

1.2. Background

In 1999 NESCAUM published a study that estimated emissions from commercial and private vessels operating in Boston Harbor.[1] That inventory included commercial marine vessels, ocean-going vessels, fishing boats, recreational vessels, and harbor craft. The study concluded that for the study year (1997) all vessels emitted 1,400 tons of NOx and that the harbor craft sector emitted approximately 49 percent of total NOx if fishing and recreational boats are included -- 23 percent if just ferries and tugboats are included. Figure 1-1 below shows the NOx contribution in 1997 from all marine vessels in Boston Harbor.

[1] NESCAUM, "Nonroad Engine Emissions in the Northeast," 1999.

Figure 1-1 Boston Harbor Vessel NOx Emissions ('99 Report)



The 1999 NESCAUM study estimated that 51 percent of all marine emissions from Boston Harbor come from ocean-going vessels (primarily tankers) carrying fuel, vehicles, textiles, and other cargo. The International Maritime Organization (IMO) sets emissions standards for ocean-going vessels (or Category 3 - "C3") with guidance from the U.S. EPA and environmental agencies from countries around the world. States and multi-state organizations are working with EPA to influence the IMO to set more stringent standards. While the IMO process unfolds, states can achieve emissions reductions in busy ports by focusing on the smaller vessels that, at least in Boston Harbor, emit nearly half of all marine NOx emissions (49 percent).

The current study adds to the 1999 NESCAUM report by providing an updated and more detailed inventory of harbor vessels. Traffic from ferry and excursion vessels has increased since the previous study, and the 1999 report did not evaluate emissions from excursion vessels, which are an important source of emissions in the harbor. The report is divided into five sections: section 1 provides an overview of the issues; section 2 summarizes the Boston Harbor vessel and emissions inventory; section 3 provides an overview of emissions control options for marine harbor craft and specific recommendations for the fleets; section 4 provides information on outreach and emission control policy options; and section 5 presents conclusions and recommendations.

2. INVENTORY METHOD AND RESULTS

2.1. Overview

The goal of this component of the study was to develop a preliminary vessel and nitrogen oxides (NOx), particulate matter (PM_{10}), Carbon Monoxide (CO), and hydrocarbon (HC) emissions inventory for harbor craft operating in Boston Harbor; this study does not include ocean-going vessels, fishing boats, or recreational vessels.

As a first step, the fleet was grouped according to engine size, age, and manufacturer. This information was needed for calculating emissions and for matching potential control options to the specific vessels in the fleet. The study relied on fuel usage, hours of use, and recent emission factors determined by engine horsepower as the primary means for calculating emissions**.**

2.2. Methods

This section describes the methodology used in developing the emissions inventory. This section: (1) describes the different vessel types and their operational characteristics; (2) provides information on how data were obtained for each vessel type; and (3) describes how emissions were estimated.

2.2.1. Vessel Types and Operational Characteristics

The scope of this inventory includes marine harbor craft that primarily operate within or near Boston Harbor. NESCAUM collected information on the following types of harbor craft:

- Ferry/Excursion Vessels
- Towboats/Pushboats/Tugboats
- Government Vessels
- Dredging Vessels

These category classifications are similar to the classifications used in the California Air Resources Board's *Statewide Commercial Harbor Craft Survey* and other ports' commercial marine vessel inventories. Table 1 provides a breakdown of the number of vessels by vessel category operating in Boston Harbor.

Table 1: Number and Type of Vessels Operating in Boston Harbor

Vessel Type	**Number of vessels**
Ferry/Excursion Vessels	35
Tugboat/pushboat/towboats	15
Government Vessels	46
Dredging Vessels	1
Total	**97**

Ferries and Excursion Vessels

Ferries and excursion vessels are common in Boston Harbor. A portion of the ferries that operate in the harbor are commuter boats, which tend to run on a fixed schedule throughout the year, with lower activity during the winter season. On average, ferries operate approximately fourteen hours a day, depending on the route. A typical route is forty-five minutes to an hour long. Excursion vessels include harbor cruises, whale watching, and charter cruises that are for hire for the general public.

Towboats/Pushboats/Tugboats

Towboats, pushboats, and tugboats are self-propelled vessels that engage in two primary operations: unit tow and line haul. A unit tow may include hauling bulk materials such as rock, sand, gravel, and scrap metal. These vessels also undertake bunkering moves (to fuel ocean-going vessels) and haul bulk liquid inventory. Another form of unit tow, called fleeting, involves moving and positioning barges around the harbor. Fleeting operations are conducted by towboats, pushboats, and tugboats. Line hauling operations typically extend beyond the harbor and entail a towboat and barge moving to and from the port.

Government Vessels

Federal, state, and local government vessels operate in Boston Harbor, including those of the U.S. Navy, Massachusetts State Police Marine Division, U.S. Coast Guard, and the Boston Police Harbor Control. The Boston Pilots Association also operates two pilot boats to transfer port pilots to and from vessels. The U.S. Coast Guard operates a number of vessels in Boston. Emissions from Coast Guard rescue and other boats that operate in and around the harbor were included in this inventory. Large Coast Guard ships that are based in Boston, but operate outside of the region were not included in this inventory.

Dredging Vessels

Dredging includes both harbor maintenance, which deploys smaller clamshell or excavator dredges to remove silt build-up, and the dredging of new channels for the port or the deepening of existing channels.

2.2.2. Data Acquisition

NESCAUM interviewed vessel owners and operators via meetings, phone calls, email, and fax to ascertain key operating parameters for individual vessels. Specific operating parameters were needed both to calculate emissions and to determine the best strategies for reducing diesel emissions from marine harbor craft. The operating parameters collected included:

- annual fuel consumption
- hours of operation
- vessel characteristics
- number and horsepower of the primary engine(s)
- passenger carrying capacity

- wet/dry exhaust; and
- hull type (catamaran or mono-hull).

For some vessels, NESCAUM was not able to collect fuel consumption, hours of use, and complete horsepower information. For these boats, we estimated horsepower and hours of use based on data from other vessels, evaluated schedules posted on websites, and looked at other available information in order to calculate emissions. For that reason the emissions inventory numbers for these vessels are just estimates and need to be refined. A list of vessels for which we did not obtain information is provided in Appendix B.

2.2.3. Inventory Method

NESCAUM collected data on three operating parameters: hours of use, fuel consumption (gallons per year), and primary engine horsepower (hp) to calculate emissions for NOx, PM, HC, and carbon monoxide (CO). The equation used to estimate diesel emissions from marine harbor craft comes from Starcrest Consulting Group's report *Port-wide Baseline Air Emissions Inventory at the Port of Los Angeles*.[2] NESCAUM used EPA emission factors for NOx, PM, and HC and cited from Starcrest's *New York, Northern New Jersey, Long Island Non-attainment Area Commercial Marine Vessel Emissions Inventory*

Table 2-1: Emission factors from EPA[3]

Minimum		g/kW-hr				
kW	HP	NO_X	CO	HC	PM_{10}	SO_2
37	50	11.0	2.0	0.27	0.9	0.81
75	101	10.0	1.7	0.27	0.4	0.81
130	174	10.0	1.5	0.27	0.4	0.81
225	302	10.0	1.5	0.27	0.3	0.81
450	603	10.0	1.5	0.27	0.3	0.81
560	751	10.0	1.5	0.27	0.3	0.81
1,000	1,341	13.0	2.5	0.27	0.3	0.81

Source: Starcrest 2003.

The emissions calculation equation is:

$$\mathbf{E} = \mathbf{kW} \times \mathbf{Act} \times \mathbf{LF} \times \mathbf{EF}$$

Where:

[2] Starcrest Consulting Group, Inc., 2003.

[3] EPA, 1999 Final Regulatory Impact Analysis: Control of Emissions from Compression-Ignition Marine Engines, EPA 420-R-99-026.

E = Emissions, g/yr
kW = Kilowatts
Act = Activity, hours/yr
LF = Load factor
EF = emission factor, g/kW-hr

Since EPA emission factors are in g/kW-hr, engine horsepower is converted to kW by dividing by 1.341. Calculated emissions were converted to tons by dividing emissions by 2,000 lbs/ton and 453.6 g/lb.

Emission factors are from the EPA Regulatory Impact Analysis. Activity (in either hours of use per year or fuel consumption) and kW information was obtained from operators. The load factor used for this calculation was .43, based on the load factor estimated in the Starcrest report (see below for a discussion of the load factor assumed for this calculation). The emission factors from Table 2.1 were used for Category 1 engines.[4] Emission factors for Category 2 engines were also taken from the Starcrest report, based on ENTEC factors for medium speed engines, which are characteristic of most of these engines. The EPA RIA emission factors for Category 1 engines could be used, but are not well defined for engines over 1,000 hp. For that reason, the ENTEC factors were used for engines over 1,000 hp. Use of these numbers results in emissions that are 11 percent to 40 percent higher for HC and PM respectively than what the result would be using EPA RIA emission factors:

g/kW-hr

NOx	**CO**	**HC**	**PM_{10}**	**SO2**
13.20	1.10	0.50	0.72	0.81

Activity was estimated for some vessels based on hours-of-use operating data. For vessels for which activity data were not available, fuel consumption data were used. In these cases, the following conversion factor was used to convert fuel consumption to hours of use:

[4] Category 1 Engines are engines with rated power at or above 37 kW but with a specific displacement of less than 5 liters per cylinder. These engines are similar to land-based nonroad diesel engines that are used in applications ranging from skid-steer loaders to large earth-moving machines.

Category 2 Engines have a specific displacement at or above 5 liters to 30 liters per cylinder. These are similar to locomotive engines.

Category 1 and Category 2 marine diesel engines are often derived from or use the same technologies as their land-based counterparts. EPA believes that most of the technology being developed to enable the land-based counterparts to achieve recently finalized emission control standards can be applied to marine diesel engines. Already, limited experience with the application of land-based nonroad Tier 2 control technologies to marine engines, as part of low-emission demonstration programs, shows that Category 1 marine diesel engines can achieve emission levels comparable to the Tier 2 standards for nonroad diesel engines.

HP-hrs = G x BTU/gal x thermal efficiency x hp-hr/BTU
Where:
G = gallons
BTU/gal = 138,690
Thermal efficiency = 40%
Hp-hr/BTU = 3.93×10^{-4}

HP-hrs was substituted in the above emissions formula for activity. The above conversion yields an estimate for activity (hours x kilowatt hours x load factor) that is substituted in the Starcrest equation as illustrated below. The estimate for activity is substituted for the parts of the equation highlighted in bold and large font:

E = **kW x Act x LF** x EF

For some operators (identified in Appendix B) neither hours of use, fuel consumption, nor complete horsepower information was available. NESCAUM therefore estimated that each of their boats has a total of 1,000 horsepower engine(s) and operated for 2,000 hours each year. For these ships, we also used emission factors for Category 1 engines.

2.3. RESULTS

This section provides the emissions inventory for harbor vessels operating in Boston Harbor, calculated in tons per year for NOx, PM, CO, and HC. Table 2-2 summarizes the findings of the inventory for the different types of vessels. In 2005 harbor craft emitted 857 tons of NOx, 20 tons of PM, 165 tons of CO, and 18 tons of HC. The highest emissions came from ferry/excursion vessels, which emitted 595 tons of NOx and 14 tons of PM. The second largest amount of NOx and PM came from towboats and tugboats which emitted 174 tons of NOx and 4 tons of PM.

Table 2-2: Harbor vessel emissions by vessel type

Boston Harbor Craft	NOx	PM	CO	HC
Ferry/Excursion Vessels	594.89	13.71	114.41	12.54
Tow Boats/Push Boats/Tug Boats	173.90	4.01	33.44	3.61
Government Vessels	84.12	1.95	16.18	1.69
Dredging	9.16	0.21	1.76	0.19
Total Emissions	**862.08**	**19.88**	**165.79**	**18.03**

Figures 2-2 and 2-3 below show that, as a percentage of total harbor vessel emissions, ferries and excursion vessels emit 70 percent of NOx and PM emissions. Tugboats emit the second largest amount of NOx and PM, contributing 20 percent of NOx PM. Government boats are the third largest category, emitting 9 percent of NOx and PM from all harbor craft vessels. The one dredge operating in Boston Harbor in 2005 emitted one percent of NOx and one percent of PM. In 2005, Ferry/excursion vessels numbered 34, government vessels numbered 42, tugboats numbered 15, and there was one dredge located in the Harbor. While the number of ferry/excursion vessels is less than the number of government vessels, activity and horsepower for the ferry/excursion vessels was significantly greater than for the government (Navy and police) boats.

Figure 2-2 Boston Harbor Craft NOx Emissions by Vessel Type

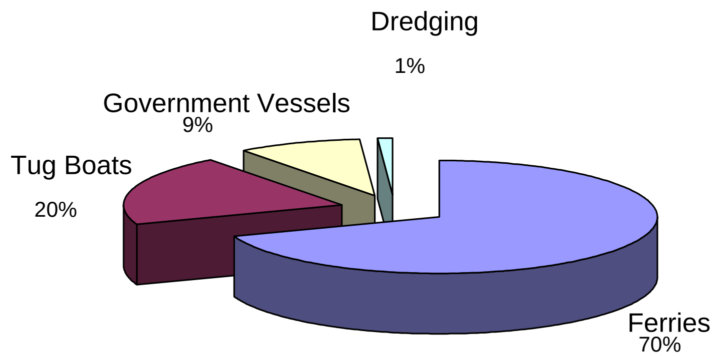
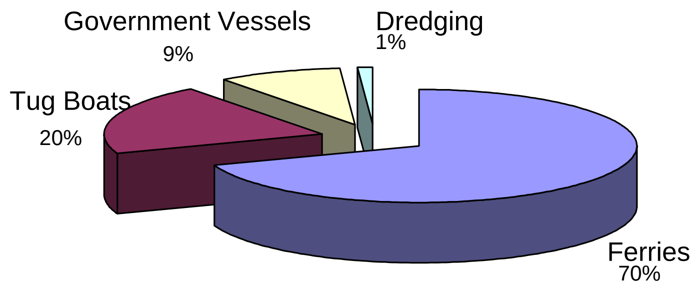


Figure 2-3 Boston Harbor Craft PM Emissions by Vessel Type



Figures 2-2 and 2-3 show that the majority of harbor craft NOx and PM emissions in 2005 came from ferry and excursion boats.

Given the low level of dredging activity in 2005, this report does not focus on control options for dredges. If, however, a harbor deepening project were to be undertaken in Boston (as in the Port of New York/New Jersey), emissions from dredges would need to be considered for mitigation. Table 2-3 provides a summary of harbor vessel emissions by vessel operator.

Table 2-3: Summary of Boston Harbor Vessel Emissions by Operator

Boston Harbor Craft	**NOx (t/y)**	**PM (t/y)**	**CO (t/y)**	**HC (t/y)**
Mass Bay Lines	34.02	0.79	6.54	0.71
Boston Harbor Commuter Service - MassPort	3.39	0.08	0.65	0.07
Harbor Express - MBTA	246.62	5.69	47.43	5.12
Odyssey Cruise Ship	6.98	0.16	1.34	0.14
Princess Yard Charters Limited	9.31	0.21	1.79	0.19
Boston Harbor Cruises	237.51	5.48	45.68	4.93
A.C.Cruise Line	18.62	0.43	3.58	0.39
Charles River Boat Company	18.62	0.43	3.58	0.39
Schooner Liberty, Inc. - Liberty	9.31	0.21	1.79	0.19
U.S Coast Guard	4.98	0.12	0.96	0.05
Spirit of Boston - Spirit of Boston	9.31	0.21	1.79	0.38
Constellation Tug Corporation	13.00	0.30	2.50	0.27
Boston Line and SVC Co	1.21	0.03	0.23	0.03
Sea Tow	2.33	0.05	0.45	0.05
Naval Ships to Charlestown	0.35	0.01	0.07	0.01
Great Lakes Dredging	9.16	0.21	1.76	0.19
Mass. State Police Marine Division	27.86	0.64	5.36	0.58
Boston Police Harbor Patrol	8.37	0.19	1.61	0.17
Boston Towing & Transportation	158.57	3.66	30.49	3.29
Boston Pilots Association	42.56	0.98	8.18	0.88
Total Emissions	**862.08**	**19.88**	**165.79**	**18.03**

The operations that emit the highest amount of NOx, PM, CO, and HC are Harbor Express (MBTA), Boston Harbor Cruises, Boston Towing and Transportation, Boston Pilots Association, and Mass Bay Lines. Together these five operations emit 84 percent of the NOx and PM emissions from all harbor craft in Boston Harbor. It should be noted that NESCAUM was not able to obtain fuel consumption, hours of use, or complete horsepower data for Boston Harbor Cruises and thus a more in depth analysis of the activity of these vessels needs to be completed. Again, activity (hours of use and fuel consumed) for ferry/excursion vessels greatly exceeds that for other categories of harbor craft. Other operators with significant emissions include A.C. Cruise Line and Charles River Boat Company (19 tons of NOx each[5]), and the Massachusetts State Police Marine Division (28 tons of NOx). Appendix B provides emissions information for each vessel in the fleets evaluated. The next section discusses emissions control options.

Emissions for some Coast Guard vessels were not included in this inventory. Three boats operate outside of the harbor for the most part - either patrolling the New England coast, or on longer trips out of the region. Only emissions from rescue boats, and two smaller vessels that operate in the Harbor were included.[6]

[5] These operators did not provide data on their boats and thus these numbers should be confirmed in a future study.

[6] The Escanaba, Seneca, and Spencer are the ships which operate outside of the Harbor.

3. EMISSION CONTROL TECHNOLOGY OPTIONS

This section provides a general overview of options for controlling emissions from harbor craft, an assessment of control technology options by vessel/engine type, and specific control technology recommendations for the vessels operating in Boston Harbor.

3.1. Emission Control Technology Options

NESCAUM evaluated available emission control options and developed a matrix providing options by the vessel type, depending on engine model, horsepower of the engine, and whether the exhaust is water jacketed or insulated dry exhaust (see Appendix A). Potential control options include clean fuels, after-treatment, repowering, and vessel replacement.[7] While not discussed in this study, a simple and inexpensive way to reduce particulate matter emissions from existing diesel engines is to ensure that they are properly maintained. Proper maintenance and tuning will not only ensure the fuel is more completely burned during combustion, but also reduce operating costs by improving fuel economy, preventing more costly maintenance, and extending engine life.

3.1.1. Refuel

Refueling involves substituting cleaner-burning fuels for the conventional diesel fuel. EPA and CARB have verified a variety of cleaner fuels for on-road applications. Though not specifically verified for nonroad applications, alternatives such as low and ultra-low sulfur diesel, biodiesel, emulsified fuel, and oxygenated diesel can reduce emissions from harbor craft. For harbor vessels using high sulfur diesel (3000 ppm) the use of low sulfur diesel (300-500 ppm) is a viable and effective strategy. Some alternative fuels present challenges, such as cold-handling concerns with biodiesel; unknown and untested durability issues with emulsified fuel in two-stroke engines; and issues with supply and lubricity.

ULSD

Fuel with reduced sulfur content is an effective refueling option for reducing emissions. Ultra-low sulfur diesel (ULSD) fuel with a maximum sulfur content of fifteen parts per million has been adopted by EPA as a part of its heavy-duty on-highway regulatory program, which will begin implementation in mid-2006. In a number of regions of the country, including Boston, ULSD already is available for use by centrally fueled fleets. Sulfur in fuel tends to affect the function and longevity of after-treatment devices, so ULSD often is required for the effective use of diesel particulate filters and can enhance the effectiveness of diesel oxidation catalysts. Reduced sulfur content also provides emission benefits without additional after-treatment, because a portion of PM

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[7] Note that all marine engines are water cooled, either direct or via a heat exchanger. Marine exhaust systems must be insulated to prevent surface temperatures in the engine room from rising above the flash point of diesel fuel. Insulating the surface of the exhaust can be accomplished with either insulating material or by water jacketing the exhaust. Some engines with water jacket exhaust go a step further and inject that water into the exhaust system for additional cooling and sound attenuation. In these systems the installation of a catalyst for instance would require redesign of the water injection location and may also require some physical insulation if water jacketing cannot be provided.

emissions is comprised of sulfates. The use of ULSD alone (without after-treatment) in nonroad applications can reduce PM emissions from 5 to 15 percent.

Biodiesel

Biodiesel is a cleaner burning fuel that can be blended into petroleum diesel to improve emission characteristics. Derived from domestic, renewable sources such as fats and vegetable oils (usually soy bean-based), biodiesel refers to the pure fuel ("neat") before blending with diesel fuel. A blend of 20 percent biodiesel and 80 percent petroleum diesel fuel (B20) has been demonstrated to provide emission benefits without adversely affecting engine operation. Pure biodiesel (B100) is biodegradable, non-toxic, and virtually free of sulfur and aromatics. The emissions reduction effectiveness varies between B20 and B100 biodiesel. Generally, NOx emissions increase from 2 to 10 percent with the level of biodiesel in the fuel blend in mobile sources,. Conversely, PM emissions decrease proportionately with higher levels of biofuel. There is a linear reduction in CO and HC emissions with the addition of biodiesel.

Emulsified Diesel Fuel

Emulsified diesel fuel (EDF) is a petroleum distillate-based fuel that undergoes a process, called emulsification, in which a proprietary chemical additive agent is used to suspend water micro-droplets in the fuel, typically with the following ratio: 77 percent diesel, 20 percent water, and 3 percent emulsifying agent. The water content ranges from 5 to 40 percent, depending on the production specification and end-user application. The use of EDF can achieve NOx reductions of 10 to 20 percent and PM reductions of 15 to 60 percent. However, significant losses in fuel economy, on the order of 10 to 30 percent, have been experienced with emulsified diesel fuel. The actual fuel economy penalty is a function of the percentage of water in the fuel, the onroad or nonroad engine application, and the age of the engine.

Oxygenated Diesel Fuel (O2D)

Oxygenated diesel is a diesel fuel blend using the oxygenate ethanol and a stabilizing proprietary additive technology. Manufacturers of oxygenated diesel fuels claim a significant reduction in PM and visible smoke plus some NOx and CO reductions. The product is fully fungible with all diesel fuels and can be blended effectively with any base diesel fuel. There is a potential NOx reduction up to 6 percent and a PM reduction up to 40 percent when used in conjunction with a diesel oxidation catalyst.

3.1.2. After-treatment

This section provides an overview of retrofit technologies available to control marine engine emissions.

Diesel Oxidation Catalyst

A diesel oxidation catalyst (DOC) is virtually identical in size and shape to a conventional muffler, with only marginal additional weight. The DOC "oxidizes" or "adds oxygen" to the CO and HC exhaust pollutants, to form carbon dioxide (CO_2) and water. Oxygen is present in diesel exhaust in large quantities, so oxidation occurs naturally; a DOC provides a substrate for increasing the oxidation rate of the otherwise unreacted species as well as lowering the temperature in the exhaust at which oxidation will occur. The soluble organic fraction (SOF) is the hydrocarbon derivative organic carbon (so called “wet” carbon) portion of PM; DOCs oxidize the SOF fraction, resulting in PM reductions. DOCs can reduce PM emissions in ferries by up to 20 percent, and this percentage can increase in two-stroke applications where the SOF content of the PM is higher.

Diesel Particulate Filter

When used in conjunction with a catalyst (“catalyzed traps”), a diesel particulate filter (DPF) is capable of reducing PM emissions by up to 90 percent. DPFs have evolved into the most effective method for reducing total PM emissions from diesel engines. DPFs remove PM through two stages. First, the DPF physically entraps the elemental carbon portion of PM. Then, through application of elevated exhaust temperatures, the DPF oxidizes these solid particulates to form gaseous products, primarily CO_2, through a process termed “regeneration.” DPFs require the use of ULSD, as the high sulfur levels in conventional diesel fuels interfere with the oxidation process.

Catalyzed Wire Mesh Filter

The catalyzed wire mesh filter (CWMF) is a relatively new technology that has been verified by EPA for onroad use in conjunction with a fuel-borne catalyst (FBC). A similar “Level 2” flow through filter (FTF) device has been verified by CARB. These devices yield emission reductions more effective than DOCs but less effective than DPFs. A CWMF requires an exhaust gas temperature of 225°C for at least 25 percent of the daily duty cycle, which is lower than a DPF typically requires. Thus, if low exhaust gas temperatures prohibit using a DPF, a CWMF might work. A CWMF weighs about the same as a DPF. EPA has verified the following emission reduction rates for CWMF when used with a fuel-borne catalyst: 0-9 percent for NOx, 55-76 percent for PM, 75-89 percent for HC, and 50-66 percent for CO.

Selective Catalytic Reduction

Selective catalytic reduction (SCR) is one of the three commercially available technologies that show significant promise in reducing NOx from diesel engines (emulsified diesel fuel and lean NOx catalysts are the other NOx-reducing technologies). Due to the low transient duty cycle of many marine applications, as well as central fueling of vessels (typical of ferries), SCR is an attractive NOx-reduction option. SCR systems are more complex than other NOx-reduction technologies and typical PM-reducing retrofit options such as DPFs and DOCs. SCR requires a dosing mechanism, typically a source of urea, to introduce a specific amount of ammonia into the exhaust stream to reduce engine-out NOx. The ammonia converts NOx to nitrogen gas and water. An SCR system can be used in conjunction with a DPF to achieve effective NOx and PM reductions. The SCR alone reduces NOx by up to 95 percent.

Lean NOx Catalyst

A lean NOx catalyst (LNC) operates much like an SCR unit, with an outside agent effecting the NOx reduction. The LNC introduces a charge of hydrocarbons into the exhaust through direct injection or through a late injection of fuel into the engine cylinders. With this system, NOx can be reduced from 30 to 50 percent.

3.1.3. Rebuild Existing Engines to Tier 2 Standards

While long lived, diesel engines do require periodic rebuilding. Rebuilding older, higher emitting engines to newer engine emissions standards can provide emissions benefits. Rebuilding engines reduces emissions by improving combustion through in-cylinder and fuel injection modifications. The Tier 1 Standard for Category 1 and 2 marine diesel engines took effect beginning with the 2004 model year. It is a NO_x standard only, at a value of 9.8 g/kW-hr. The Tier 2 Standards (g/kW-hr) for Category 1 and 2 marine diesel engines are as follows:

Tier 2 Standards For Category 1 & 2 Marine Diesel Engines

Category	Displacement (liters/cylinder)	Power (kW)	Model Year	HC + NO_x	PM	CO
C-1	< 0.9	≥ 37	2005	7.5	0.4	5.0
C-1	0.9 – 1.2		2005	7.2	0.3	5.0
C-1	1.2 – 2.5		2004	7.2	0.2	5.0
C-1	2.5 – 5.0		2007	7.2	0.2	5.0
C-2	5 – 15		2007	7.8	0.27	5.0
C-2	15 – 20	<3300	2007	8.7	0.5	5.0
C-2	15 – 20	≥3300	2007	9.8	0.5	5.0
C-2	20 – 25		2007	9.8	0.5	5.0
C-2	25 – 30		2007	11.0	0.5	5.0

3.1.4. Repower Existing Engines with New Tier 2 Engines

Replacement of the engine (repowering) may be appropriate where a fleet operator has diesel-powered equipment (e.g., certain nonroad equipment) with a useful life that is longer than the life of the engine. Repowering may also be an appropriate alternative where use of ULSD is not a viable option, because new engines are engineered to dramatically reduce emissions, even when using the currently available diesel fuel. In some cases, however, repowering may not be cost-effective. To prevent damage to the vehicle or equipment, owners should consult original equipment manufacturers to ensure that the torque and horsepower of replacement engines are properly matched to the original application.

3.2. Operational Strategies to Reduce Diesel Emissions

Other control strategies do not involve the application of technology per se, but rather address the way in which diesel vehicles are used. Reducing idling time from harbor craft is an effective operational strategy. Using off-shore power, also known as "cold ironing," can reduce idling time. This strategy is most effective for vessels that have long hotelling times, multiple annual vessel calls, and high auxiliary power needs. Cold ironing uses shoreside power at berth rather than running auxiliary diesel engines.

3.3. Assessment of Control Options by Vessel/Engine Type

This section assesses the limitations in applying certain control strategies to harbor craft, based upon vessel and engine characteristics. Considerations include two-stroke engines vs. four-stroke engines, vessel fully loaded speed (surrogate for duty cycle), space constraints, engine age, and wet versus dry exhaust.

3.3.1. Engine Characteristics

Diesel engines operate under either two-stroke or four-stroke combustion cycles,[8] and, which type is prevalent for a specific application depends on a number of technical and economic factors. Most modern diesel engines that power on-highway trucks and buses, nonroad construction equipment, and many vessels are four-stroke engines. Locomotives, especially those used in commuter rail applications, typically are two-stroke engines. For the ferries inventoried in this study, four-stroke engines predominate, although some two-stroke engines are in use. The difference between the two types of combustion cycles, as well as the underlying reasons why each diesel engine type may have been selected for specific vessels, is discussed below.

Combustion Cycle

All engines essentially are energy conversion devices that convert chemical energy (i.e., supplied fuel) into mechanical energy (i.e., for turning wheels, propellers, etc. to propel the vehicle or vessel). This combustion cycle to release the chemical energy involves the following four events: intake of air into the combustion chamber; compression of the intake air to a specific in-cylinder temperature and pressure; injection of diesel fuel, which ignites and burns as it is injected producing additional pressure and temperature with application of resultant force to the piston; exhaust and release of combustion gases from the engine. These four distinct events – intake, compression, power, and exhaust – are common to both two- and four-stroke engines. The two-stroke engine performs some of these events simultaneously, whereas the four-stroke engine performs these cycles in distinct steps. Accommodating this fundamental difference in the combustion cycle requires significantly different power, emissions, space, and cost considerations, which determines their application to certain vessel types.

Four-Stroke Engines

Four-stroke engines distinctly separate the four steps of the combustion cycle where each event discussed takes place during one cycle of the piston (i.e. intake stroke,

[8] Two-stroke engines are also referred to as two-cycle engines; similarly, four-stroke engines are also referred to as four-cycle engines.

piston travels to bottom dead center (BDC); compression stroke, piston travels to top dead center (TDC); expansion stroke piston travels to BDC; exhaust stroke, piston travels to TDC). One advantage of a 4-stroke engines is more precise management of intake air than in a two-stroke engine making nearly all of the intake air available for use in the combustion process. A result is that the four-stroke engine typically has lower emissions.[9] With precise control of fuel injection relative to TDC through electronic controls and turbo-charging to provide more intake air, modern four-stroke diesel engines are considerably cleaner than their older counterparts, and are therefore good candidates for installation of some type of after-treatment to the exhaust.

Two-Stroke Engines

In contrast to the four-stroke engine, the two-stroke engine combines the four step process of intake/compression, expansion/exhaust, into two cycles of the piston, a two step process – hence the name, "two-stroke" or "two-cycle" engine. In a two-stroke diesel engine the intake event happens at bottom dead center (BDC) and is combined with compression event as the piston travels one stroke or cycle to top dead center (TDC); The expansion stroke takes place as the piston travels to toward BDC with the exhaust event happening in the same stroke or cycle of the piston. In a diesel two-stroke engines the intake air is supplied by either a blower or a turbocharger which is forced into the cylinder via air intake ports near the bottom of each cylinder, exhaust gases escape through conventional cam actuated valves in the head. Two-stroke engines pose a few problems related to emissions in addition to those from a four-stroke engine. The first issue is that two-stroke engines tend to have poorer lubrication oil control, which results in more lube oil on the cylinder walls that is partially combusted leading to high PM SOF levels. A second issue is that the exhaust and intake events in a two-stroke engine overlap far more than they do in a four-stroke engine, resulting in "scavenging" air passing through the cylinder directly into the exhaust. Not only does this mean that some air is not available for combustion (leading to lower air/fuel ratios) but the exhaust temperatures are also lower than a four-stroke, making oxidation catalysts less effective.

It is generally accepted that emissions from most two-stroke engines are so high as to preclude the use of any after-treatment device since the high soot content in the exhaust would cause premature plugging of the device. Recent innovations in low oil consumption ring and piston assemblies as well as innovations in the oxidation catalyst technology itself have overcome many of these issues.

Advantages and Disadvantages – Control Strategy Limitations

Four-stroke engines have become the predominant choice for most on-highway, nonroad, and marine vessel applications because of their durability, ease of maintenance, lower emissions (when compared with two-stroke), and good fuel economy. However,

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[9] Engine emissions characteristics often are referred to as the engine "emissions signature." Dirtier engines, such as the two-stroke, typically have higher emissions signatures than the cleaner four-stroke.

the two-stroke engine is attractive for some marine applications, for the following reason: Most two-stroke engines have fewer moving parts, which makes them less costly to build and maintain (i.e., fewer moving parts translates into fewer components that can fail). Two-stroke engines spin slower, are far more reliable than four stroke engines, and the engines can be run with some cylinders out of operation resulting in better vessel reliability and availability. However, the initial lower cost of the two-stroke engine must be weighed against the lower fuel consumption of the four-stroke engine. Indeed, vessel operators consider yearly hours of service as one factor in determining whether to specify a two-stroke or four-stoke engine. Lighter service translates into less fuel demand, making the initial lower cost of the two-stroke engine more attractive.

While a number of limiting factors, such as engine age, engine compartment space constraints, and use of wet exhaust systems, may limit the options for emission control devices (e.g., DPF, DOC), in general, the comparatively cleaner exhaust and higher exhaust temperatures from the four-stroke engine makes it a more viable candidate for add-on control technology. A four-stroke engine that is well-maintained, is relatively new, and utilizes a thermally insulated dry exhaust system is a likely candidate for any of the systems described above: DPFs, CWMFs, DOCs, SCR, and LNC.

The two-stroke engine exhibits a number of operational characteristics that preclude using most add-on control technologies such as DPFs, however DOCs are still possible. First and foremost, the exhaust has very high PM levels, which would plug most devices, with the possible exception of the DOC. Second, even if the exhaust signature were sufficiently clean to allow use of after-treatment, the exhaust temperatures are generally too low, compromising the ability to effectively reduce NOx and/or PM. For devices that require elevated exhaust temperatures for soot regeneration (DPF and CWMF), plugging would result from the lower exhaust temperatures characteristic of two-stroke engines. Lower exhaust temperatures also significantly diminish the emission-reducing efficiency of the remaining devices (DOC, SCR, LNC). An SCR unit, for example, typically requires an exhaust temperature "sweet-spot" to maintain an 80 – 90 percent NOx-reduction capability. At temperatures outside this range (too low or too high), SCR NOx-reduction drops off dramatically. As a result a DOCs is probably the only option for retrofitting a two-stroke engine short of re-powering the vessel with a new engine.

Engine Age

Determining what model year engine is a suitable starting point for the deployment of control technology is complex, with engine duty cycle (see below), mechanical condition, and state of maintenance being paramount considerations. Many engine manufacturers have based their marine product technologies on other nonroad applications that have been subject to federal regulation since the late 1990s. In general, engines manufactured after 2000 are possible candidates for any of the five control technologies previously described, and older engines must be evaluated on a case-by-case basis. DOCs, which have the lowest maintenance requirements and least susceptibility to plugging, are likely a viable option for engines as old as the mid-1980s. Finally, engines that cannot utilize any of the five technologies due to high emission signatures or low exhaust temperatures are candidates for some, if not all, of the clean fuels options.

3.3.2. Vessel Characteristics

In addition to engine type and engine age, marine vessels have three other characteristics that influence control technology considerations. Two of these – wet or dry exhaust and space constraints – are physical characteristics of the vessel itself, while the third, duty cycle, is an operational characteristic that directly influences the threshold exhaust temperature necessary for effective operation of the control device. This section focuses on a description of ferry characteristics given their large contribution to the inventory in Boston Harbor. More information on tugboat and government vessel characteristics is needed and could be included in a follow-up study to this report.

Wet Versus Dry Exhaust

Perhaps more so than in the on-highway and construction sectors, safety is of paramount concern for ferries, with the U.S. Coast Guard invariably involved in control technology deployment. Within this context, perhaps the overarching safety issue is the risk of fire on board the vessel. The engine exhaust system typically is in an enclosed space within the hull; the high exhaust temperatures must be isolated from the rest of the craft to minimize the risk of fire. Two technologies are employed: the first is a thermal blanket to insulate the hot exhaust from the craft, and the second is a wet exhaust cooling design.

Dry systems, utilizing a thermal blanket, have been used successfully in on-highway applications to maintain the exhaust gas temperatures at a sufficiently elevated level to promote regeneration for DPF-equipped trucks. Wrapping the exhaust on a typical ferry vessel accomplishes two functions: isolating the hot exhaust pipe from the vessel to reduce the risk of fire, and maintaining the exhaust gas temperature in the pipe, for the potential use of a DPF. Wet systems divert sea water into the exhaust itself, cooling the exhaust gases and thereby reducing the risk of exhaust-heat-induced fires. While it is an effective and often lower-cost method than the insulated blanket, the resultant cooled exhaust precludes the use of any control system after the water injection point, essentially requiring that the control device be integrated into the exhaust system prior to the water injection point.

Vessel Space Constraints

For the sake of profitability, operators of ferries want to maximize the vessel space devoted to carrying passengers. Toward this end, it is not surprising that engine compartment space is minimized, making for insufficient space within the hold for emission control technology. When a DOC is to be employed as a direct muffler replacement, these space constraints often can be overcome. For other technologies, such as some DPFs and SCR, inventive, custom-built designs with unique shapes must be developed, or the vessel engine room must be modified at considerable expense. In the worst case, the technology must be rejected as a viable emissions-reduction option.

Duty Cycle

The final characteristic determining the suitability of a specific control system involves the duty cycle (i.e., the operation of the vessel itself) and how it affects exhaust gas temperature. Heavy duty cycles are characterized by longer routes and/or higher speeds with a full load of passengers. Lighter duty cycles are characterized by shorter routes, at lower speeds, often with vessels not filled to capacity. Heavy duty cycles tend to generate exhaust gas temperatures, higher than lighter duty cycles. While vessel duty cycle provides a first screen for determining the feasibility of various control devices, temperature data logging of the exhaust gases under real-world operating conditions is the only certain method for making a final decision.

4. OUTREACH AND POLICY OPTIONS

4.1. Overview

Marine vessel activity is projected to grow and will constitute a greater share of the overall NOx and PM emissions inventory in future years. Since more stringent emissions standards will not take full effect for at least another decade, an important approach in the short term will be to use incentives and voluntary actions to reduce diesel emissions. This section offers recommendations for encouraging diesel emissions reduction programs through education and outreach, policy, and partnerships.

4.2. Education and Outreach

One of the most important elements in promoting a voluntary diesel emissions reduction program is an effective education and outreach campaign. EPA has administered a number of outreach programs through the Voluntary Diesel Retrofit Program. One of the more successful is the Clean School Bus USA program, in which EPA has worked with state and local officials to reach out to school administrators and school bus fleet operators to participate in retrofit programs. Together they have organized workshops and seminars to emphasize the importance of reducing diesel emissions from school buses, which have provided a forum for stakeholders to become better informed, initiate a dialogue, and exchange information. Program materials provide background information on air quality, diesel pollution and its effects on public health, and available EPA-verified emission control technologies. A similar approach could be taken with marine operators.

Marine operators are more likely to participate in a diesel emissions reduction program if they can see advantages, such as improved air quality, long-term reduction in costs, improved fuel economy, improved relations with workers, and being viewed by the community as good corporate citizens.

4.3. Policy Options

Several U.S. ports are facing pressures to implement programs that reduce diesel emissions from on-road vehicles and nonroad equipment because of both nonattainment issues and the negative impact of diesel emissions on surrounding communities. Some policy options to reduce diesel emissions from marine harbor craft include the following.

4.3.1. Incentive Programs

Federal, State, and Local Grant Programs

Through grant programs, equipment owners receive direct funding to purchase cleaner equipment, cleaner engines, emission control technologies, and cleaner fuels. Grant programs leverage additional funding to cover incremental costs of lower emissions technology. Grants distributed for diesel emissions reduction programs are administered by EPA, states, regional air quality districts, cities, and ports.

The most extensive grant program to reduce diesel emissions is EPA's Voluntary Diesel Retrofit Program, which encompasses such initiatives as Clean School Bus USA, several regional diesel Collaboratives, Clean Ports USA, Diesel Retrofits to Benefit Sensitive Communities, SmartWay, and Diesel Retrofit Grants. Equipment owners who apply for any of the above grants are required to meet criteria established by EPA.

State Implementation Plans (SIPs).

States with areas that do not meet National Ambient Air Quality Standards (NAAQS) are required under the Clean Air Act (CAA) to submit State Implementation Plans, demonstrating how the nonattainment areas will attain the NAAQS within a set time period. Marine operators who participate in diesel emissions reduction programs can generate credit for the state toward required SIP emissions reductions.

Mobile Source Emission Reduction Credits (MERCs)

Credits may be traded between similar sources (e.g., credits generated by one power plant are then traded to another power plant in need of reductions). Similarly, a credit program has been established for emissions reductions from on-road and nonroad transportation sources. This program provides an incentive for marine operators who want to exchange or profit from MERCs.

Supplemental Environmental Projects (SEPs)

A SEP is an environmentally beneficial project (i.e., improves, protects, or reduces risks to public health or benefits the environment at large) that a defendant voluntarily agrees to undertake to settle an enforcement action but that the defendant is not otherwise legally required to perform. SEPs have been used more frequently in recent years. Notable were several SEPs (including one with Toyota Motor Corporation) totaling $20 million for the retrofit of 2,500 school buses.

The U.S. Coast Guard's Qualship 21 Program

In 2001 the U.S. Coast Guard developed "Qualship 21," a program that offers to reduce the frequency of vessel safety inspections for marine vessels that demonstrate a quality track record.

Tax Incentives

Tax incentives are extensively used by governments to influence the behavior of individuals and corporate entities. They typically reduce the cost of items or activities by reducing or eliminating associated taxes, via exemptions, deductions, and credits. Several states have offered tax incentives to promote diesel emissions reduction programs.

Environmental Impact Statement (EIS) Approvals

Retrofit requirements or recommendations can be included as mitigation measures pursuant to federal or state environmental impact statements/reports for projects triggering environmental review.

4.3.2. Contract Specification Programs

Modified Contracting Procedures

Although the Clean Air Act generally prohibits state and local governments (except California) from setting their own emission standards for either new or in-use engines, some states have added provisions to their construction contracts requiring or encouraging the use of cleaner equipment and/or retrofitting or repowering of older equipment. Provisions added to contracts can take a number of forms:

- The contractor is required to adhere to specific requirements for the duration of the contract. For example, the cost of retrofitting diesel equipment is embedded into the project budget when submitting the bid.
- A contractor who commits to using cleaner diesel equipment for the job will receive additional scoring points in the bid.
- The winning bidder may receive a contract allowance to retrofit or repower the contractor's equipment for the job.

4.3.3. Environmental Stewardship and Non-Monetary Incentives

Marine operators may choose to take steps to reduce emissions with the goal of improving operational efficiency or embracing environmental stewardship. Companies are increasingly finding that it makes good business sense to proactively participate in environmental stewardship. Governments can play a role in encouraging environmental stewardship in many ways, including:

- Providing public recognition
- Providing outreach materials on reducing diesel emissions
- Providing facility-specific guidance on assessing baseline emissions and how to plan for improvements
- Facilitating information exchange and leveraging funding

Environmental Management System (EMS)

One proactive approach to environmental stewardship is developing an Environmental Management System (EMS), which is a plan integrating environmental decision-making into a company's day-to-day operations. Some of the benefits of developing an EMS include;

- Improved community relations and public image
- Cost savings
- Improved internal communication

- Increased competitiveness and market opportunities.

4.4. Partnerships

Building partnerships and collaborating on projects with fleet owners/operators and other local, state, and regional stakeholders are effective means to reduce diesel emissions from harbor craft. By bringing together partners from different entities, varied complementary skills and experiences are combined to solve a defined problem. Partnerships create opportunities to apply complementary skills and experience, share a vision, promote mutual respect, and identify opportunities for creative synergy. Partnerships throughout the country carry out diesel emissions reduction programs. These partnerships may include government, business, environmental non-profit organizations, and local community groups with a shared vision of protecting the environment.

The Blue and Gold Fleet ferry retrofit project in San Francisco, California, is a successful partnership formed to reduce diesel emissions from harbor craft. Every year more than two million people visit Alcatraz by way of the 14 ferries of the Blue and Gold Fleet. Each diesel-powered ferry vessel makes several daily trips. The Blue and Gold Feet is a National Park Service concessionary, and therefore the partners want to do their part to have the least impact on the environment.

Under the West Coast Diesel Collaborative, the Blue and Gold Fleet formed a partnership, working with EPA, the National Park Service, the San Francisco Bay Area Water Transit Authority, Lubrizol, Cleaire, and other governmental and environmental organizations to retrofit all 14 ferries with emissions control technologies. The technologies include Lubrizol's water emulsion fuel alternative, PuriNOx, and Cleaire's Longview SCR device.

NESCAUM has discussed strategies to reduce harbor craft emissions with a number of stakeholders during the course of this project, including Massport, MBTA, Greater Boston Breathes Better (GB3), Environmental Defense, DOT Volpe Center, fuel providers, and emission control technology providers. The following fleets were identified as candidates for a harbor vessel emission reduction project:

Table 4-1:

Fleets
▪ Massport ▪ MBTA ▪ Mass Bay Lines ▪ Harbor Express ▪ Harbor Cruises

In addition, we identified an expanded group of potential partners for a wider collaboration:

- Asthma Regional Council

- The Boston Harbor Association
- Boston Natural Areas Network
- Boston Water and Sewer Commission
- Charles River Watershed Association
- The Children's Museum
- Environmental Defense
- EPA Region 1
- Friends of the Boston Harbor Islands
- Greater Boston Breathes Better (GB3)
- Hull Lifesaving Museum
- Island Alliance
- John F. Kennedy Library and Museum
- Massachusetts Bay Transportation Authority
- Massachusetts Department of Conservation and Recreation
- Massachusetts Executive Office of Environmental Affairs
- Massachusetts Port Authority
- Massachusetts Water Resources Authority
- Museum of Science
- National Park Service
- Neponset River Watershed Association
- NESCAUM
- New England Aquarium
- Save the Harbor
- U.S. Department of Transportation – Volpe Center
- Water Transportation Advisory Committee

5. CONCLUSIONS and RECOMMENDATIONS

This section provides recommendations for reducing emissions from harbor craft operating in Boston Harbor. It is divided into two parts: technical recommendations and policy recommendations. Boston Harbor vessels examined in this study emitted approximately 857 tons of NOx, 20 tons of PM, 165 tons of CO, and 18 tons of HC. Harbor craft emissions are significant when compared to total emissions from the 1999 NESCAUM inventory of Boston Harbor, which were estimated to be 1,400 tons of NOx and 150 tons of PM for all commercial marine vessels. Emission control programs such as retrofits and fuels changes could reduce this number significantly.

Of the 857 tons of NOx and 20 tons of PM emitted by Boston Harbor craft, 70 percent of these emissions came from ferries and excursion boats. Given the proximity of the emissions from these vessels to passengers (unlike dredging or other operations), a focus on controlling emissions from this source could provide the greatest public health benefit.

5.1. Technical Recommendations

Of the ferry/excursion vessel operations evaluated in the study, two fleets are responsible for a majority of the emissions: Harbor Express (MBTA) and Harbor Cruises. Together these fleets emit approximately 485 tons of NOx and 11 tons of PM per year. Controlling emissions from these fleets would greatly reduce overall emissions from harbor craft in Boston. The fleet with the third highest emissions of all harbor vessels was Boston Towing & Transportation. Recommendations for these three fleets with the highest emissions appear below.

Harbor Express (MBTA)

Several vessels in this fleet (Flying Cloud, Lightening, Voyager, Doc Edgerton) are candidates for SCR, LNC, DOCs, and possibly passive DPFs, as engine power is high and exhaust temperatures are likely to be high. Other vessels in the fleet are either too old or have wet exhaust and therefore are not viable candidates for the above technologies. For these vessels, DOCs may be effective in some cases. For all vessels, clean fuels such as emulsified diesel may be a possibility.

Emissions Control Recommendations:

- Install DPFs on the Voyager and Doc Edgerton.
- Install DOCs on vessels that either are too old or have exhaust temperatures too low for DPF use (see specific technology recommendations in Appendix A). In addition, the Flying Cloud and Lightening have wet exhaust and were recently re-powered with new Tier 2 engines.[10] DOCs are a good technology choice for these two vessels.
- For NOx control, consider use of emulsified diesel fuel for all fleet vessels. This strategy could reduce 60 tons of NOx a year and between 2 and 7 tons of PM a year (depending on whether DOCs or DPFs are used). Alternatively, SCR or LNC could be used instead of emulsified fuel if concerns about water emulsion come up during a more comprehensive analysis of engine characteristics. It should be noted that the use of emulsified fuel in marine vessels has both cold weather issues in New England as well as potential hull/fuel tank corrosion issues that have not been fully vetted by USCG.

Boston Harbor Cruises

For a number of vessels in the fleet (e.g., Nora Vittoria, Aurora, Anna, Bay State, James Dougherty, Eugene Louise, Fort Independence, Frederick Nolan), SCR, DOCs, and passive DPFs are possible control options, since exhaust gas temperatures should be

[10] It should be noted that the recent repower of the Flying Cloud and Lightening with Tier 2 engines will reduce emissions from these engines - and thus emissions reported in this inventory are likely somewhat higher than actual for these two boats.

sufficiently high and since engine power is high. However, if exhaust is wet, then SCR, and DPFs are not viable options. Instead, DOCs, clean fuels such as ULSD and/or emulsions are possible. DOCs and clean fuels should be considered for the other vessels in the fleet.

Emissions Control Recommendations:

- Evaluate DPF/SCR candidate boats to determine whether or not wet exhaust is used. If exhaust is dry, then retrofit boats with DPFs, LNC, or SCR.
- Retrofit Edward Rowe Snow, Andrews, Salacia, and other boats that are not good DPF candidates with DOCs.
- If wet exhaust is used in most of the fleet, use DOCs, clean fuels such as emulsified diesel and/or ultra-low sulfur diesel in the fleet.

Boston Towing and Transportation

This fleet emits approximately 48 tons of NOx and 3 tons of PM each year. NESCAUM was not able to obtain sufficient information to make specific technology recommendations for the engines in this fleet. As part of the development of a comprehensive strategy to control emissions from Boston Harbor fleets, it will be critical to obtain information on engine type, age, exhaust type, and other specifics from this fleet.

5.2. Policy Recommendation

Section 4, “Outreach and Policy Options,” contains a number of different policy options to control harbor craft emissions. That section described the use of SEP funds, contractual obligations, and EIS approvals to require diesel emissions reductions.

This section presents a specific policy approach to reducing diesel emissions from Boston Harbor vessels: using Logan Airport NOx cap funds.

Logan Airport NOx Emissions Cap

Massport, under its Air Quality Initiative (AQI), agreed in 2001 to establish a NOx and VOC emissions cap for Logan Airport at 1999 levels for airport-related emissions. Massport agreed to reduce emissions from aircraft, ground service equipment, and airport stationary sources first, followed by off-airport projects or emissions offsets projects if the NOx and VOC cap could not be met by on-airport reductions. While the emission caps have never been exceeded (due to the drop in airline flights after 9/11/2001), landings and take-offs at Logan Airport have recently returned to pre-9/11 levels. Given this, and the commensurate growth in NOx emissions from the increased flights, the airport will likely need to begin emission reduction projects to meet the NOx cap.

Since Boston Harbor is adjacent to the airport, reducing emissions from harbor vessels could provide a good opportunity for Massport to meet its NOx emissions cap and at the same time provide a public health benefit. Furthermore, Massport (the operator of Logan Airport) operates its own ferries and/or has contractual arrangements with ferry operators to run water shuttles to and from downtown Boston and the airport.

If NOx credits are needed, Massport could first start by using NOx-reducing technologies such as emulsified diesel on all ferries that shuttle passengers back and forth from downtown Boston. Massport could insert retrofit requirements into its contracts with ferry operators when they come up for renewal. Beyond the ferries operated by Massport, other harbor vessels - such as excursion boats - could also be retrofitted. This might require some negotiation since operators are often reluctant to take boats out of service for retrofitting or to risk using a new technology on their engines. However, excursion vessel operators have an incentive to clean up their fleets, since most of the people taking the boats are tourists, who would likely prefer riding on cleaner, retrofitted boats rather than the older, dirtier vessels that shuttle people back and forth to the Harbor Islands.

Northeast Diesel Collaborative Opportunities

One of the priorities identified by Steering Committee members of the Northeast Diesel Collaborative is to reduce diesel emissions at ports in the Northeast. Given this focus, an emission reduction project at Boston Harbor could be included in a regional effort to reduce port-related emissions. Funding identified through the Collaborative, such as those sources listed above and including supplemental environmental project funds, offsets, contractual requirements, fees, and or grant funds could be used to reduce emissions as part of the Collaborative effort.

Appendix A

Specific Engine Characteristics and Technology Options

Boston Harbor Craft	Total hp	Stroke	No. Eng	Engines/YR Model/Make	People Cap	Catamaran or Mono-hull	Wet or Dry Exhaust	Speed Fully Loaded	Catg. (EPA /IMO)	Comments Re Technology Options
Mass Bay Lines										
Freedom	800	4	2	1974 Caterpillar D343	346	Catamaran	Wet Exhaust	14 knots	2	Wet exhaust precludes use of DPFs, CWMFs, SCR, or LNC. DOCs or clean fuels -- ULSD, BioD, FBCs or EDF are viable options.
Massachusetts	1,200	4	2	Detroit Diesel Series 60	300	Catamaran	Wet Exhaust	20 knots	2	
Nantascot	250	2	1	1961 Detroit Diesel 871	255	Mono-hull	Dry Exhaust	10 knots	2	Hi soot content of 2-cycle engine precludes use of any ECT in the exhaust, i.e. DPFs, DOCs, CWMFs, SCR, or LNC; clean fuels -- ULSD, BioD, FBCs or perhaps EDF are the only viable options.
New Boston	250	2	1	1964 Detroit Diesel 871	390	Catamaran	Dry Exhaust	9 knots	2	
Harbor Belle	130	4	1	1986 Volvo Penta	149	Mono-hull	Wet Exhaust	8 knots	1	Wet exhaust precludes use of DPFs, CWMFs, SCR, or LNC; clean fuels. DOCs, ULSD, BioD, FBCs or EDF are viable options.
Samuel Clemens	250	4	1	1974 Cummins NH 856	273	Mono-hull	Dry Exhaust	9 knots	2	EGTs most likely too low for SCR (poor efficiency) or DPFs (regen issues) based upon the low "fully loaded speed"; CWMF & LNC may work; DOCs should work if engines are not too sooty (they are VERY old at 1974);clean fuels would be a viable option.
Seaport Belle	210	4	1	1989 Cummins GBT 5.9	149	Mono-hull	Dry Exhaust	9 knots	2	EGTs most likely too low for SCR (poor efficiency) or DPFs (regen issues) based upon the low "fully loaded speed"; CWMF & LNC may work; DOCs should work if engines not too sooty (they are old at 1989); clean fuels would be a viable option.
Mass Port - Commuter Service										
Justine - Logan Airport Commuter Service	550	2	1	1982 Detroit Diesel	200+	Mono-hull	Wet Exhaust		2	Hi soot content of 2-cycle engines, & wet exhaust, precludes use of any ECT in the exhaust, i.e. DPFs, DOCs, CWMFs, SCR, or LNC; clean fuels -- ULSD, BioD, FBCs or EDF are the only viable options.
Rowes Wharf Water Taxi	130	4	1	1993 Volvo	<150	Mono-hull	Wet Exhaust		1	Wet exhaust precludes use of DPFs, DOCs, CWMFs, SCR, or LNC. DOCs, clean fuels -- ULSD, BioD, FBCs or EDF are viable options.

Boston Harbor Craft	Total hp	Stroke	No. Eng	Engines/YR Model/Make	People Cap	Catamaran or Mono-hull	Wet or Dry Exhaust	Speed Fully Loaded	Catg. (EPA /IMO)	Comments Re Technology Options
Princess Yard Charters Limited										
Majestic Princess					200				2	Insufficient information
Boston Harbor Cruises										
Aurora		4	4	1998 Cummins KTA 38	400	Catamaran		35	2	SCR, DOCs, and potentially passive DPFs -- exhaust gas temps (EGTs) should be sufficiently high (good SCR performance & DPF regen) since engine power is high and there appears to be high speed operation (35 knots); these Cummins KTA engines are relatively new & clean; only caution is if exhaust is wet, then neither SCR, DPF or DOC works, w/only option being clean fuels (ULSD &/or emulsions)
Nora Vittoria		4	4	1998 Cummins KTA 38	400	Catamaran		35	2	
Massachusetts	2,400	2	2	1988 General Motors 1271	346	Mono-hull		20	3	Hi soot content of 2-cycle engine precludes use of any ECT in the exhaust, i.e. DPFs, DOCs, CWMFs, SCR, or LNC; clean fuels -- ULSD, BioD, FBCs or perhaps EDF are the only viable options.
Laura	2300	4	4	1989 Caterpillar 3408	349	Mono-hull		21	2	EGTs most likely too low for SCR (poor efficiency) or DPFs (regen issues) based upon the low "fully loaded speed"; CWMF & LNC may work; DOCs should work assuming exhaust is not too sooty (they are old at 1989);clean fuels would be a viable option with either wet or dry exhaust.
Bostonian II	440	4	2	1979 Caterpillar 3306	149	Mono-hull		16	2	As per the Laura (immediately above) with the caveat that the age of the engines (1979) might make them too sooty even for DOCs.
Rookie		4	2	1985 Caterpillar 3412	149	Mono-hull		21	2	EGTs most likely too low for SCR (poor efficiency) or DPFs (regen issues) based upon the low "fully loaded speed"; CWMF & LNC may work; DOCs should work assuming exhaust is not too sooty (they are old at 1985);clean fuels would be a viable option with either wet or dry exhaust.

Boston Harbor Craft	Total hp	Stroke	No. Eng	Engines/YR Model/Make	People Cap	Catamaran or Mono-hull	Wet or Dry Exhaust	Speed Fully Loaded	Catg. (EPA /IMO)	Comments Re Technology Options
Andrews		4	1	1995 Caterpillar 3208	49	Mono-hull		8	2	EGTs most likely too low for SCR (poor efficiency) or DPFs (regen issues) based upon the low "fully loaded speed"; CWMF & LNC may work; DOCs should work assuming exhaust is not too sooty (engine are comparatively new at 1995); clean fuels would be a viable option with either wet or dry exhaust.
Edward Rowe Snow	440	4	2	1982	193	Catamaran		11	2	EGTs most likely too low for SCR (poor efficiency) or DPFs (regen issues) based upon the low "fully loaded speed"; CWMF & LNC may work; DOCs should work assuming exhaust is not wet or engines too sooty (they are old at 1982);clean fuels would be a viable option with either wet or dry exhaust.
Salacia			2		300	Catamaran		18	2	EGTs most likely too low for SCR (poor efficiency) or DPFs (regen issues) based upon the low "fully loaded speed; DOCs should work assuming exhaust is not too sooty (age unknown); clean fuels would be a viable option with either wet or dry exhaust.
Anna	1800	4	3	1981 Caterpillar 3406	149	Mono-hull		21	2	DOC, CWMF, SCR, LNC, and potentially passive DPFs -- exhaust gas temps (EGTs) should be sufficiently high (good SCR performance & DPF regen) since engine power is high and there appears to be high speed operation (30 knots); two cautions are age of engines for all these vessels that may exhibit high soot loading and determination if exhaust is wet -- for either case, neither SCR or DPF will work. If so, DOC or clean fuels (ULSD &/or emulsions) are likely viable.
Bay State	700	4	2	1976	561	Mono-hull		20	2	
James J. Doherty	2340	4	4	1992 Caterpillar 3406	348	Mono-hull		21	2	
Eugine Louise	1755		3 or 4	1990	149	Mono-hull		18	2	
Fort Independence	700	4	2	1984	519	Mono-hull		20	2	
Frederick L. Nolan, Jr.	864	4	2	1985	561	Mono-hull		18	2	
Alison	456	2	1	1981	35	Mono-hull		10	2	Hi soot content of 2-cycle engine precludes use of DPFs, CWMFs, SCR, or LNC. DOC or clean fuels -- ULSD, BioD, FBCs or perhaps EDF are viable options.
Betty Joe Tyler	670	2	2	1981 General Motors 671	49	Mono-hull		18	3	

Boston Harbor Craft	**Total hp**	**Stroke**	**No. Eng**	**Engines/YR Model/Make**	**People Cap**	**Catamaran or Mono-hull**	**Wet or Dry Exhaust**	**Speed Fully Loaded**	**Catg. (EPA /IMO)**	**Comments Re Technology Options**
Breeds Hill	330	4	1	1981	36	Mono-hull		10	2	EGTs most likely too low for SCR (poor efficiency) or DPFs (regen issues) based upon the low "fully loaded speed"; CWMF & LNC may work; DOCs should work assuming exhaust is not too sooty (they are VERY old at 1981);clean fuels would be a viable option with either wet or dry exhaust.
Bunker Hill	330	2	2	1981 General Motors 871	36	Mono-hull		16	3	Hi soot content of 2-cycle engine precludes use of any ECT in the exhaust, i.e. DPFs, DOCs, CWMFs, SCR, or LNC; clean fuels -- ULSD, BioD, FBCs or perhaps EDF are the only viable options.
Lulu	2300	2	4	1991	149	Mono-hull		18	2	
Matthew J. Hughs	2300	4	4	1989 Caterpillar 3408	349	Mono-hull		21	3	DOC, CWMF, SCR, LNC, and potentially passive DPFs -- exhaust gas temps (EGTs) should be sufficiently high (good SCR performance & DPF regen) since engine power is high and there appears to be high speed operation (30 knots); two cautions are age of engine (1989) that may exhibit high soot loading and determination if exhaust is wet -- for either case, neither SCR or DPF works, w/only option being DOC, clean fuels (ULSD &/or emulsions)
Native Son	1800	4	4	1965	102	Mono-hull		10	2	EGTs most likely too low for SCR (poor efficiency) or DPFs (regen issues) based upon the low "fully loaded speed"; CWMF & LNC may work; DOCs should work assuming exhaust is not too sooty (they are VERY old at 1965);clean fuels would be a viable option with either wet or dry exhaust.
A.C.Cruise Line										
Cape Ann					539				2 or 3	Insufficient information
Virginia C II					215				2	
Charles River Boat Company										
Charles I					110				2	Insufficient information
Charles II					49				1	
Schooner Liberty, Inc. - Liberty					49				1	
Spirit of Boston - Spirit of Boston									3	

Boston Harbor Craft	Total hp	Stroke	No. Eng	Engines/YR Model/Make	People Cap	Catamaran or Mono-hull	Wet or Dry Exhaust	Speed Fully Loaded	Catg. (EPA /IMO)	Comments Re Technology Options
Harbor Express – MBTA										
Flying Cloud	1920	4	2	Detroit Diesel 2000 series	149	Catamaran		30 knots	2	SCR, DOCs, and potentially passive DPFs -- exhaust gas temps (EGTs) should be sufficiently high (good SCR performance & DPF regen) since engine power is high and there appears to be high speed operation (30 knots); these DDC (actually German-made MTUs) engines are relatively clean (knowing how new they are would help); only caution is if exhaust is wet, then neither SCR or DPF works, w/only option being DOC, clean fuels (ULSD &/or emulsions)
Lightning	1920	4	2	Detroit Diesel 2000 series	149	Catamaran		30 knots	2	
Voyager III (325 max passengers)	3840	4	4	2000 Detroit Diesel	349	Catamaran		30 knots	2	
Adventurer	3840	2	2	Detroit Diesel		Catamaran		18 knots	2	Hi soot content of 2-cycle engine precludes use of any ECT in the exhaust, i.e. DPFs, DOCs, CWMFs, SCR, or LNC; clean fuels -- ULSD, BioD, FBCs or perhaps EDF are the only viable options.
Doc Edgerton	7720	4	4	2000 Detroit Diesel		Catamaran		30 knots	2	SCR, DOCs, and potentially passive DPFs -- exhaust gas temps (EGTs) should be sufficiently high (good SCR performance & DPF regen) since engine power is high and there appears to be high speed operation (30 knots); these DDC (actually German-made MTUs) engines are relatively clean (knowing how new they are would help); only caution is if exhaust is wet, then neither SCR or DPF works, w/only option being DOC, clean fuels (ULSD &/or emulsions)
Odyssey Cruise Ship	800	4	2	400 HP Diesel	600	Catamaran		10.5 knots	2	EGTs most likely too low for SCR (poor efficiency) or DPFs (regen issues) based upon the low "fully loaded speed"; CWMF & LNC may work; DOCs should work assuming exhaust is not too sooty (age unknown); clean fuels would be a viable option with either wet or dry exhaust.
Constellation Tug Corporation										Insufficient information
Orion	2750								2	
Draco	2850								2	

Boston Harbor Craft	Total hp	Stroke	No. Eng	Engines/YR Model/Make	People Cap	Catamaran or Mono-hull	Wet or Dry Exhaust	Speed Fully Loaded	Catg. (EPA /IMO)	Comments Re Technology Options
Boston Line and SVC Co										
#1	400								2	
#2	400								2	
Sea Tow										
Rescue 1	400								2	
Rescue 2	270								1	
Rescue 3	280								1	
Reliant	300								2	
Responder	300								2	
Rescue 17	90								1	
Naval Ships to Charlestown										
1	5000								3	Insufficient information
2	5000								3	
3	5000								3	
4	5000								3	
5	5000								3	
6	5000								3	
Great Lakes Dredging										
Dredge # 54	2340								2	Insufficient information but mostly likely very sooty engines, typical of dredges will preclude use of any ECT in the exhaust, i.e. DPFs, DOCs, CWMFs, SCR, or LNC; clean fuels -- ULSD, BioD, FBCs or EDF are the only viable options.
Mass. State Police Marine Division										
Patroller 1 -41'	680	4	2	(2) 903 Cummins Diesel					2	Insufficient information
Patroller 2 -41'	680	4	2	(2) 903 Cummins Diesel					2	
Patroller 3 -41'	680	4	2	(2) 903 Cummins Diesel					2	

Boston Harbor Craft	**Total hp**	**Stroke**	**No. Eng**	**Engines/YR Model/Make**	**People Cap**	**Catamaran or Mono-hull**	**Wet or Dry Exhaust**	**Speed Fully Loaded**	**Catg. (EPA /IMO)**	**Comments Re Technology Options**
Patroller 4 -44'	680	2	2	(2) Detroit Diesel "Drippers"					2	Hi soot content of 2-cycle engine precludes use of any ECT in the exhaust, i.e. DPFs, DOCs, CWMFs, SCR, or LNC; clean fuels -- ULSD, BioD, FBCs or perhaps EDF are the only viable options.
Patroller 5 -32'	680	4	2	(2) C Series Cummins						Insufficient information
#12 Monarch	450	2		2 stroke						Hi soot content of 2-cycle engine precludes use of any ECT in the exhaust, i.e. DPFs, DOCs, CWMFs, SCR, or LNC; clean fuels -- ULSD, BioD, FBCs or perhaps EDF are the only viable options.
#9 -27' Whaler	450	2		2 stroke						
25' Whaler 1	300	2		2 stroke						
25' Whaler 2	300	2		2 stroke						
25' Whaler 3	300	2		2 stroke						
17' Whaler 1	90	2		2 stroke						
17' Whaler 2	90	2		2 stroke						
17' Whaler 3	90	2		2 stroke						
27' Interceptor	600	2		2 stroke						
Kawasaki Jet ski 1 (2004)	1200	4		4 stroke						Insufficient information; HP values should be re-checked, very high for jet ski type of watercraft
Kawasaki Jet ski 2 (2004)	1200	4		4 stroke						
Kawasaki Jet ski 3 (2003)	1200	4		4 stroke						
Kawasaki Jet ski 4 (2003)	1200	4		4 stroke						
Kawasaki Jet ski 5 (1999)	1200	4		4 stroke						
Kawasaki Jet ski 6 (1999)	1200	4		4 stroke						
*Patrollers										Insufficient information
Max- 2600 RPM 40 G/hr										
Cruise 2300 RPM 30 G/hr										
Fuel Consumption best estimates										
Boston Police Harbor Patrol										
Patroller 1 -41' "St. Michael"	680									Insufficient information
Patroller 2 -41'	680									
57' "Guardian"										
27' Interceptor "Protector"	600									

Boston Harbor Craft	**Total hp**	**Stroke**	**No. Eng**	**Engines/YR Model/Make**	**People Cap**	**Catamaran or Mono-hull**	**Wet or Dry Exhaust**	**Speed Fully Loaded**	**Catg. (EPA /IMO)**	**Comments Re Technology Options**
27' Interceptor "Persuader"	600									
Boston Towing & Transportation										
1	1200									
2	1200									
3	1500									
4	1500									
5	2400									
6	2400									
7	3000									
8	3000									
9 Tractor Tug	4000									
10 tractor Tug	4000									
80 G/hr all tugs										
Boston Pilots Association										
1	800	4		Caterpillar 8206						
2	800	2		Detroit Diesel 892						Hi soot content of 2-cycle engine precludes use of any ECT in the exhaust, i.e. DPFs, DOCs, CWMFs, SCR, or LNC; clean fuels -- ULSD, BioD, FBCs or perhaps EDF are the only viable options.

Abbreviations:

ECT	Emission Control Device (generic term)
EGT	"Exhaust Gas Temperature" (generic term)
DPF	Diesel Particulate Filter
DOC	Diesel Oxidation Catalyst)
CWMF	Catalyzed Wire Mesh Filter
SCR	Selective Catalytic Reduction
LNC	Lean NOx Catalyst
ULSD	Ultra-Low Sulfur Diesel
BioD	Biodiesel
FBC	Fuel Borne catalyst
EDF	Emulsified Diesel Fuel

Appendix B: Emissions Inventory Detail

Table B-1 below provides information for those operators that provided either hours of use or fuel consumption for 2005.

Table B-1 Vessel Inventory Information for Operators that Provided Information

Boston Harbor Craft	NOx (tpy)	PM (tpy)	CO (tpy)	HC (tpy)
Mass Bay Lines				
Freedom	1.86	0.04	0.36	0.04
Massachusetts	29.07	0.67	5.59	0.60
Nantascot	0.93	0.02	0.18	0.02
New Boston	0.35	0.01	0.07	0.01
Harbor Belle	0.19	0.00	0.04	0.00
Samuel Clemens	0.81	0.02	0.16	0.02
Seaport Belle	0.81	0.02	0.16	0.02
Boston Harbor Commuter Service - MassPort				
Justice - Logan Airport Commuter Service	2.54	0.06	0.49	0.05
Rowes Wharf Water Taxi	0.85	0.02	0.16	0.02
Harbor Express - MBTA				
Flying Cloud	63.32	1.46	12.18	1.32
Lightning	63.32	1.46	12.18	1.32
Voyager III (325 max passengers)	62.79	1.45	12.08	1.30
Adventurer	28.60	0.66	5.50	0.59
Doc Edgerton	28.60	0.66	5.50	0.59
Odyssey Cruise Ship	6.98	0.16	1.34	0.14
Constellation Tug Corporation				
Orion	9.26	0.21	1.78	0.19
Draco	3.74	0.09	0.72	0.08
Boston Line and SVC Co				
#1	0.60	0.01	0.12	0.01
#2	0.60	0.01	0.12	0.01
Sea Tow				
Rescue 1	0.58	0.01	0.11	0.01
Rescue 2	0.61	0.01	0.12	0.01
Rescue 3	0.62	0.01	0.12	0.01
Reliant	0.31	0.01	0.06	0.01
Responder	0.19	0.00	0.04	0.00
Rescue 17	0.02	0.00	0.00	0.00
Naval Ships to Charlestown				
1	0.06	0.00	0.01	0.00
2	0.06	0.00	0.01	0.00
3	0.06	0.00	0.01	0.00
4	0.06	0.00	0.01	0.00
5	0.06	0.00	0.01	0.00
6	0.06	0.00	0.01	0.00
Great Lakes Dredging				
Dredge # 54	9.16	0.21	1.76	0.19
Mass. State Police Marine Division				
Patroller 1 -41'	2.33	0.05	0.45	0.05
Patroller 2 -41'	2.33	0.05	0.45	0.05
Patroller 3 -41'	2.33	0.05	0.45	0.05
Patroller 4 -44'	2.33	0.05	0.45	0.05
Patroller 5 -32'	2.33	0.05	0.45	0.05
#12 Monarch	1.40	0.03	0.27	0.03
#9 -27' Whaler	1.40	0.03	0.27	0.03
25' Whaler 1	1.86	0.04	0.36	0.04
25' Whaler 2	1.86	0.04	0.36	0.04
25' Whaler 3	1.86	0.04	0.36	0.04
17' Whaler 1	1.86	0.04	0.36	0.04
17' Whaler 2	1.86	0.04	0.36	0.04
17' Whaler 3	1.86	0.04	0.36	0.04
27' Interceptor	1.86	0.04	0.36	0.04

Inventory for ships with partial operating data

Table B-2 shows emissions estimates for Boston Harbor Cruises, A.C. Cruiseline, Charles River Boat Company, Schooner Liberty and the Spirit of Boston. Parameters, such as hours of activity, horsepower, or fuel consumption, were not available. NESCAUM estimated these parameters based on previous studies. Further work will be needed to more accurately estimate emissions from these vessels, given the large number of ships operated by these companies.

Table B-2: Emissions Inventory with Partial Operational Data

Emissions Inventory with Partial Operational Data				
Boston Harbor Craft	**NOx (t/y)**	**PM (t/y)**	**CO (t/y)**	**HC (t/y)**
Princess Yard Charters Limited	9.31	0.21	1.79	0.19
Boston Harbor Cruises	237.51	5.48	45.68	4.93
A.C.Cruise Line	18.62	0.43	3.58	0.39
Charles River Boat Company	18.62	0.43	3.58	0.39
Schooner Liberty, Inc. - Liberty	9.31	0.21	1.79	0.19
Spirit of Boston - Spirit of Boston	9.31	0.21	1.79	0.19
Total Emissions	**302.67**	**6.98**	**58.21**	**6.29**