Report to the Report to the Joint Standing Committee
on Environment and Natural Resources
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Air Emissions from Marine Vessels

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Executive Summary

The Maine Department of Environmental Protection released a report in January 2005 summarizing emissions and regulations related to marine vessels in Maine. This report serves to update that document, providing the latest available emissions data and outlining the changes to federal and international regulations.

The 2014 National Emissions Inventory, a triennial inventory compiled by the U.S. Environmental Protection Agency (EPA) is the most recent data available for emissions from marine vessels. Based on this data set, commercial marine vessels contribute 40% (138 tons/year) of the sulfur dioxide (SO_2), 2.7% (70 tons/year) of the particulate matter (PM), 8% (2,681 tons/year) of the nitrogen oxides (NO_x), and 0.1% (43 tons/year) of volatile organic compound (VOC) emissions from the mobile sources sector. Apart from sulfur dioxide, emissions from marine commercial vessels appear minor in comparison to other source categories; however, the Department cannot conclude that marine vessels contribute insignificant levels of air emissions in Maine because the emissions inventory method used by the EPA may not be accurate or robust enough to capture a complete picture of marine vessel emissions.

Air emissions from commercial marine vessels are regulated at the international and federal level, and there have been significant changes to both areas of regulation since the 2005 report. Changes to international regulations include more stringent fuel sulfur content limits and NO_x emissions standards required by the MARPOL Annex VI amendments of 2008, energy efficiency requirements of the MARPOL Annex VI Chapter 4 amendments of 2011, and 2018 amendments focused on greenhouse gas emission reductions. In 2010 specific portions of U.S. and Canadian waters were designated as Emissions Control Areas, which are subject to more stringent emission related requirements. Federal regulation updates include the 2008 Locomotive and Marine Rule, which introduced Tier III and Tier IV emission standards for new marine diesel engines, and reductions in marine diesel sulfur content levels. In addition to the international and federal requirements, some states and ports have programs, regulatory and voluntary, to address local impacts of vessel emissions, and there are national and international organizations that provide industries and communities guidance on voluntarily reducing emissions from marine vessels and ports.

In order to comply with the numerous international and federal regulations governing marine vessels, the industry employs several emissions control strategies and methods. Details about the technologies included in this report include marine emission scrubber systems, selective catalytic reduction technology, and diesel particulate filters. Information is also provided about strategies such as using shore power, prohibiting soot blowing, and reducing speed.

The advancement in technologies and regulations will significantly reduce emissions from these vessels in 2020 and future years. While Maine already employs several strategies to address emissions from marine vessels, this report provides options for further consideration.

Section 1. Introduction

In January 2005, the Maine Department of Environmental Protection (DEP) completed a legislative report addressing the air quality impacts from all types of marine vessels in Maine, potential health threats due to marine engine emissions, laws and rules pertaining to marine vessels at the international, national and state levels, options Maine could consider in addressing marine vessel emissions, and the Department's recommendations.[1]

Since the 2005 report was published, cruise ship calls have more than doubled. Maritime transport is essential to the world's economy as over 90% of the world's trade is carried by sea, and it is, by far, the most cost-effective way to move goods and raw materials around the world.[2] Both cargo and cruise ship activity continue to grow both locally and globally. The US Environmental Protection Agency (EPA) recognizes that marine vessels can contribute to deterioration of air quality in ports and along coastal areas. Most marine vessels operate using diesel engines fueled by either diesel (distillate) or residual (a much higher sulfur) fuel. Diesel exhaust is made up of hundreds of components, both gases and particles. Some of the gaseous components include nitrogen compounds (e.g., nitrogen oxides), sulfur compounds, carbon dioxide, and carbon monoxide. A single engine on a cruise or cargo ship can be large enough that, if it were based on land, it may be considered a major source and require mandatory emission controls. While many cruise and cargo ships have installed air quality control equipment to reduce their emissions, the air quality concern related to cruise and cargo ships has grown with the expansion of ship activity and its associated emissions.

While the EPA recognizes this air quality issue, many ships operating in U.S. coastal waters are flagged or registered elsewhere so regulation is different than it is for land-based air pollution sources. A proposal was submitted by the US and Canada for the International Convention for the Prevention of Pollution from Ships (MARPOL) to be amended by the International Maritime Organization (IMO) to include coastal ports in the US and Canada as emission control areas (ECA), requiring ships entering these waters to comply with the ECA standards of reduced emissions of nitrogen oxides, sulfur oxides, and particulate matter.[3] This proposal was accepted and became enforceable in August 2012.

In late 2018 the Compliance Section of the Maine DEP Bureau of Air Quality received complaints about general haze that complainants attributed to cruise ships. Due to this and additional interest from coastal citizens groups on updated information related to marine vessel emissions, the Department began work on updating the 2005 report with more recent emissions inventory data; current laws, rules, and programs; and options for Maine to reduce emissions related to marine vessels.

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[1] Air Emissions from Marine Vessels. Report to the Standing Committee on Natural Resources. Maine Department of Environmental Protection. January 15, 2005, http://www.maine.gov/dep/air/emissions/docs/marine-vessel-emissions2005.pdf

[2] See IMO profile at UN, https://business.un.org/en/entities/13

[3] Designation of North American Emission Control Area to Reduce Emissions from Ships. U.S. EPA. March 2010. EPA-420-F-10-015, https://nepis.epa.gov/Exe/ZyPDF.cgi/P100AU0I.PDF?Dockey=P100AU0I.PDF.

With an updated report already in progress, the Department received a directive from the Legislature on April 2, 2019 requesting an updated report on air emissions from marine vessels be provided to the Joint Standing Committee on Environment and Natural Resources by January 15, 2020.

Section 2. Air Quality Impacts from Marine Vessels

2.1 Background

Maine has 3,478 miles of coastline[4] with six cargo ports[5] and 10 cruise ship ports (see Figure 2.1).[6] Cruise ship traffic has increased dramatically over the last decade (see Figure 2.2). Maine received a total of 599,045 visitors (passenger and crew) by cruise ship in 2019.[6] Cruise ship traffic is heaviest in Bar Harbor, which had 158 cruise ship calls in 2019 (356,093 total visitors, up from 78 calls in 2003).[6] Portland had 99 calls in 2019 (217,105 total visitors, up from 22 in 2003).[6] On the recreational side, Maine has 124,378 registered recreational vessels (2018)[7] (compared to 61,000 in 2002) as well as out-of-state visitors. While 22,382 vessels are registered for saltwater use only, 97,800 recreational vessels are registered for use in Maine's freshwater rivers and 5,785 lakes.[8]

1. Portland
2. Bath
3. Boothbay Harbor
4. Rockland
5. Camden
6. Belfast
7. Bucksport
8. Castine
9. Bar Harbor
10. Eastport

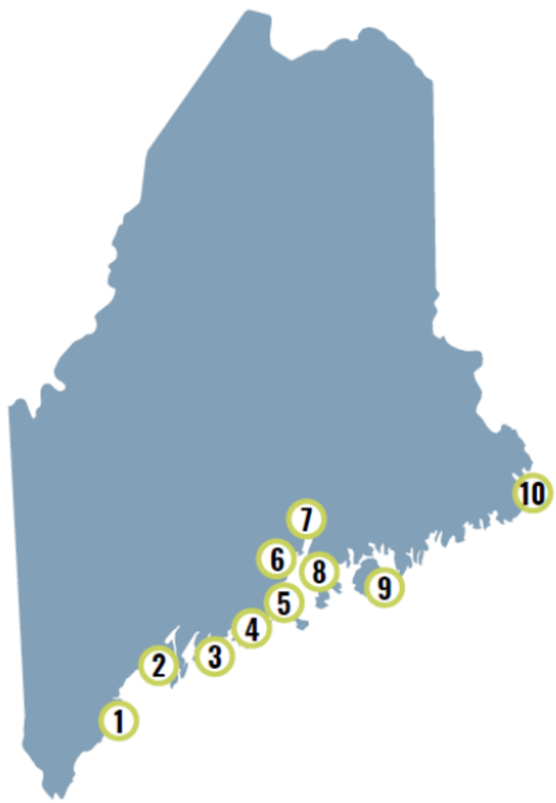

Figure 2.1. Cruise ship ports in Maine.[6]

[4] NOAA Office of Coastal Management, Shoreline Mileage of the United States, https://coast.noaa.gov/data/docs/states/shorelines.pdf
[5] Eastport, Bangor, Bucksport, Winterport (on the Penobscot River), Searsport, and Portland Harbor (in Casco Bay). Maine Port Authority. Cargo Ports. https://www maineports.com
[6] Cruise Maine, https://www.cruisemaine.org/our-ports-1
[7] Maine Inland Fisheries and Wildlife, Boat Registration data for 2018.
[8] Maine DEP. Monitoring and Assessment of Lakes – Data, https://www.maine.gov/dep/water/monitoring/lake/lakedata htm

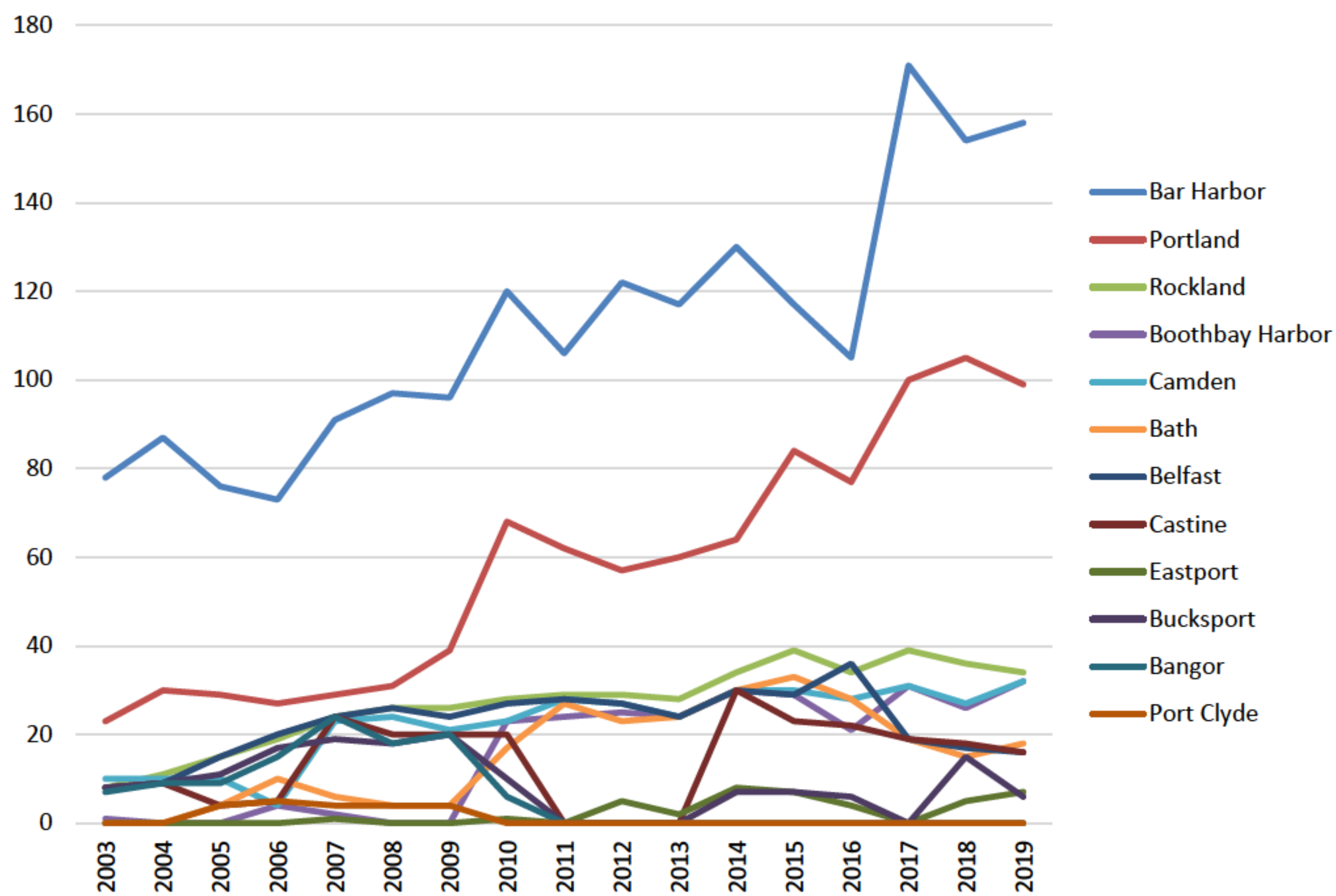

Figure 2.2. Cruise ship calls at Maine ports (2003-2019).

2.2 Monitoring

The Department monitors ambient air concentrations of a range of pollutants throughout the state. Pollutants monitored include particulate matter ($PM_{2.5}$ and PM_{10}), sulfur dioxide (SO_2), nitrogen oxides (NOx), ozone, carbon monoxide, mercury, and 67 hazardous air pollutants. The monitoring sites and the parameters measured at each site can be seen in the Department's Annual Air Monitoring Plan.[9]

As detailed in the Annual Air Monitoring Plan, one of the primary purposes of the ambient air monitoring network is to determine whether the ambient concentrations of pollutants in the state exceed ambient air quality standards set by EPA. The EPA has set National Ambient Air Quality Standards for six principal pollutants, which are called "criteria" air pollutants. The State of Maine remains in attainment with all ambient air quality standards. For more information on

[9] Maine DEP's Annual Air Monitoring Plan 2020, https://www.maine.gov/dep/air/monitoring/docs/2020-air-monitoring-plan.pdf

ambient air monitoring concentrations, please see the Five-Year Assessment of Maine's Ambient Air Monitoring Network[10] or the Maine DEP Air Monitoring and Reporting website[11].

The Department has not conducted any site-specific monitoring that could indicate how marine vessel emissions impact ambient air quality in surrounding communities. Some investigatory analysis of possible cruise ship influence on ambient air quality was completed in 2015 using data from the McFarland Hill monitoring site in Acadia. This preliminary data review did not result in any conclusions suggesting cruise ships reduced air quality at the McFarland Hill site. Changes in pollutants such as SO_2 and NO_X were well within the expected variability due to wind direction and shifting weather patterns and were not clearly linked to cruise ship presence, so no further data investigation was completed.

There are few unexplained elevated concentrations or "spikes" in the ambient air monitoring data. Elevated concentrations of all pollutants are investigated as they occur.

2.3 Emissions Inventory

National Emissions Inventory
EPA's 2014 National Emissions Inventory is the most recent data available for emissions from marine vessels. When reviewing this data, it is important to note that much of this data is based on extremely intricate models using the best available data as inputs. The methodology and modeling used in the development of each triennial NEI is continuously being changed and improved, so different NEI years should not be compared (e.g., 2011 versus 2014). EPA expects the next NEI to be released by middle to late 2020. The 2014 NEI methodology is thought to have exaggerated the emissions from pleasure craft data included in this report.

Sulfur Dioxide (SO_2)
Sulfur dioxide (SO_2) is the compound of most concern within the entire group of sulfur oxides (SO_X).[12] The largest source of SO_2 is the burning of fossil fuels, most notably fossil fuels with high sulfur content. SO_2 affects both human health and the environment. Health effects include difficulty breathing and harm to the respiratory system. Environmental effects include links to acid rain and regional haze.

Based on data from EPA's most recent triennial National Emissions Inventory (2014), mobile sources contribute 3% (348 tons/year) of the sulfur dioxide (SO_2) emissions in Maine. Of the mobile source SO_2 emissions, commercial marine vessels (cargo ships entering and leaving Maine ports) contribute 40% (138 tons/year). By comparison, pleasure craft (recreational vessels)[13] are responsible for 1% (3 tons/year). Figure 2.3 illustrates these SO_2 emission

[10] Maine Department of Environmental Protection, Bureau of Air Quality, Five Year Assessment of Maine's Ambient Air Monitoring Network (December 1, 2015), https://www.maine.gov/dep/air/monitoring/docs/2015%20Five-Year%20Assessment.pdf
[11] Maine DEP Air Monitoring and Reporting, https://www maine.gov/dep/air/monitoring/index html
[12] EPA. Sulfur Dioxide Basics. https://www.epa.gov/so2-pollution/sulfur-dioxide-basics
[13] Pleasure craft include recreational marine vessels, specifically the following source classification codes: 2282005010, 2282005015, 2282010005, 2282020005, 2282020010. These include 2-stroke and 4-stroke gasoline engines as well as diesel engines.

comparisons. For context, Figure 2.4 shows the trend in Maine's ambient air concentrations of SO_2 remain below the National Ambient Air Quality Standard.

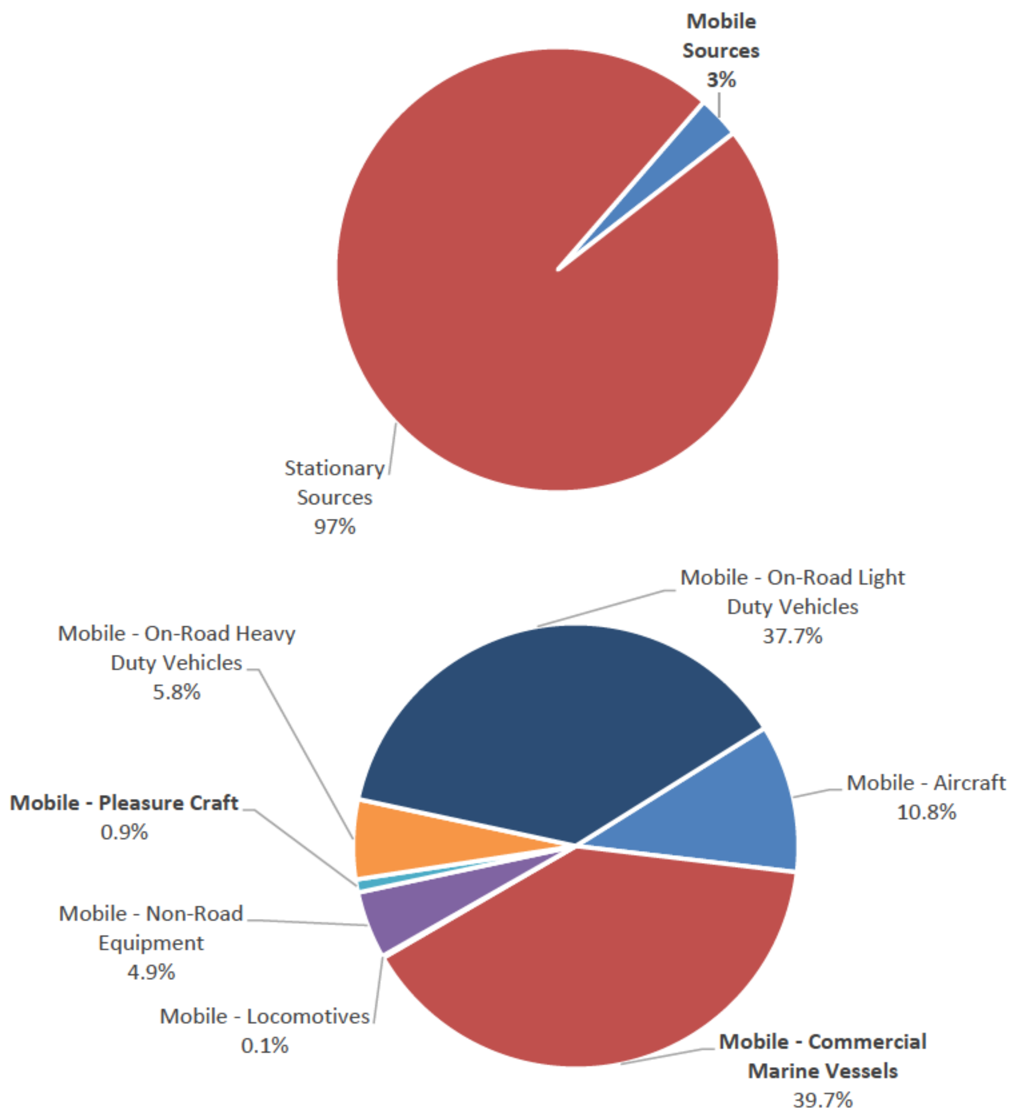

Figure 2.3. Sulfur dioxide (SO_2) emissions in Maine (2014 NEI). The top figure represents the full emissions inventory, and the bottom figure breaks out the mobile sources category.

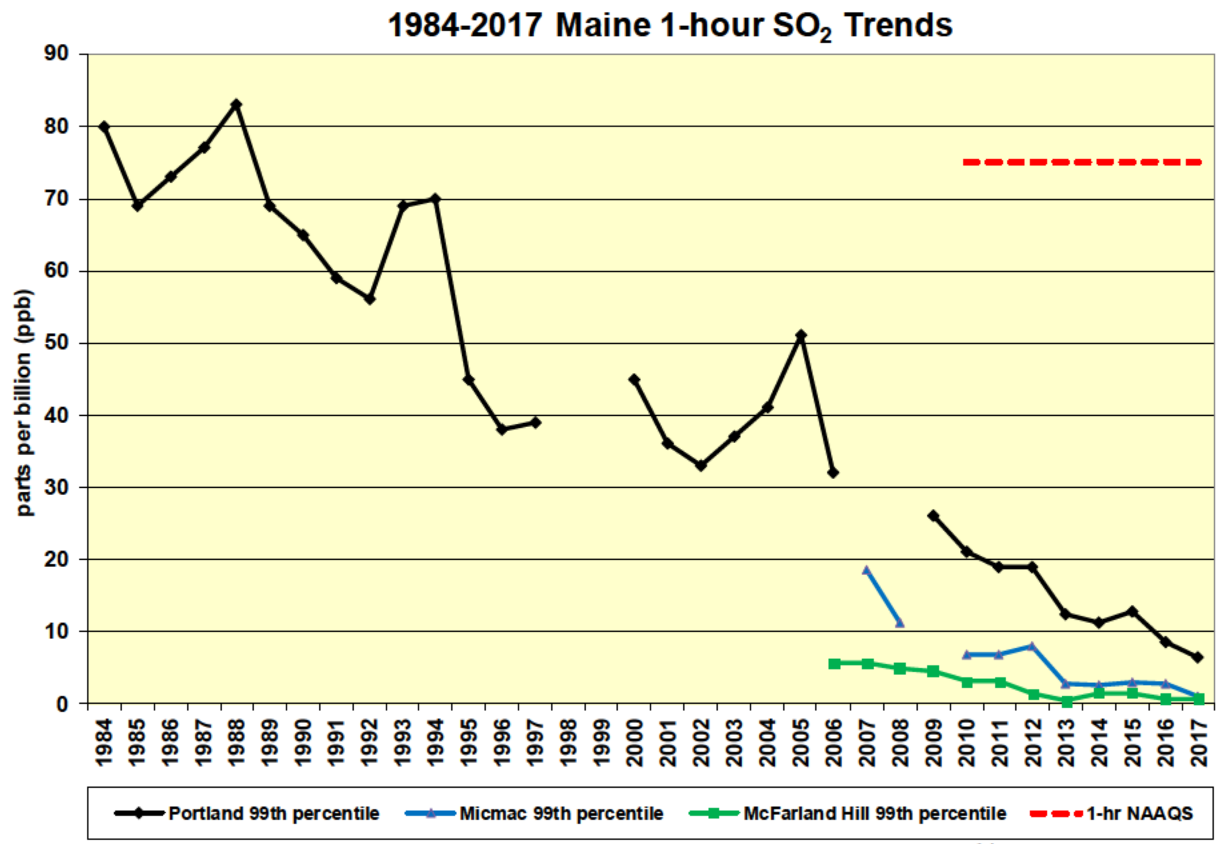

Figure 2.4. Ambient air concentrations of SO_2 in Maine.[14]

Particle Pollution

Particle pollution is the amount of particulate matter, such as dust, liquid droplets, smoke, or soot in the air.[15] Particles are defined by their size. Particulate matter 10 (PM_{10}) is 10 micrometers in diameter or smaller, and particulate matter 2.5 ($PM_{2.5}$) is 2.5 micrometers and smaller. Exposure to particle pollution can affect both the lungs and the heart. Examples of health concerns linked to particle pollution include asthma, respiratory symptoms, irregular heartbeat, and difficulty breathing. Children, older adults, and those suffering from heart or lung diseases are particularly susceptible to particulate pollution health effects.

Based on data from EPA's most recent triennial National Emissions Inventory (2014), mobile sources contribute 7% (5,590 tons/year) of the particulate matter (PM_{10}) emissions in Maine. Of the mobile source particulate matter emissions, commercial marine vessels (cargo ships entering and leaving Maine ports) contribute 2.7% (70 tons/year). By comparison, pleasure craft (recreational vessels) are responsible for 2.4% (63 tons/year). Figure 2.5 illustrates these particulate matter emission comparisons. For context, Figure 2.6 shows the trend in Maine's highest monitored levels of ambient air concentrations of PM_{10}, measured at the Portland monitoring site, remain below the National Ambient Air Quality Standard.

[14] See Maine DEP Five Year Assessment of Maine's Ambient Air Monitoring Network, https://www.maine.gov/dep/air/monitoring/index.html

[15] EPA. Particulate Matter (PM) Basics. https://www.epa.gov/pm-pollution/particulate-matter-pm-basics

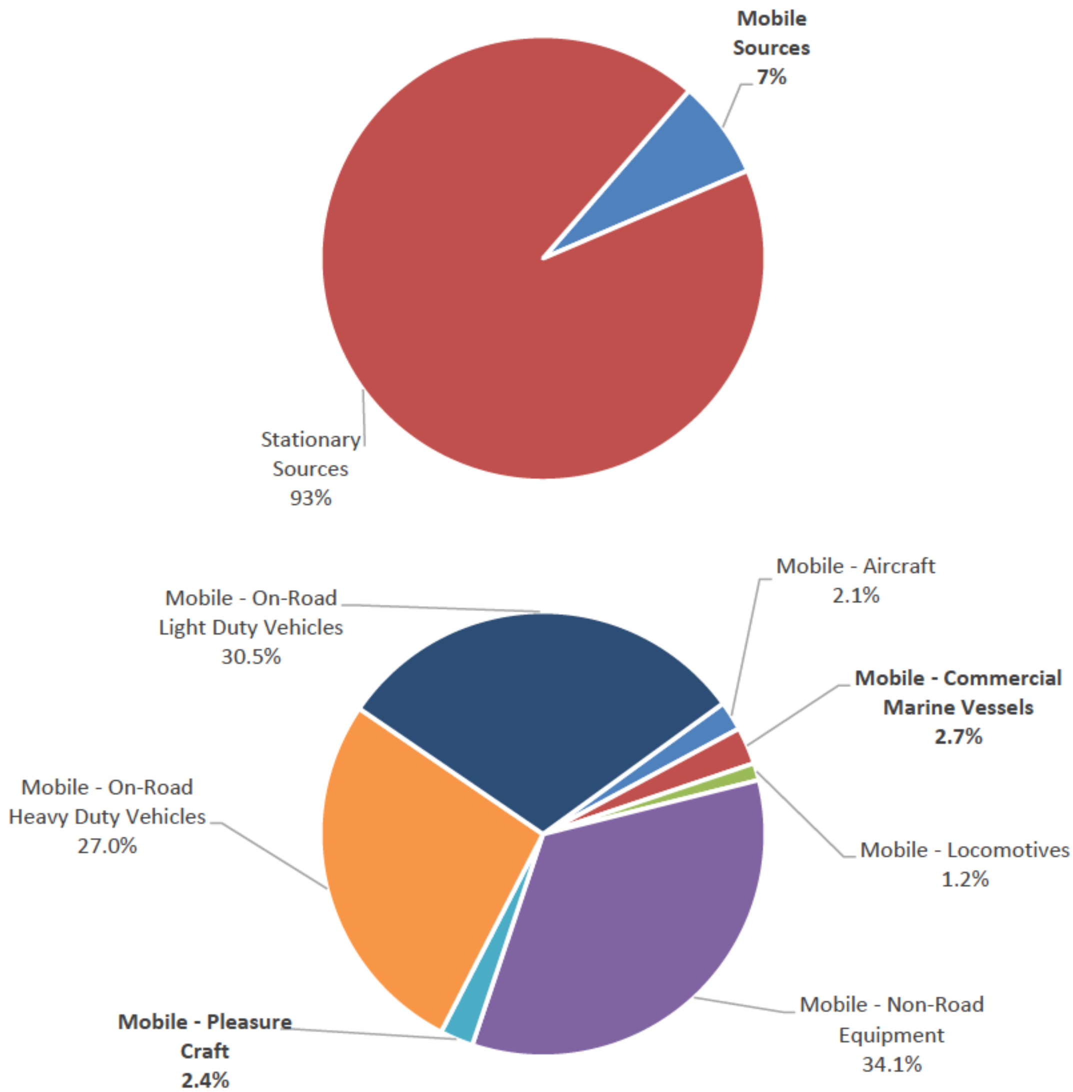

Figure 2.5. Particulate matter (PM_{10}) emissions in Maine (2014 NEI). The top figure represents the full emissions inventory, and the bottom figure breaks out the mobile sources category.

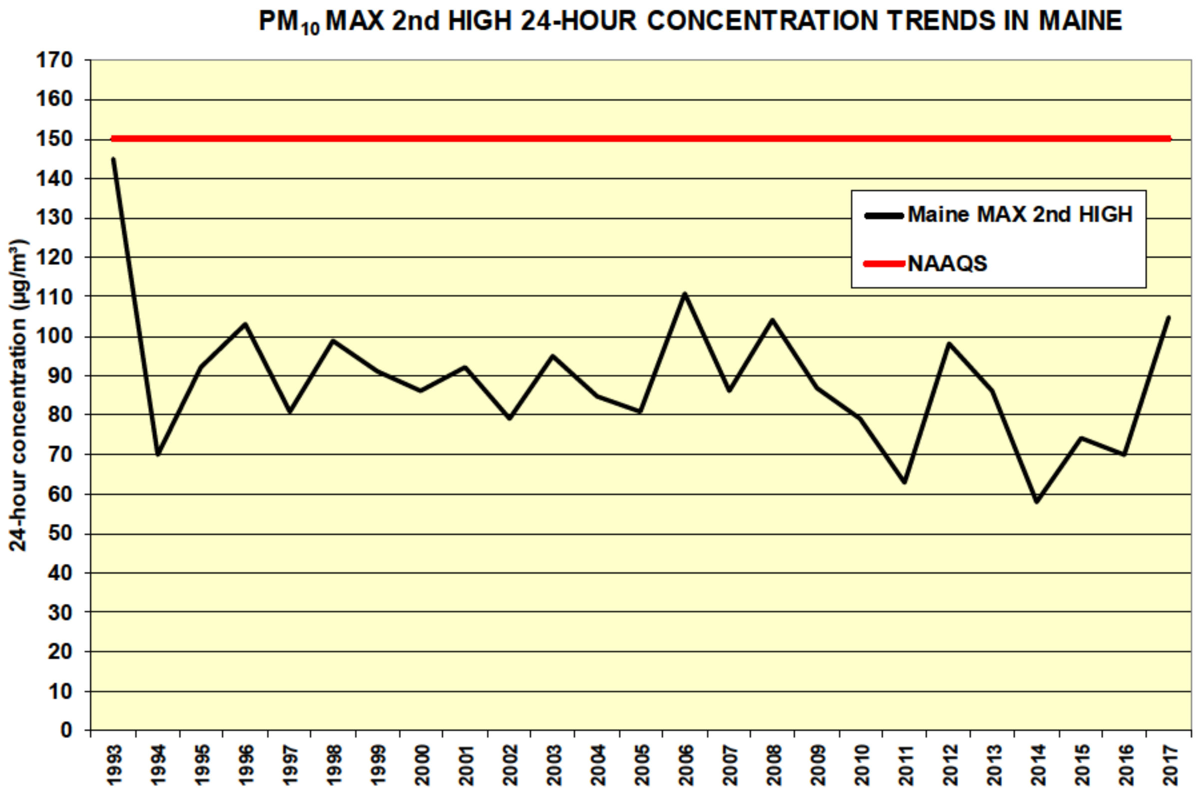

Figure 2.6. Ambient air concentrations of PM_{10} in Maine.[16]

Regional Haze

Particle pollution and SO_2 emissions also contribute to regional haze, or reduced visibility. This is particularly important in Class I areas in Maine (Acadia National Park near Bar Harbor, Moosehorn National Wildlife Refuge in Pembroke, and Roosevelt Campobello International Park near New Brunswick, Canada), where a blanket of haze can obscure the views that attract many tourists to the park. Much of the haze in the eastern U.S. is made up of sulfate particles and the high sulfur content of residual fuels may exacerbate this problem.

Nitrogen Oxides (NO_x)

Nitrogen oxides (NO_x) are a group of highly reactive gases that include nitrogen dioxide (NO_2), nitrous acid, and nitric acid.[17] NO_2 is often used as the indicator of the whole group of nitrogen oxides. The primary source of NO_2 in the atmosphere is the burning of fossil fuel. For example, NO_2 is included in emissions from cars, trucks, busses, power plants, and off-road equipment such as locomotives, and marine and freshwater vessels. NO_x is linked to respiratory diseases, such as asthma, and reacts with other compounds in the atmosphere to form both particulate matter and ozone.

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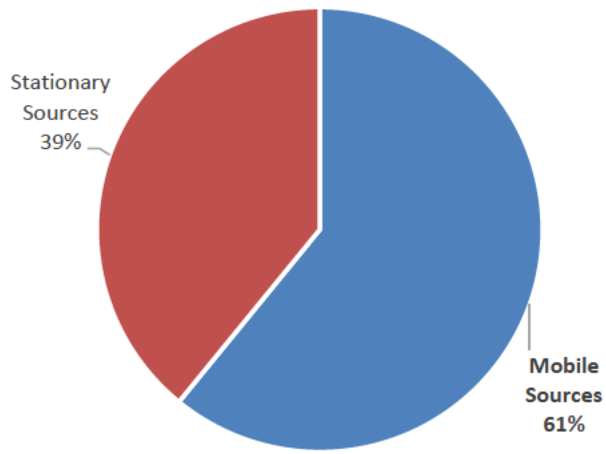
[16] See Maine DEP Five Year Assessment of Maine's Ambient Air Monitoring Network, https://www.maine.gov/dep/air/monitoring/index.html

[17] EPA. Basic Information about NO_2, https://www.epa.gov/no2-pollution/basic-information-about-no2

Based on data from EPA's most recent triennial National Emissions Inventory (2014), mobile sources contribute 61% (33,382 tons/year) of the nitrogen oxide (NO_x) emissions in Maine. Of the mobile source NO_x emissions, commercial marine vessels (cargo ships entering and leaving Maine ports) contribute 8% (2,681 tons/year). By comparison, pleasure craft (recreational vessels) are responsible for 4% (1,259 tons/year). Figure 2.7 illustrates these NO_x emission comparisons. For context, Figure 2.8 shows the trend in Maine's ambient air concentrations of NO_x remain below the National Ambient Air Quality Standard.



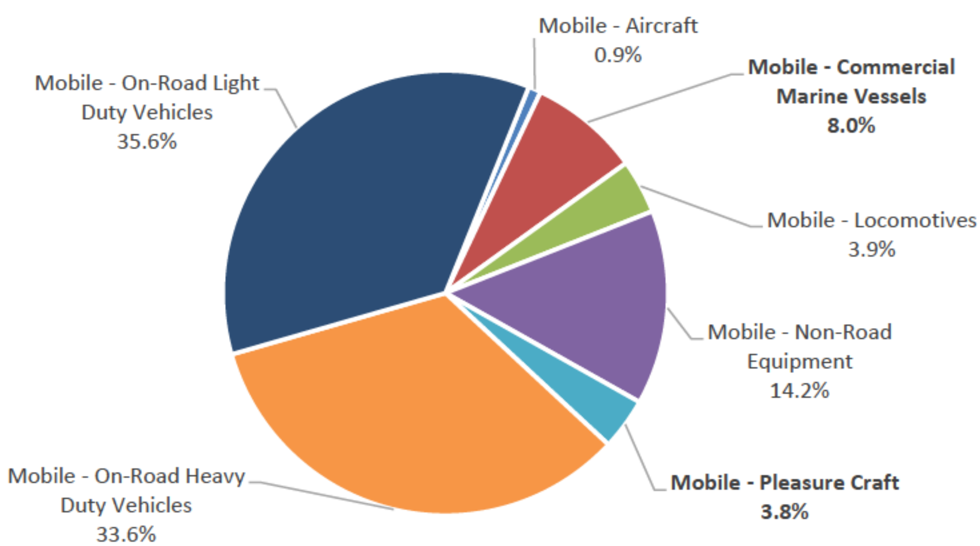


Figure 2.7. NOx emissions in Maine (2014 NEI). The top figure represents the full emissions inventory, and the bottom figure breaks out the mobile sources category.

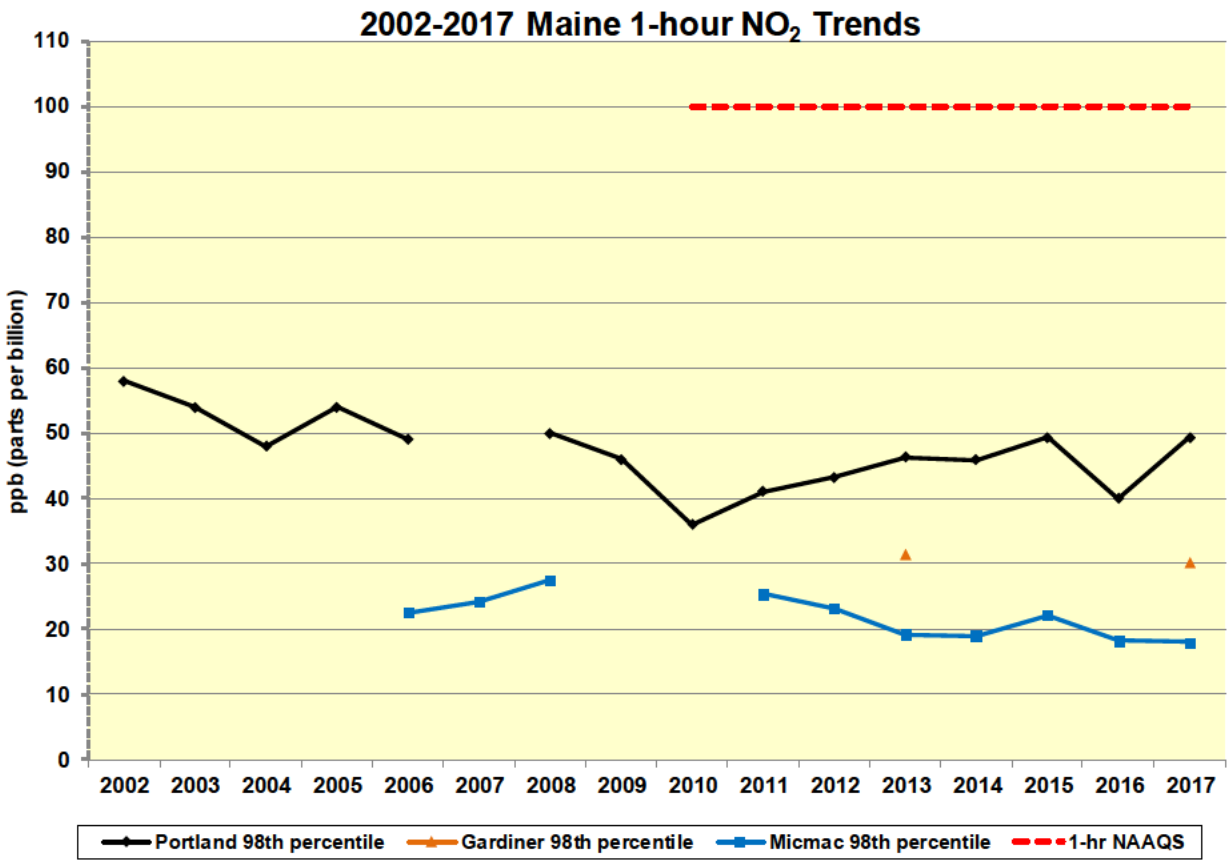


Figure 2.8. Ambient air concentrations of NO_2 in Maine.[18]

Volatile Organic Compounds (VOC)

Volatile organic compounds (VOC) are a group of compounds containing carbon that react with other atmospheric compounds in sunlight (i.e., photochemically reactive).[19] With the proper atmospheric conditions, VOCs react with NO_X to form ozone. VOCs are gasses emitted from certain solids or liquids, such as paints, fuels, and solvents, and include a long list of compounds varying in toxicity and reactivity. Health effects of VOCs include eye, nose, and throat irritation; headaches and nausea; liver, kidney, and central nervous system damage; and cancer.[20]

Based on data from EPA's most recent triennial National Emissions Inventory (2014), mobile sources contribute 7% (32,950 tons/year) of the volatile organic compound (VOC) emissions in Maine. Of the mobile source VOC emissions, commercial marine vessels (cargo ships entering and leaving Maine ports) contribute 0.1% (43 tons/year). By comparison, pleasure craft (recreational vessels) are responsible for 11% (3,474tons/year). Figure 2.9 illustrates these VOC emission comparisons.

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[18] See Maine DEP Five Year Assessment of Maine's Ambient Air Monitoring Network, https://www.maine.gov/dep/air/monitoring/index.html

[19] EPA. What is the definition of VOC? https://www.epa.gov/air-emissions-inventories/what-definition-voc

[20] EPA. Volatile Organic Compounds' Impact on Indoor Air Quality. https://www.epa.gov/indoor-air-quality-iaq/volatile-organic-compounds-impact-indoor-air-quality

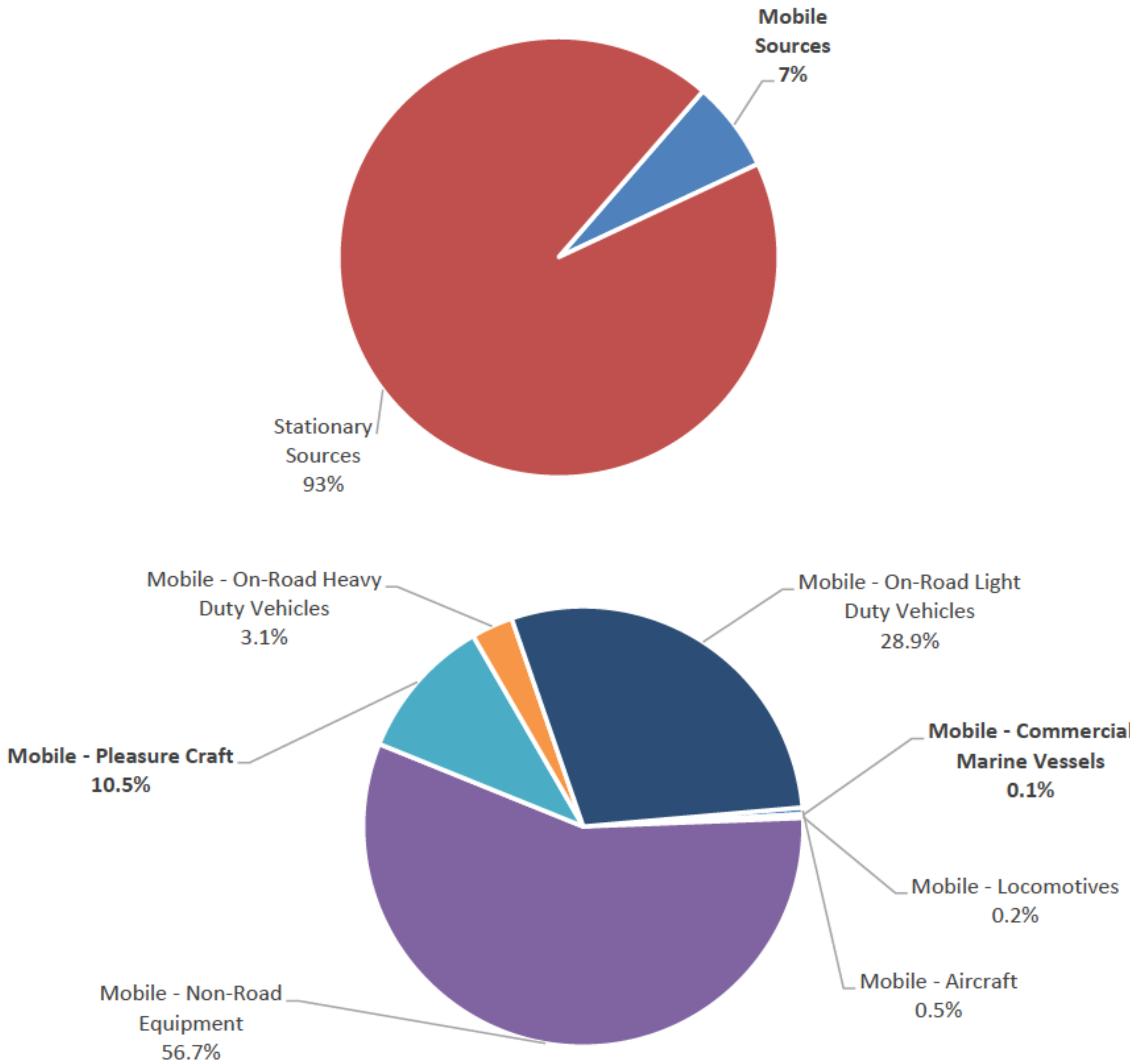


Figure 2.9. Volatile organic compounds (VOCs) emissions in Maine (2014 NEI). The top figure represents the full emissions inventory, and the bottom figure breaks out the mobile sources category. Stationary sources include biogenics.

Ozone

While contributions to ozone from commercial marine vessels and other sources are not directly measured, the precursors of ozone, nitrogen oxides and volatile organic compounds, are included in the above data. Nitrogen oxides combine with volatile organic compounds in the presence of sunlight to form ozone air pollution. Breathing elevated levels of ozone can make it more difficult to breathe, especially deeply and vigorously. It can cause shortness of breath, inflame and damage the respiratory system, increase the risk of infection in the lungs, and lead to chronic obstructive pulmonary disease (COPD).[21] These are risks even for healthy people, but can be more dangerous for people with respiratory diseases like asthma.

Maine has been classified as attainment/unclassifiable for ozone since 2006. Figure 2.10 shows the trend in Maine's ambient air concentrations of ozone.

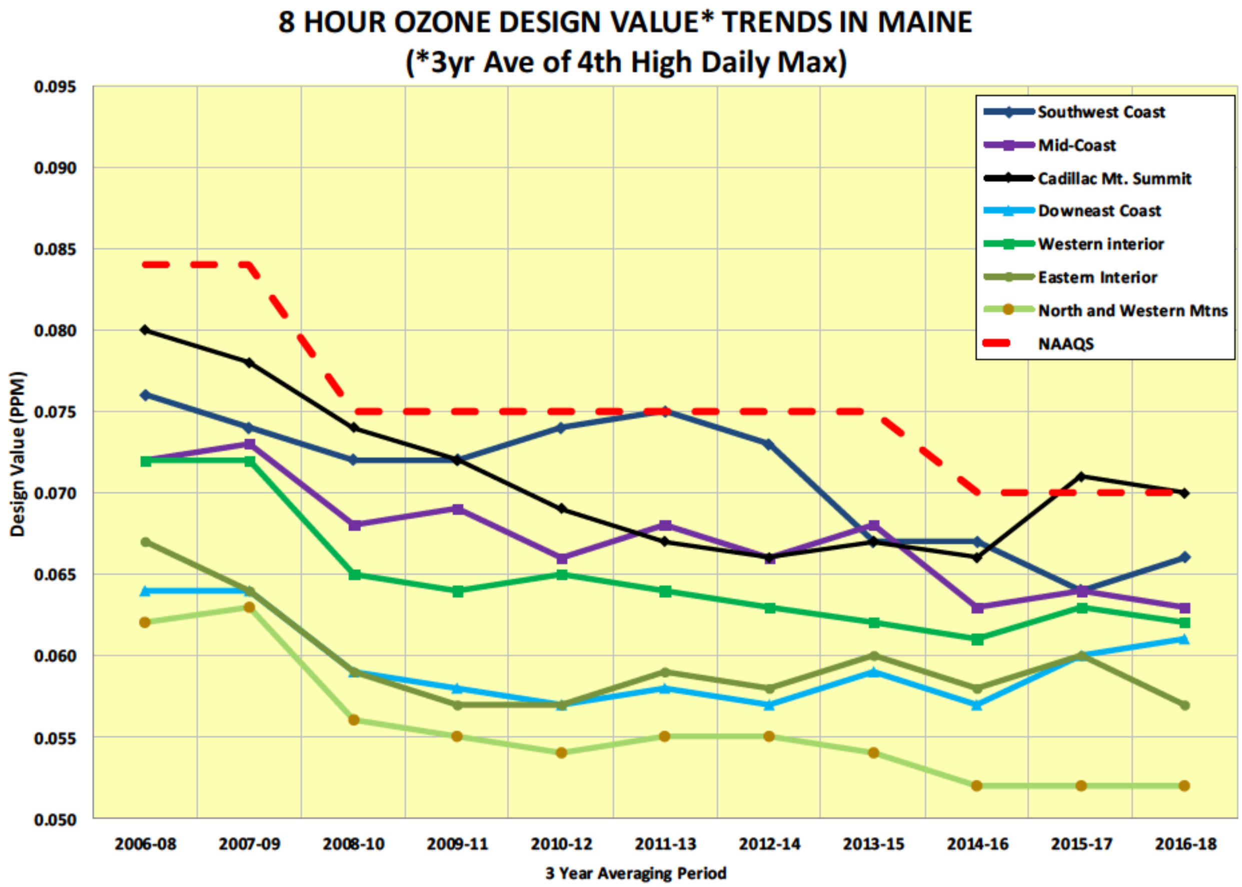


Figure 2.10. Ambient air concentrations of ozone in Maine.[22]

Carbon Monoxide (CO)

Carbon monoxide (CO) is an odorless gas produced by combustion. The primary sources of CO to the atmosphere are cars, trucks, and other equipment that burns fossil fuels.[23] Health effects of CO include reduced oxygen in the blood stream, thus reduced oxygen reaching the heart and brain, which causes dizziness, confusion, unconsciousness, and death. Those with heart disease are particularly susceptible to even short-term elevated CO levels because their hearts need more oxygen than usual.

[21] U.S. EPA. Health Effects of Ozone Pollution, https://www.epa.gov/ground-level-ozone-pollution/health-effects-ozone-pollution

[22] See Maine DEP Five Year Assessment of Maine's Ambient Air Monitoring Network, https://www.maine.gov/dep/air/monitoring/index.html

[23] EPA. Basic Information about Carbon Monoxide (CO) Outdoor Air Pollution, https://www.epa.gov/co-pollution/basic-information-about-carbon-monoxide-co-outdoor-air-pollution

Based on data from EPA's most recent triennial National Emissions Inventory (2014), mobile sources contribute 56% (208,334 tons/year) of the carbon monoxide (CO) emissions in Maine. Of the mobile source CO emissions, commercial marine vessels (cargo ships entering and leaving Maine ports) contribute 0.2% (458 tons/year). By comparison, pleasure craft (recreational vessels) are responsible for 7% (13,536 tons/year). Figure 2.11 illustrates these CO emission comparisons.

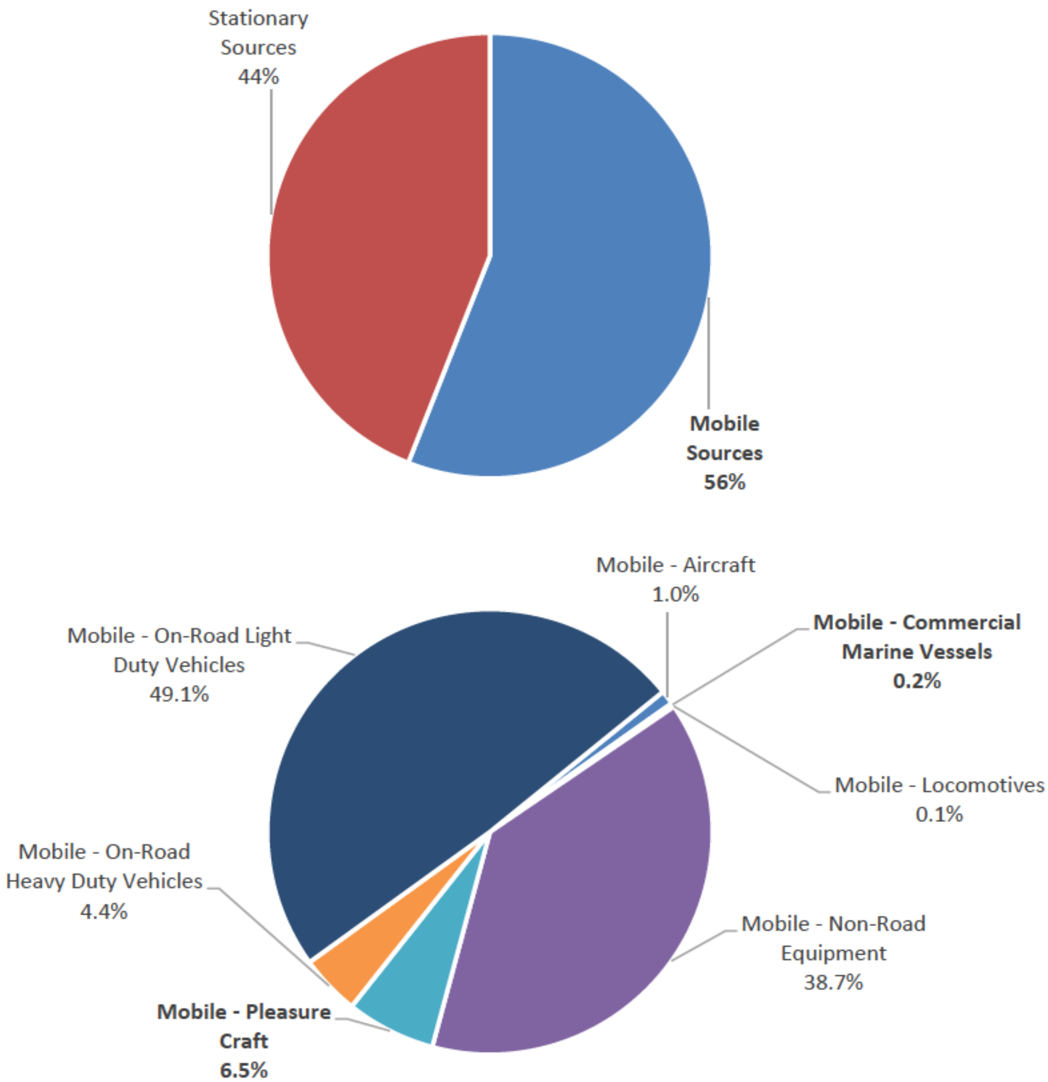


Figure 2.11. Carbon monoxide (CO) emissions in Maine (2014 NEI). The top figure represents the full emissions inventory, and the bottom figure breaks out the mobile sources category.

Emissions Inventory Summary

Apart from SO_2, emissions from commercial marine vessels appear minor in comparison to other source categories; however, the Department cannot conclude, based on this inventory data, that marine vessels contribute insignificant levels of air emissions in Maine. The emissions inventory method used by US EPA may not be accurate or robust enough to capture a complete picture of marine vessel emissions. The commercial marine inventory only considers cargo ships entering and leaving Maine ports. At this point, Maine DEP's inventory resources do not allow for a more detailed marine vessel emissions inventory, one that would also include the fishing fleet, ferries, cruise ships and tug boats, compare operation in different modes (hotelling, cruising, etc.), and assess land-side port emissions such as cargo-handling equipment, trucks, and locomotives.

In addition, a single engine on a cruise or cargo ship is large enough that, if it were based on land, would be considered a major source and require mandatory emission controls. Even marine engines built to today's standards could potentially emit as much pollution (on an annual basis) as Maine's largest utility. This combined with the potential growth in cargo and cruise ship traffic and the need to address regional haze prevents the Department from disregarding marine vessels as a potentially important air emissions source.

Section 3. Legal Authority and Requirements

3.1 International Agreement

International Maritime Organization

Air emissions from commercial marine vessels are regulated at both the national and international level. The International Maritime Organization (IMO) is an agency of the United Nations which promotes maritime safety, efficiency of navigation and prevention and control of marine air and water pollution from ships. IMO became active in 1958 and currently has 174 Member States.[24] As a direct result of the Torrey Canyon oil spill disaster, which spilled more than 25 million gallons of crude oil off the coast of the United Kingdom in 1967, the IMO convened to prepare an international agreement establishing restrictions on the contamination of the sea, land and air by ships. The resulting global standards are embodied in the International Convention on the Prevention of Pollution from Ships, known as MARPOL, a combination of two treaties adopted in 1973 and 1978.[25]

In 1997 MARPOL Annex VI was adopted to include "Prevention of Air Pollution from Ships" (a.k.a., 1997 Protocol and Tier 1). MARPOL Annex VI set limits on NO_x and SO_2 emissions from ship exhaust and prohibited deliberate emissions of ozone depleting substances from ships of 400 gross tonnage and above, shipping to ports or offshore terminals under the jurisdiction of Member States that have ratified Annex VI.

To enter into force, Annex VI required ratification by 15 nations representing more than 50% of the world shipping tonnage. The fifteenth nation ratified Annex VI on May 18, 2004 and it entered into force on May 19, 2005.

MARPOL Annex VI was amended in 2008, most importantly to set more stringent fuel sulfur content limits and more stringent NO_x emission standards, especially for vessel operation in designated Emission Control Areas (ECAs). By October 2008, Annex VI was ratified by 53 countries (including the United States), representing 81.88% of tonnage. The revised Annex VI became effective on July 1, 2010.

United States adoption of IMO: MARPOL Annex VI regulations became effective in the United States (U.S.) in January 2009 for all U.S. flagged vessels over 400 gross tons and for all non-U.S. flagged ships operating in U.S. waters.[26] U.S. flagged vessels are also subject to requirements of the U.S. Clean Air Act and its implementing regulations. U.S. flagged vessels operating only domestically and in compliance with U.S. Environmental Protection Agency

[24] IMO Member States, IGOs and NGOs, http://www.imo.org/en/About/Membership/Pages/Default.aspx
[25] IMO International Convention for the Pollution from Ships (MARPOL), http://www.imo.org/en/About/Conventions/ListOfConventions/Pages/International-Convention-for-the-Prevention-of-Pollution-from-Ships-(MARPOL).aspx
[26] EPA MARPOL VI Air Pollution Prevention Requirements, https://www.epa.gov/sites/production/files/documents/jointletter062711.pdf

(U.S. EPA) exhaust emission standards are excluded by regulation from Annex VI NOx engine standards.

Specifically, Annex VI adopted in 2008:

(1) Tier[27] I (the first set of standards) NO_x requirements for existing pre-2000 engines,
(2) Tier II and III NO_x emission standards for new engines, and
(3) more stringent fuel quality requirements beginning July 2010.[28]

The MARPOL Annex VI regulations address the following air pollutants:

Nitrogen oxides (NO_x)

The NO_x emission limits of Regulation 13 of MARPOL Annex VI apply to each marine diesel engine with a power output of more than 130 kW installed on a ship that was either constructed after January 1, 2000 or that has undergone a major conversion on or after January 1, 2000. A marine diesel engine is defined as any reciprocating internal combustion engine operating on liquid or dual fuel. There are two exceptions: engines used solely for emergencies and engines on a ship operating solely within the waters of the country in which they are flagged. The latter exception only applies if these engines are subject to an alternative NO_x control measure. In the U.S. those engines are subject to U.S. EPA marine engine standards.

Pre-2000 Engines: Under the 2008 Annex VI amendments, Tier I standards become applicable to existing engines installed on ships built between January 1990 to December 1999, with a displacement ≥ 90 liters per cylinder and rated output ≥ 5000 kW, subject to availability of an approved engine upgrade kit.

NO_x emission limits are set for diesel engines depending on the engine maximum operating speed as shown in Table 3.1 and presented graphically in Figure 3.1. Tier I and Tier II limits are global, while the Tier III standards apply only in NO_x Emission Control Areas.[29]

Table 3.1. MARPOL NO_X Limits

Tier	Date	NOx Limit g/kwh		
		Engine speed<130 rpm	130 rpm<engine speed<2000 rpm	Engine speed >2000 rpm
Tier I	2000	17.0	$45 \times n^{-0.2}$	9.8
Tier II	2011	14.4	$44 \times n^{-0.23}$	7.7
Tier III	2016*	3.4	$9 \times n^{-0.2}$	1.96

*In NOx Emission Control Areas (Tier II standards apply outside ECAs)[23]

[27] "Tier" designations indicate the federal emission standards that apply to an engine based on the size of the engine and the date it was manufactured.
[28] IMO Prevention of Air Pollution from Ships, http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Pages/Air-Pollution.aspx
[29] Dieselnet IMO Marine Engine Regulations, https://www.dieselnet.com/standards/inter/imo.php#intro

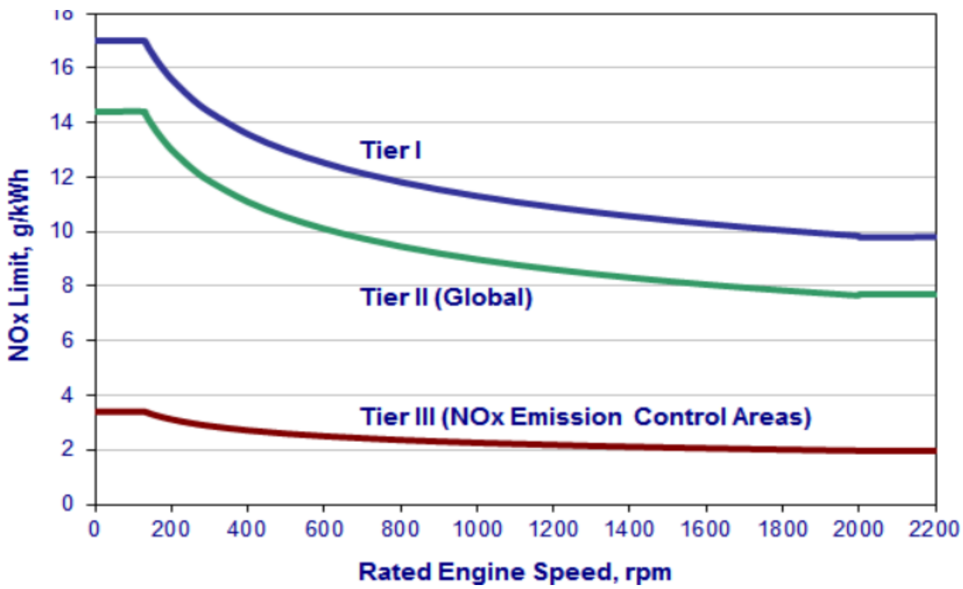


Figure 3.1. MARPOL Annex VI NOx Emissions Limits

Engine speed for an internal combustion engine refers to the rate, in revolutions, that an engine operates over the period of one minute (expressed as RPM). "Rated" engine speed is the maximum speed expressed in RPMs at which an engine has been tested to produce the maximum power output that can be achieved from that engine. Lower "rated engines speeds" are indicative of larger engines for applications in vessel propulsion or large-scale power generation. Higher "rated engine speeds" are indicative of smaller engines for applications in powering small vessels or motor vehicles. Engine efficiency (sometimes called fuel efficiency or thermal efficiency of an engine) refers to the ratio of energy input to useful power output and is expressed as a percentage. Engine efficiency changes for different engine speeds are due to changing resistances from friction and backpressures associated with the different engine speeds and fuel consumptions at which an engine may operate. Engine efficiency may also change depending on engine speed. Typically, internal combustion engines operating at slower engine speeds will consume less fuel (have a higher fuel economy) to travel a certain distance than the same engine operating at a higher speed.

Tier II standards are expected to be met by combustion process optimization. The parameters examined by engine manufacturers include fuel injection timing, pressure, and rate (rate shaping), fuel nozzle flow area, exhaust valve timing, and cylinder compression volume.
Tier III standards are expected to require dedicated NO_x emission control technologies such as various forms of water induction into the combustion process (with fuel, scavenging air, or in-cylinder), exhaust gas recirculation, or selective catalytic reduction.[30]

Sulfur oxides (SO_x)
Recognizing that global marine shipping is the largest source of global anthropogenic sulfur emissions and is the primary source of black carbon in the arctic; the IMO enacted regulations to lower the fuel sulfur content from 3.5 wt.% to 0.5 wt.% in 2020. These regulations require ship

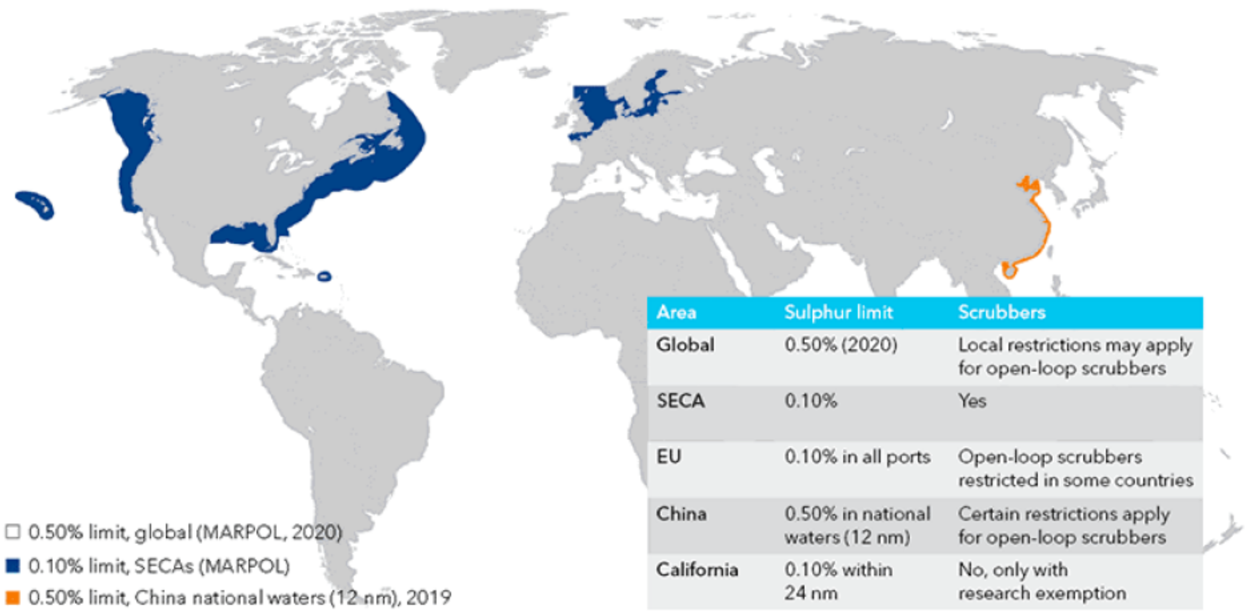
[30] Dieselnet IMO Maine Emissions Regulations, https://www.dieselnet.com/standards/inter/imo.php

operators either to use higher-cost, low-sulfur heavy fuel oil (HFO) or to seek other alternatives for reducing sulfur emissions (i.e., scrubbers, natural gas, distillates, and/or biofuels).[31] Annex VI regulations include caps on sulfur content of fuel oil as a measure to control SO_2 emissions and indirectly, PM emissions (there are no explicit PM emission limits). The main type of "bunker" oil for ships is HFO, derived as a residue from crude oil distillation. Crude oil contains sulfur which, following combustion in the engine emits SO_2 in the ship's exhaust.

Limiting sulfur oxides (SO_x) emissions from ships will improve air quality and the environment. IMO regulations designed to reduce SO_x emissions from ships first became effective in 2005, under MARPOL Annex VI regulations. Since then, the limits on sulfur oxides have been progressively tightened as shown in Table 3.2 and Figure 3.2

Table 3.2. Global Sulfur Standards

Year	Global sulfur standard
2000-2012	45,000 ppm (4.5%)
2012	35,000 ppm (3.5%)
2020	5,000 ppm (.5%)



Area	Sulphur limit	Scrubbers
Global	0.50% (2020)	Local restrictions may apply for open-loop scrubbers
SECA	0.10%	Yes
EU	0.10% in all ports	Open-loop scrubbers restricted in some countries
China	0.50% in national waters (12 nm)	Certain restrictions apply for open-loop scrubbers
California	0.10% within 24 nm	No, only with research exemption

Figure 3.2: Global Sulfur Standards[32]

In January 2020, the limit for sulfur in fuel oil used on board ships operating outside designated emission control areas will be reduced to 0.50%, by weight. As of March 1, 2020, ships will be

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[31] ORNL Understanding the Opportunities for Biofuels for Marine Shipping Biofuel, https://info.ornl.gov/sites/publications/Files/Pub120597.pdf

[32] DNV-GL Sulphur Limit in ECAs, https://www.dnvgl.com/news/sulphur-limit-in-ecas-increased-risk-of-psc-deficiencies-and-detentions-142911

permitted to have as cargo high-sulfur HFO, but not in the fuel tanks unless scrubbers are being used. This is intended to allow ports to detain ships without scrubbers carrying non-compliant fuels. This will significantly reduce the amount of SO_x emitted from ships and should provide health and environmental benefits throughout the world, particularly for populations living close to ports and coasts.[33]

Greenhouse Gas Emissions

In 2011, amendments to MARPOL Annex VI introduced mandatory measures to reduce emissions of greenhouse gases (GHG). MARPOL Annex VI, Chapter 4 introduces two mandatory mechanisms intended to ensure an energy efficiency standard for ships: (1) the Energy Efficiency Design Index (EEDI), for new ships, and (2) the Ship Energy Efficiency Management Plan (SEEMP) for all ships.

- The EEDI is a performance-based mechanism that requires a certain minimum energy efficiency in new ships. Ship designers and builders are free to choose the technologies to satisfy the EEDI requirements in a specific ship design.
- The SEEMP establishes a mechanism for operators to improve the energy efficiency of ships.

The regulation requires most new ships to be 10% more efficient beginning in 2015, 20% more efficient by 2020, and 30% more efficient by 2025. The regulations apply to all ships of 400 gross tonnage and above operating in international waters and became effective in January 2013. Flexibilities exist in the initial period of up to six and a half years after the effective date, when the IMO may waive the requirement to comply with the EEDI for certain new ships, such as those that are already under construction.

In April 2018, the IMO adopted an Initial Strategy on the reduction of GHG emissions from ships. The strategy calls for strengthening the EEDI requirements and several other measures to reduce emissions, such as operational efficiency measures, further speed reductions, measures to address methane and VOC emissions, alternative low-carbon and zero carbon fuels, as well as market-based measures.[34] IMO agreed in April 2018 to cut carbon emissions from ships by at least 50% by 2050 compared with 2008 levels.

In addition, IMO adopted other programs to reduce emissions from international shipping:

Ozone-depleting Substances

Annex VI prohibits deliberate emissions of ozone depleting substances, which include halons and chlorofluorocarbons (CFCs). New installations containing ozone-depleting substances are prohibited on all ships. But new installations containing hydro-chlorofluorocarbons (HCFCs) are permitted until January 1, 2020.

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[33] IMO Sulphur 2020, http://www.imo.org/en/MediaCentre/HotTopics/Pages/Sulphur-2020.aspx

[34] IMO UN Agency pushes forward on shipping emissions reduction, http://www.imo.org/en/MediaCentre/PressBriefings/Pages/11-MEPC-74-GHG.aspx

Shipboard Incineration

Annex VI requires that shipboard incineration occur only in an onboard incinerator. Incinerators installed on board a ship on or after January 1, 2000 must meet requirements laid out in the regulation, and incineration of certain materials such as garbage and polychlorinated biphenyls (PCBs) are prohibited or limited to certain conditions.

Emission Control Areas

Two sets of emission and fuel quality requirements are defined by Annex VI: (1) global requirements, and (2) more stringent requirements applicable to ships when operating in Emission Control Areas (ECA). An Emission Control Area can be designated for SO_x and PM, SOx or NO_x, or all three types of emissions from ships.

On March 26, 2010, the IMO amended MARPOL designating specific portions of U.S. and Canadian waters as an ECA. The U.S. and Canada proposed the designation for ECA reflecting similar interests, shared geography and interrelated economies. The North American Emission Control Area includes most coastal waters up to 200 nautical miles from the coasts of the continental United States and large portions of coastal waters around Alaska and Hawaii. In addition, the North American ECA includes significant portions of the Canadian coasts and the French Islands of Saint Pierre and Miquelon off Newfoundland.

Existing Emission Control Areas include:

- Baltic Sea (SO_x: adopted 1997/in effect 2006; NO_x: 2017/2021)
- North Sea (SO_x: adopted 2005/in effect 2007; NO_x: 2017/2021)
- North American ECA, including most of U.S. and Canadian coast (PM & SO_x: adopted 2010/ in effect 2012). NO_x adopted 2010/in effect 2016
- US Caribbean ECA, including Puerto Rico and the U.S. Virgin Islands (PM & SO_x: adopted 2011/ in effect 2014). NO_x adopted 2011/ in effect 2016 [35]

[35] Dieselnet IMO Marine Engine Regulations, https://www.dieselnet.com/standards/inter/imo.php

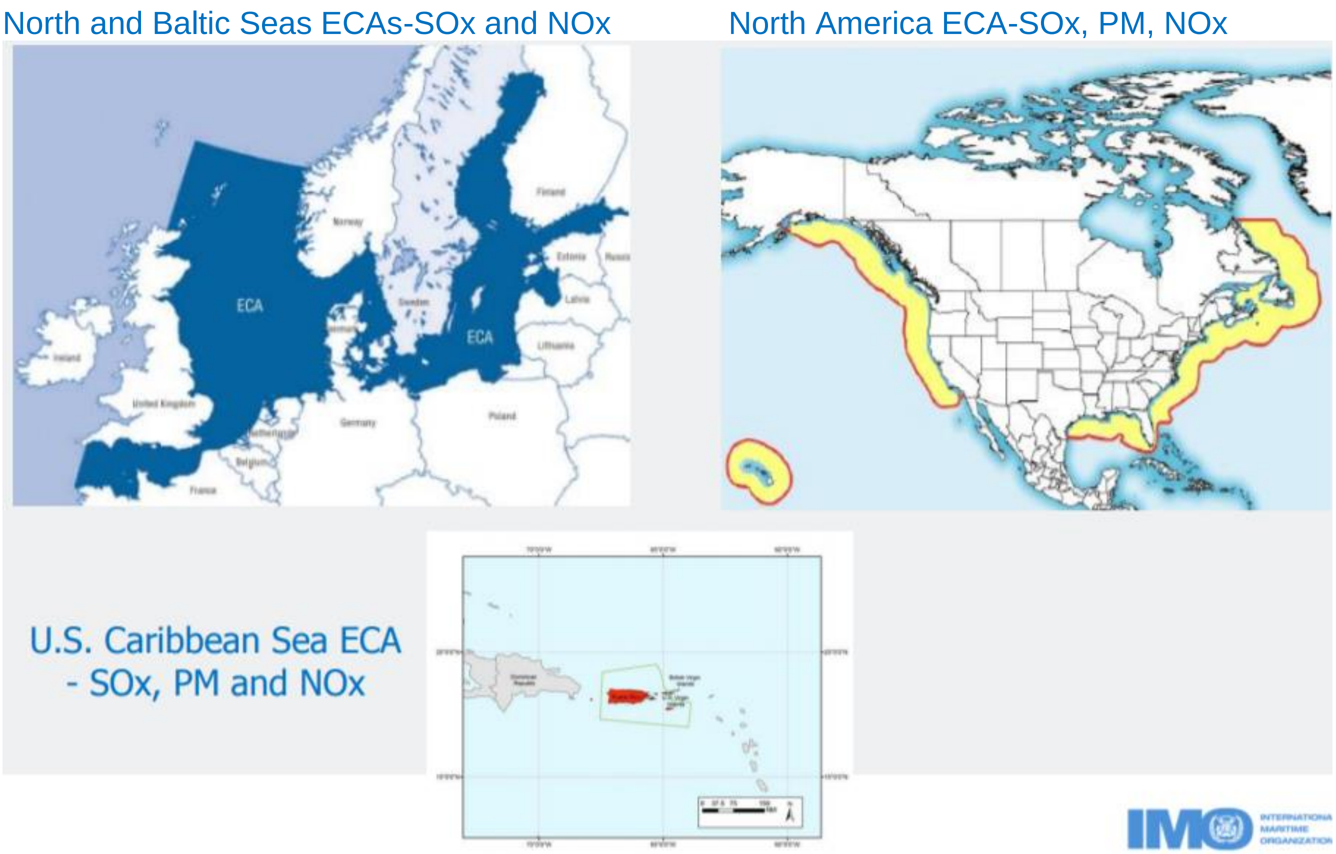

Figure 3.3. IMO Designated Emission Control Areas (ECAs)

Ships are significant contributors to the U.S. and Canadian mobile-source emission inventories, though most are flagged or registered elsewhere. Ships complying with ECA standards will reduce their emissions of NO_x, SO_x, and fine particulate matter ($PM_{2.5}$). Table 3.3 compares the fuel sulfur requirements globally with the more stringent fuel requirements with the ECAs.

In 2020, according to EPA, emissions from these ships operating in the North American ECA are expected to be reduced annually by 320,000 tons for NO_x, 90,000 tons for $PM_{2.5}$, and 920,000 tons for SO_x, which is 23 percent, 74 percent, and 86 percent, respectively, below predicted levels in 2020 absent the ECA.[36]

[36] EPA's Designation of North American Emission Control to Reduce Emissions from Ships Fact sheet, March 2010

Table 3.3. Emission Control Areas Emission Standards

	Year	Fuel Sulfur	Percent Sulfur	NOx
Emission Control Area Standards	2000 to July 2010	15,000 ppm	1.5%	Globally Tier I
	2010	10,000 ppm	1.0%	Globally Tier II in 2011
	2015	1,000 ppm	.1%	
	2016	1,000 ppm	.1%	Tier III (after-treatment forcing)

The most stringent ECA fuel standard is primarily met through fuel switching. In most cases, ships already have the capability to store two or more fuels. However, to meet the 1,000 ppm fuel sulfur requirement, some vessels may need to be modified for additional distillate fuel storage capacity. The near-term options for shipowners to comply with the IMO sulfur regulations include fueling with costlier low-sulfur distillate fuels, such as marine diesel oil (MDO) and low-sulfur distillate marine gas oil (MGO) when operating in ECAs. However, few refineries are equipped to produce low-sulfur HFO. Likewise, the current production rates of distillates do not allow the necessary expansion required to fuel the world fleet of shipping vessels, which consume around 87 billion gallons annually. This quantity is more than is used for aircraft and is more than double the diesel fuel used in the United States by medium- and heavy-duty freight vehicles.[37] The other near-term option is to install emission control systems, which also requires a significant investment. As an alternative to using lower sulfur fuel, ship operators may choose to equip their vessels with exhaust gas cleaning devices known as scrubbers which removes sulfur compounds from the exhaust.

Scrubber technology combines the removal of sulfur with the reduction of particulate matter and black carbon to allow ships to operate within the Emission Control Area while meeting the 2015 requirements; however, California prohibits the use of scrubbers within 24 nautical miles of the California coast except as a temporary research exemption.

Enforcement

The international standards apply to both U.S. vessels and to foreign vessels operating in international waters. Engines installed on vessels flagged or registered in the U.S. are subject to fuel standards and engine emission standards that U.S. EPA has adopted under the Clean Air Act.

The above requirements are enforced through the survey/inspection of ships subject to Annex VI. After a ship is surveyed, it will be issued an International Air Pollution Prevention Certificate and is subject to subsequent surveys and inspections. The U. S. Coast Guard is responsible for ensuring U. S. owned and registered ships comply with MARPOL in U.S. waters and overseas. U.S. EPA and the U.S. Coast Guard are taking measures to promote compliance with the

[37] ORNL Understanding the Opportunities for Biofuels for Marine Shipping Biofuel, https://info.ornl.gov/sites/publications/Files/Pub120597.pdf

regulations including investigating potential violations and pursuing enforcement actions and related penalties for any violations.

3.2 Federal Regulations

States are limited in the actions they may take in regulating air emissions from marine vessels. Section 209 of the Clean Air Act Amendments of 1990 prohibits states from adopting or enforcing any standard relating to the control of emissions from nonroad engines or nonroad vehicles, which include marine engines. Section 209 provides one exception to this prohibition, in that States can adopt and enforce such standards if they are identical to standards adopted by the State of California. California has not adopted its own emission standards for marine engines, so Maine cannot take advantage of this exception at this time. However, Maine and other states have implemented voluntary pollution reduction programs to limit marine vessel emissions. Some of these programs are detailed in Section 5 of this report.

Section 213 of the Clean Air Act Amendments of 1990 requires the U.S. EPA to promulgate and revise regulations that set standards for emissions from nonroad engines and vehicles (including marine vessels) if these engines and vehicles are found to cause or contribute to air pollution.

Emission Standards for Category 1 and 2 Marine Engines

The definitions for the different categories of marine diesel engines are contained in the Code of Federal Regulations, Title 40, Part 94.2 (40 CFR Part 94.2). Category 1 marine diesel engines, those having a rated power greater than or equal to 37 kilowatts and a per-cylinder displacement less than 5 liters, are similar to land-based nonroad engines used in construction and farm equipment.

Category 2 marine diesel engines, those with per-cylinder displacement at or above 5 liters but less than 30 liters, are most often similar to locomotive engines. Category 1 and Category 2 marine diesel engines are used as propulsion engines (i.e., an engine that moves a vessel through the water or directs the movement of a vessel (40 CFR Part 94.2)) on tugboats, fishing vessels, supply vessels, and smaller cargo vessels. They are also used as auxiliary engines (i.e., a marine engine that is not a propulsion engine (40 CFR Part 94.2)) to provide electricity for navigation equipment and crew service or other services such as pumping, powering winches, or handling anchors.

Category 3 marine diesel engines, which are the primary focus of this report, are defined as having per-cylinder displacement at or above 30 liters. These are very large engines used for propulsion on large vessels such as container ships, tankers, bulk carriers, and cruise ships. Most of these engines are installed on ocean-going vessels, though a few are found on ships in the Great Lakes. Category 3 marine diesel engines have no land-based mobile source counterpart, though they are similar to engines used to generate electricity in certain power-plant applications. In marine applications they are either mechanical drive or indirect drive. Mechanical drive engines can be direct drive (engine speed is the same as propeller speed; this is common on very large ships) or have a gearbox (i.e., they have reduction gears; this is common on ships using medium-speed Category 3 marine diesel engines). Indirect drive engines are used to generate electricity that is then used to turn the propeller shaft. These are common in cruise ships, since they have heavy electricity demands. Category 3 marine diesel engines typically operate at a lower speed and higher power than Category 1 and Category 2 engines, with the slowest speed being about 60 rpm.[38]

1999 Marine Engine Rule

On November 23, 1999, the U.S. EPA signed the rule "Control of Emissions of Air Pollution from New Compression-Ignition Marine Engines at or above 37 kW" *(64 FR 73300, Dec 29, 1999, 40 CFR Parts 89, 92).* U.S. EPA adopted a voluntary emission control program for the first set of standards (Tier 1) for marine diesel engines at or above 37 kW equivalent to the internationally negotiated NO_X limits for marine diesel engines with per cylinder displacement of 2.5 to 30 liters. In this rule U.S. EPA did not adopt the MARPOL Annex VI NO_X emission limits under U.S. law but encouraged engine manufacturers to make Annex VI compliant engines available and ship owners to purchase and install them on all vessels constructed on or after January 1, 2000.

In 2003 (68 FR 9746, February 28, 2003; 40 CFR Part 94), U.S. EPA made the Tier 1 standards mandatory and enforceable for new engines on U.S. vessels. The Tier 1 standards began to apply in 2004 through 2006. Beginning in 2007, the Tier II standards finalized in 1999 *(64 FR 73300, Dec 29, 1999, 40 CFR Parts 89, 92)* went into effect. The adopted Tier II standards for Category 1 and 2 engines are based on the land-based standards for nonroad engines. This regulation applies to emissions of nitrogen oxides plus total hydrocarbons (NO_x + THC), particulate matter (PM), and carbon monoxide (CO) with varying standards and effective dates (ranging from engines built in 2004 through those built in 2007) depending on engine category and size.

This rule does not apply to Category 1, 2, and 3 marine diesel engines that are not imported into the United States and installed on foreign vessels that enter U.S. ports.

The 2008 Locomotive and Marine Rule

On June 30, 2008 the Locomotive and Marine Rule introduced Tier III and Tier IV emission standards for marine diesel engines *(73 FR 37196, June 30, 2008; 40 CFR Part 94)* which apply to both newly manufactured and remanufactured marine diesel engines to include:

- Newly-built engines: Tier III standards apply to engines (mostly after 2009) used in commercial, recreational, and auxiliary power applications (including those below 37 kW that were previously covered by nonroad engine standards). The Tier IV emission standards are modeled after the 2007/2010 highway engine program and the Tier IV nonroad rule, with an emphasis on the use of emission after-treatment technology. Tier IV standards, based on after-treatment, apply to engines above 600 kW (800 hp) on commercial vessels which began phasing in over 2014-2017. For engines below 600 kw the Tier III standards continue to apply.

[38] What is a Category 1,2, and 3 Marine Diesel Engine (68 FR 9746, February 28, 2003; 40 CFR Part 94)

- Remanufactured engines*:* The standards apply to commercial marine diesel engines above 600 kW built from 1973 through Tier II which requires the use of an EPA certified remanufacture system to achieve at least a 25% reduction in PM. The standards do not apply for engines that are rebuilt without removing cylinder liners.[39]

- Recreational marine engines: In 2008 U.S. EPA finalized regulations (73 FR 59033, October 8, 2008; 40 CFR Part 91) controlling emissions of NO_x + THC from gasoline spark-ignition marine engines, specifically outboard engines, personal watercraft, and sterndrive/inboard engines.

Emission Standards for Category 3 Marine Engines
Category 3 marine diesel engines typically range in size from 2,500 to 70,000 kW (3,000 to 100,000 hp). These are very large marine diesel engines used for propulsion power on ocean-going vessels such as container ships, oil tankers, bulk carriers, and cruise ships. In 2003, EPA adopted "Control of Emissions from New Marine Compression-Ignition Engines at or Above 30 Liters Per Cylinder", (68 FR 9746, February 28, 2003; 40 CFR Part 94) establishing Tier 1 emission standards for marine engines equivalent to the IMO MARPOL Annex VI limits. The EPA Tier 1 limits went into effect for new engines built in 2004 and later.

2009 Category 3 Engine Rule
On December 18, 2009, U.S. EPA signed a new emission rule for Category 3 engines (75 FR 22892, April 30, 2010, 40 CFR Parts 80, 85, 86, et el), which introduced Tier II and Tier III standards in harmonization with the 2008 Amendments to IMO MARPOL Annex VI. Tier III standards apply when a ship is operating in an ECA. Outside an ECA, Tier II limits apply.

3.3 Federal Fuel Standards

Marine ships generally use three types of fuels: heavy fuel oil HFO (residual), marine gas oil MGO (distillate), and marine diesel oil MDO (a blend of HFO and MGO).

Diesel
In June 2004, U.S. EPA finalized regulations controlling emissions from nonroad diesel engines and fuels (69 FR 38958; June 29, 40 CFR Part 94). While the engine standards promulgated under that rulemaking did not apply to marine engines, the fuel standards did. Beginning June 1, 2007, refiners were required to produce marine diesel fuel with a maximum sulfur content of 500 ppm (parts per million). By comparison, on-road diesel (used by heavy trucks, etc.) could not exceed 15 ppm (0.0015%) beginning in 2006. To enable catalytic after-treatment methods, the U.S. EPA established a sulfur cap in marine fuels. The maximum sulfur content of 15 ppm shown in table 2.4 for locomotive and marine diesel produced at refineries became effective June 1, 2012 (the sulfur limits are not applicable to residual fuels).

Residual

[39] EPA's Federal Marine Compression-Ignition (CI): Exhaust Emission Standards" https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100OA0B.pdf

Federal sulfur standards apply only to diesel, or distillate, fuel and not to residual fuel. Residual refers to the heavier number 6 fuel oil that remains after the distillate fuel oils and lighter hydrocarbons are distilled in the refining processes. Residual or HFO is regulated under MARPOL. Residual fuel currently has a sulfur content averaging to 25,000 ppm (2.5%) and a maximum of 35,000 ppm (3.5%) under MARPOL Annex VI as shown in Table 3.4. In January 2020 the global sulfur content will drop to 5,000 ppm (0.5%) which is still significantly higher than U.S. EPA's requirement for 15 ppm sulfur content for distillate fuel.

Table 3.4. Marine Fuel Standards

Standard	Applicability	Sulfur Content		Effective Date
MARPOL	Global	35,000 ppm*	3.5%	January 1,2012
		5,000 ppm	.5%	January 1, 2020
	Emission Control Areas	1,000 ppm	.1%	January 1, 2015
EPA	Distillate Fuel ** (marine diesel)	15 ppm	.0015	June 1, 2012

*ppm=parts per million

**EPA has set no standards for the heavy, high-sulfur residual fuel used by most ocean-going vessels.

In 2017 (the most recent year for which data is available) 22% of the residual fuel sold in Maine was for vessel bunkering.[40]

[40]EIA Petroleum and Other Liquids, https://www.eia.gov/dnav/pet/PET_CONS_821RSD_DCU_SME_A.htm

Section 4. Emissions Control Technologies & Methods

Most engines utilized as prime movers and as auxiliary power sources on marine vessels, both ocean-going and intercoastal, are diesel engines. Diesel engines have a high thermal efficiency, high fuel economy and are durable. Some marine vessels utilize a steam turbine for prime propulsion and electricity generation with steam generated from a marine boiler. Marine boilers combust liquid fuel to generate heat for steam production. Both diesel engines and marine boilers are emitters of air pollution that can negatively impact the air quality in and around ports while the vessel is transiting through the port's waters or while the vessel is at anchor or berthed. This section explores some strategies that have been employed at ports to reduce the impacts of emissions from marine vessel operations.

4.1 Emission Control Technology

Marine Emissions Scrubber Systems

In January 2020, the International Maritime Organization's (IMO's) International Convention for the Prevention of Pollution from Ships (MARPOL), 1973 as modified by the Protocol of 1978, also known as MARPOL 73/78, Annex VI Prevention of Air Pollution from Ships, will be implementing new restrictions on sulfur emissions that will require sea going vessels to either utilize more expensive low sulfur fuel or to install equipment that will control oxides of sulfur emissions. The IMO regulations mandate that the sulfur content in fuels used by sea-going vessels must be limited to 0.50% by weight globally and 0.10% by weight when operating within ECAs (Emission Control Areas, which include The Baltic Sea Area, The North Sea area, The United States, Canada, and the United States Caribbean Sea area). Until January 2020, the maximum sulfur cap in fuels is 3.5% by weight.

As a result, many corporations that operate sea-going vessels are opting to install scrubber systems as an alternative to capture the sulfur compounds in exhaust gases so that they can continue to use less expensive higher-sulfur fuels. Marine scrubber systems, also called exhaust gas cleaning systems (EGCS), use a scrubbing medium to interact with the vessel's prime mover or auxiliary engine exhaust gases to remove target pollutants. Often the target pollutant is sulfur oxides (SO_x) but particulate matter (PM) and nitrogen oxides (NO_x) can also be captured and controlled.

As the exhaust gases pass through the scrubber, the gases mix with the scrubber medium which will either absorb or react with the target pollutants and remove them from the exhaust gas stream prior to the exhaust gases being released to the atmosphere.

Marine scrubber systems can fall into two categories: wet (water or water-based solution) systems or dry (powder/granulated or solid) systems depending on the scrubber medium. A scrubber may also use a wet medium and incorporate a packed bed or other method to slow the exhaust gases down and increase the contact time between the exhaust gases and the scrubber medium. The scrubber type is chosen based on the specific target pollutant (SO_x or NO_x) and the scrubber medium which will provide the appropriate capture or reaction needed to remove the target pollutant, as well as the feasibility of installation and operation.

Both wet and dry scrubbers operate on the principle of mixing exhaust gases with scrubber medium to capturing the target pollutant(s). After use, scrubber medium must be replaced with fresh media. The used scrubber media, now saturated with the target pollutant, must be contained, treated and properly disposed of; reused; or in some cases treated and directly released. For more information on EGCS operation see Appendix A of this document.

EGCS Washwater Discharges
In the case of wet scrubber designs in which sea water is used as a scrubber medium, the washwater is often discharged directly back to the surrounding sea water. One drawback to the open-loop wet scrubber system is that the washwater is directly discharged back into the open sea water with very little treatment to remove dissolved pollutants. Discharges of EGCS washwater is not to be confused with "graywater" discharges. The specific definition for graywater, as defined by the Clean Water Act[41] and by the U.S. EPA[42], does not include EGCS washwater.

Discharged washwater falls under the oversight of IMO's MARPOL convention and EPA. MARPOL's requirements require that the washwater be of a pH of no less than 6.0. Starting in 2013, EPA began regulating discharges, separate from sewage discharges, that are incidental to the normal operation, which include EGCS medium discharges, with a vessel general permit (VGP) program. The VGP applies to commercial vessels greater than 79 feet in length. The Vessel Incidental Discharge Act (VIDA) was signed into law in 2018 and requires EPA to develop new national standards of performance for commercial vessel incidental discharges and the U.S. Coast Guard (USCG) to develop corresponding implementing regulations.[43] In the interim, the VIDA legislation extends the 2013 VGP's provisions, leaving them in effect until new regulations are final and enforceable. The following interim requirements apply until EPA publishes future standards by December 2020 and the USCG publishes corresponding implementing regulations under VIDA (anticipated in 2022):

- For large, non-fishing commercial vessels: The existing vessel discharge requirements established through the EPA 2013 Vessel General Permit (VGP) and the USCG ballast water regulations, and any applicable state and local government requirements.

- For small vessels and fishing vessels of any size: The existing ballast water discharge requirements established through the EPA 2013 VGP and the USCG ballast water regulations, and any applicable state and local government requirements.

EPA's VGP requires that exhaust gas scrubber washwater discharge not contain oil, including

[41] Title 33 – Navigation and Navigable Waters, https://www.govinfo.gov/content/pkg/USCODE-2010-title33/pdf/USCODE-2010-title33-chap26.pdf
[42] EPA. Graywater Discharges from Vessels (November 2011), https://www3.epa.gov/npdes/pubs/vgp_graywater.pdf
[43] EPA. National Pollutant Discharge Elimination System (NPDES): Vessels – VGP, https://www.epa.gov/npdes/vessels-vgp

oily mixtures, in quantities that may be harmful as determined in accordance with 40 CFR Part 110. Sludge or residues generated in treating exhaust gas scrubber washwater discharge must not be discharged in waters subject to this permit and must be delivered ashore to adequate reception facilities.

In addition, owner/operators of vessels with exhaust gas cleaning systems that result in washwater discharges must meet exhaust gas scrubber washwater discharge standards for pH, polycyclic aromatic hydrocarbons (PAH), turbidity, and nitrates/nitrites. The VGP also contains monitoring and reporting requirements to demonstrate compliance with the discharge standards.

China and Singapore have banned the direct discharge of open loop scrubber systems into coastal waters which took effect on January 1, 2020. China's ban does not extend to all of China's territorial waters because of the increased costs to the shipping industry. In areas that open loop scrubber medium discharge is banned, vessel operators will have to either switch to a closed loop scrubbing method or switch to the use of low-sulfur fuel oil.

The California Air Resources Board does not allow the use of scrubbers or any other compliance options other than low-sulfur marine gas or diesel oil within 24 nautical miles of the California coast line. However, a temporary research exemption allowing the use of a scrubber may be granted.

Most Carnival Cruise Lines, Royal Caribbean and Norwegian ships were outfitted with open-loop wet scrubbers, designed to reduce air emissions from these cruise ships.

Selective Catalytic Reduction (SCR) Technology

Selective Catalytic Reduction (SCR) is an emissions control technology used to convert oxides of nitrogen (NO_x) gases generated from fuel combustion into diatomic nitrogen (N_2), water (H_2O) and small amounts of carbon dioxide (CO_2). This technology is a well proven and commonly used method to control NO_x emissions in heavy duty diesel engines as well as other combustion processes that have high NO_x emissions. SCR is capable of NO_x reduction efficiencies in the range of 70% to 90% with higher reductions possible bur generally are not cost-effective.[44]

SCR uses anhydrous ammonia, aqueous ammonia or urea to cause a reduction reaction with the NO_x present in the exhaust gases. One of these reagents is sprayed in liquid form into a combustion process exhaust stream as it passes by a specific catalyst. The liquid is often called the diesel exhaust fluid (DEF). Much like a catalytic converter for an automobile, an SCR unit utilizes precious metals as a catalyst material to increase the rate of the desired reduction reaction. The catalyst material is often vanadium/tungsten oxides which are plated on to a titanium or ceramic substrate.

[44] EPA Air Pollution Control Strategy Fact Sheet, https://www3.epa.gov/ttncatc1/dir1/fscr.pdf

All heavy-duty diesel engines produced after January 1, 2010 must meet EPA's emission standards of 0.20 g/bhp-hr for NO_x and 0.01 g/bhp-hr for PM.[45] This level of emission control for diesel engines is often accomplished with the use of SCR and conjunction with a particulate filter.

SCR has been used for decades to reduce stationary source emissions. In addition, marine vessels worldwide have been equipped with SCR technology, including cargo vessels, ferries and tugboats.[46]

One difficulty with SCR in a marine application is the need to store DEF and replenish the DEF when the carried supply runs low. In marine applications, DEF is carried in a storage tank that must be maintained by the vessel operator.

Diesel Particulate Filter

A diesel particulate filter (DPF) is a control mechanism designed to capture entrained particulate matter (PM) from the exhaust gases of a reciprocating internal combustion diesel engine (diesel engine). Particulate filters can achieve capture efficiencies of greater than 90% and can range in capture efficiencies from approximately 50% to 99% depending on the design and construction material.

DPFs can be utilized for PM control for diesel engines in marine applications such as tug boats, passenger ferries, yachts, fishing vessels and marine launches. Older marine vessels can be retrofitted to reduce emissions of pollutants and fuel consumption. EPA's SmartWay program has a list of verified technologies for marine engine upgrade kits to reduce emissions.[47] For more information on diesel particulate filter operation see Appendix B of this document.

4.2 Port Technology

Shore Power

Providing electrical power from a shore side source can significantly reduce emissions from berthed vessels. Electricity delivered to a ship from a shore-based source is called "shore power." This process is sometimes called Alternative Maritime Power (AMP) or "cold ironing" because the shore power allows for the ship's electrical generation equipment to be shut down and allowed to get cold. According to EPA's Ports Initiative, use of shore power can reduce overall pollutant emissions by greater than 90% under the right circumstances and mix of energy sources. This strategy provides an emission's benefit to ports or terminals with a high number of frequently returning vessels that spend longer periods of time berthed.

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[45] MECA Regulatory background on the U.S. Mobile Source Emission Control Program, http://www.meca.org/regulation/us-epa-20072010-heavyduty-engine-and-vehicle-standards-and-highway-diesel-fuel-sulfur-control-requirements

[46] Diesel Technology Forum "What is SCR" https://www.dieselforum.org/about-clean-diesel/what-is-scr

[47] Verified Marine Technologies for SmartWay and Clean Diesel, https://www.epa.gov/verified-diesel-tech/learn-about-marine-technology

Shore power requires that dockside infrastructure be created to accommodate vessel needs for electrical power. The shoreside electrical infrastructure requirements include an industrial substation to receive power transmitted from the local grid and a transformer to adjust the voltage to be compatible with the ship's electrical specifications. Infrastructure requirements include distribution switchgear, circuit breakers, safety grounding, underground cable conduits, electrical vaults, and power and communications receptacles and plugs. An existing berth must be modified to accommodate the installation of shore power cables and accessories. For the construction of a new berth, technical requirements and specifications of shoreside electrical and infrastructure can be included in the design phase.

Installing shore power is an expensive effort. The cost of a shore power system consists of both fixed investment and operational costs. Fixed investment constitutes the investment in shore power infrastructure. There can be a significant difference between retrofit and new-build projects, with retrofits sometimes costing up to twice as much as incremental new-build investments. Shore power may also require retrofitting vessels that intend to use the shore connection if shore power capabilities are not already in place. This requires agreements with ship owners to invest in these retrofits. Costs for shipside modifications have been estimated to range from $300,000 to $2 million, depending on vessel type and size and the need for an onboard transformer. Grid improvements may also be required depending on expected usage and power availability. The cost of the dockside improvements could turn out to be cost prohibitive if there is a low likelihood of shore power utilization. The operational cost is primarily related to electricity costs and taxes, both of which vary by region as well as possible staffing and regular maintenance costs.

Although very little study has been done on the life cycle emissions reductions and cost effectiveness of installing shore power, examples of per ton costs for emissions reductions from large ports that have installed shore power connections show the cost may range from as low as $7,000 to higher than $100,000 per ton of combined criteria pollutant reduction.

Reducing or Prohibiting Soot Blowing

Some marine vessels use steam for vessel propulsion or for power generation. Steam can be generated in a steam boiler that utilizes the heat from petroleum combustion or in a waste heat boiler that uses the heat from exhaust gases from another process such as diesel engine operations. Soot accumulates on the surfaces of heat exchange tubes and interrupts heat transfer, reducing the steam generation efficiency. This can also cause the build-up of scaling on the internal surfaces of the heat exchange tubes reducing the tubes life span and further reducing heat exchange efficiencies.

Soot blowing is the process of cleaning heat exchange surfaces that come into direct contact with hot gases of combustion or hot diesel exhaust emissions. Jets of pressured steam, either superheated or dry saturated, impinge on the heat exchange surfaces blowing deposited soot free. The soot becomes entrained in the exhausting gas stream and exits the exhaust stack.

On board a marine vessel that utilizes steam generation units, soot blowing may take place as often as every 8-hour shift. Exhausting emissions from a marine vessel's combustion equipment during soot blowing can be visibly dark. The visibility of emissions is often expressed as opacity which is the federally recognized method of quantifying visible emissions. Opacity is the degree to which an exhaust plume will block the image from the background. Visible emission opacity can be measured by eye, by an observer certified in EPA's Method 9 Visible Emissions Observations or with an opacity monitor which electronically measures the opacity of an exhaust stream.

Speed Reduction

Vessel Speed reduction (VSR) is also an effective strategy to reduce emissions of criteria pollutants from marine vessels as they pass near populated areas. In addition to reducing emissions of particulate matter (soot), oxides of nitrogen (NO) and greenhouse gases, traveling at reduced speed consumes less fuel by the vessel's primary propulsion engine to travel the same distance. Reducing fuel consumption reduces the resulting emissions from the combustion of fuel.

VSR has the collateral benefits of reducing a vessel's fuel use (fuel cost savings), increasing safety in congested shipping zones and reducing risk to marine life that shares shipping lanes.

Many U.S. ports have adopted voluntary vessel speed reduction programs as part of their marine vessel emissions reduction plans. Often incentives for speed reduction motivate ship operators to participate reducing vessel speeds in speed reduction areas. Incentives have included reduced docking fees or docking fee rebates.

Compliance with vessel speed reduction requirements are often tracked by the automatic identification system (AIS). The AIS is a marine vessel tracking system which is a primary method of collision avoidance. Vessels are tracked by using ship board transponders. The IMO's International Convention for the Safety of Life at Sea (SOLAS) requires that all international voyaging ships with 300 or more gross tonnage (GT), and all passenger ships regardless of size be outfitted with an AIS transponder. AIS is also widely used by the commercial fishing industry as oversight of fishing fleet activities and search and rescue in the event of a marine emergency.

Section 5. Other State, Federal, and Port Programs

As knowledge of the health and environmental effects of marine vessel emissions expands, states are beginning to broaden their approach to addressing these impacts. This section highlights programs, regulatory or voluntary, currently being implemented in other coastal states and ports to address emissions from marine vessels. There are a multitude of programs that have been adopted, some of which are mentioned in this report which is not all inclusive. The programs included in this report are considered most relatable to Maine's present, and projected, maritime circumstances.

5.1 Regulatory Programs

Visible Emission Standards
The State of Alaska's Marine Visible Emissions Standards statute (18 AAC 50.070) sets standards for maximum opacity (reduced visibility) of emissions from ships operating within three miles of the Alaska coastline. The Alaska Department of Environmental Conservation conducts opacity monitoring of cruise ships and ferries in Alaska's ports to ensure compliance. If visible emissions standards are exceeded, vessels are required to report excess emissions as per 18 AAC 50.240.[48]

In Maine, 06-096 Code of Maine Rules (CMR) Chapter 101, regulates visible emissions and Chapter 146 sets diesel-powered motor vehicle emissions standards. The Department has consulted with the Maine Attorney General's (AG's) Office regarding potential applicability of these regulations to marine vessels, which advises that neither of these rules ought to be interpreted as applying to marine vessels. In addition, the AG's Office advises that state-specific opacity standards for large, ocean-going marine vessels could conflict with Section 209 of the Clean Air Act and would have to be drafted carefully to minimize federal preemption concerns.

Soot Blowing Prohibition
Michigan's Natural Resources and Environmental Protection Act, Act 451 of 1994, 324.6101, prohibits soot blowing within one mile of land, except, "under an emergency condition for the safe navigation of the vessel or to alleviate or extinguish a flash fire in the boiler uptakes or during departure-arrival operations." The Port District of South Louisiana which includes a 54-mile stretch of the Mississippi River between New Orleans and Baton Rouge has a "no soot blowing while in port" policy with 24-hour monitoring at all piers and local agent oversight to help enforce the policy.

Shore Power
Starting in 2014, the California Air Resources Board (CARB) has required that at least 50% of a fleet's visits to major California ports either use shore power for most of their time in port or reduce their use of onboard auxiliary power generation by at least 50% compared to a historical

[48] 18 Alaska Annotated Code 50, Air Quality Control, http://www.legis.state.ak.us/basis/aac.asp#18.50

baseline. This requirement rose to 70% of all visits or baseline power in 2017 and 80% by 2020. CARB's regulations apply to container vessels, passenger vessels, and refrigerated cargo vessels.

Cargo Handling Requirements

On December 8, 2005, the California Air Resources Board adopted regulations for cargo handling equipment, including yard trucks (hostlers), rubber-tired gantry cranes, container handlers, and forklifts. This regulation went in to effect on December 31, 2006. The Cargo Handling Equipment (CHE) Regulation establishes requirements for in-use and newly purchased diesel-powered equipment at ports and intermodal rail yards. The CHE Regulation has resulted in reductions of diesel particulate matter (PM) and oxides of nitrogen (NO_X) at ports and intermodal rail yards throughout California.[49]

Vessel Incineration Ban

Shipboard waste incinerators are not required to install control technology typically inherent to shoreside waste incinerators. In California, beginning on November 28, 2007, ocean-going vessels, including cruise ships, are prohibited from conducting onboard incineration operations within three nautical miles of the California coast.[50]

Commercial Harbor Craft Regulation

Adopted in 2007, amended in 2010, and expected to be fully implemented by 2022, California adopted the commercial harbor craft regulation, which mainly dictates fuel use and engine requirements aboard vessels such as crew/supply boats, fishing vessels, tugs, barges, and ferries within 24 nautical miles of the California coastline. All owners/operators replacing an engine on their existing harbor craft vessel are required to install an engine that meets the U.S. EPA standards in effect at the time of engine acquisition. There are additional requirements for propulsion engines on new ferries. Owners/operators of ferries, excursion vessels, tugboats, towboats, crew and supply vessels, barges, and dredges must comply with additional in-use engine requirements per a compliance schedule.[51]

The California's Air Resources Board (ARB) enforces a 0.10% sulfur limit within 24 nautical miles of the California coast. The regulation does not allow the use of scrubbers or any other compliance options other than low-sulfur marine gas or diesel oil. However, a temporary research exemption allowing the use of a scrubber may be granted. Both the ECA requirements and ARB's regulations must be complied with when calling at port in California.

Fees

At least one state with high commercial passenger vessel traffic has adopted a per passenger tax to fund infrastructure improvements necessary to accommodate these vessels. Under Title 52, *Transportation Taxes*, of Alaska's State Statutes (AS 43.52.200), the State of Alaska has

[49] California Air Resources Board. "Cargo Handling Equipment Regulatory Activities." https://www.arb.ca.gov/ports/cargo/cargo.htm
[50] California Air Resources Board. "Oceangoing Ship Onboard Incineration." https://www.arb.ca.gov/ports/shipincin/shipincin.htm
[51] California Air Resources Board. "Commercial Harbor Craft Regulatory Activities." https://www.arb.ca.gov/ports/marinevess/harborcraft.htm

imposed a tax on overnight accommodations on commercial passenger vessels that anchor or moor on the State's marine water with the intent to allow passengers to embark or disembark.[52] Currently the tax rate is set at a rate of $34.50 per passenger. Passengers are liable for payment which is collected from the passenger by the person that provides the travel aboard the commercial vessel and is paid to the Department in the manner and at the times required by the Department by regulation. Proceeds from the tax are deposited into a "commercial vessel passenger tax account" in Alaska's general fund.

Funds from the commercial vessel passenger tax account are distributed to Alaskan ports of call at a rate of $5 per passenger for each port visit on a commercial passenger vessel voyage. Monies distributed to ports are intended to fund improvements to port facilities, harbor infrastructure and other services provided by the port of call to the commercial passenger vessel and its passengers. In addition to appropriations for the payments to ports, the Alaska State Legislature may appropriate money from the commercial vessel passenger tax account for projects that (1) improve port and harbor infrastructure, (2) provide services to commercial passenger vessels and the passengers on board those vessels, or (3) improve the safety and efficiency of the interstate and foreign commerce activities in which the vessels and the passengers on board those vessels are engaged.

Several Alaskan cities that are frequented by commercial passenger vessels have implemented local ordinances that levy a per passenger fee. For example, in 1999, City and Borough of Juneau voters passed Proposition 1, assigning a tax of $5 per cruise ship passenger to assist in funding projects that enhance the tourism experience and offset community impacts created by the cruise ship industry.[53] This fee has since been increased to $8 per passenger.

Marine Vapor Recovery Systems

Vapor recovery is the act of capturing volatile organic compounds (VOCs) emitted from petroleum-based liquid materials prior to the vapors being released into the atmosphere. In the marine vessel context, vapor recovery occurs when petroleum-based liquid fuels or liquid cargo is being loaded onto or unloaded from a marine vessel. During loading and off-loading, liquid petroleum-based materials displace the vapors that are present in storage tanks. These vapors are vented from the tank to prevent tank over pressurizing. Additionally, the movement of the liquid increases the off gassing, generating additional vapors that require venting. These vapors are largely VOCs and other air pollutants.

Vapor Control Systems (VCS) act to capture the vapors so that they can be either destroyed or condensed and reintroduced back into its product of origin.

The 1990 Amendments to the Clean Air Act (CAA), Section 183, *Federal Ozone Measures*, Subpart (f), *Tank Vessel Standards,* required the U.S. EPA and the U.S. Coast Guard to promulgate regulations and standards applicable to the emission of VOCs and other air pollution from the loading or offloading of tank vessels. In addition, the U.S. Coast Guard was required to promulgate regulations associated with the safety of equipment designed to control VOCs and

[52] Alaska's State Statutes, http://www.legis.state.ak.us/basis/statutes.asp
[53] City and Borough of Juneau, https://beta.juneau.org/manager/marine-passenger-fee-program

meet standards established by regulations.

The U.S. Coast Guard established requirements pertaining to the safe installation and operation of any control equipment designed and installed to meet pollution standards. These requirements are found in Title 33 CFR, *Navigation and Navigable Waters*, Part 154, *Facilities Transferring Oil or Hazardous Material in Bulk*, Subpart P, *Marine Vapor Control Systems*[54] and in Title 46 CFR, *Shipping*, Chapter I, *Coast Guard, Department of Homeland Security*, Part D, *Tank Vessels*, Part 39, *Vapor Control Systems.*[55]

Requirements for the control of emissions for loading operations at facilities with the potential to emit hazardous air pollutants are established in Title 40, *Protection of Environment*, of the Code of Federal Regulations (CFR), Part 63, *National Emissions Standards for Hazardous Air Pollutants for Source Categories*, Subpart (Y), *National Emissions Standards for Marine Tank Vessel Loading Operations.*[56] These requirements established by EPA apply to all existing sources that meet the major source threshold of the potential to emit 10 tons per year or more of any hazardous air pollutant or 25 tons per year or more of any combination of hazardous air pollutants and all new sources with some defined exceptions. No Maine tank vessel loading facilities meet the major source threshold for hazardous air pollutant emissions; however, some Maine tank operations facilities meet the major source threshold for VOC emissions with the potential to emit 50 tons per year of VOC emissions. Although a tank operations facility has been determined to be a major source for VOC emissions, it may not meet the applicability threshold for being subject to the 40 CFR Part 63, Subpart Y, NESHAP requirements for vapor controls.

Maine has no requirements for marine vessels to install or operate vapor control systems onboard marine vessels, and no Maine tank operations facility currently utilizes vapor control during marine vessel unloading activities. The only exception is the unloading of gasoline from a marine vessel into a shore-based tank. These tanks utilize floating roofs to minimize the space above the liquid level for vapors to accumulate and require venting. There is minimal loading of marine vessels from shore-based tanks occurring in Maine. Occasionally some tank operations facilities may load product onto a barge or fuel onto a marine vessel. For more information on marine vapor controls please refer to Appendix C of this document.

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[54] Marine Vapor Control Systems, https:// Marine vapor control systems. www.govinfo.gov/content/pkg/CFR-2015-title33-vol2/pdf/CFR-2015-title33-vol2-part154-subpartP-subjectgroup-id1146.pdf

[55] 46 CFR Part 39 https://www.govinfo.gov/app/details/CFR-2007-title46-vol1/CFR-2007-title46-vol1-part39/context

[56] Marine Vessel Loading Operations, https:// Marine vessel loading operations. www.epa.gov/stationary-sources-air-pollution/marine-vessel-loading-operations-national-emission-standards

5.2 Voluntary Programs and Initiatives

Vessel Repowering

Ohio has a diesel mitigation trust fund grant to repower eligible tug boats and ferries.[57] Alaska is using 10% of its Volkswagen Settlement funds to repower marine vessels (program requires matching funds and caps at $200k per vessel).[58] In addition to installing shore power, Washington is using its allocated portion of the Volkswagen Settlement funds to repower tugboats and electrify its state ferry vessels.[59] New York receives funding from the Clean Diesel National Grant Program, which can be applied to repowering marine vessels.[60]

Biofuels

Complying with IMO's low sulfur fuel requirements increase operational costs. Because of such costs, biofuels have become an attractive alternative since they are inherently low in sulfur and provide greenhouse gas benefits. Based on an assessment conducted by Oak Ridge National Laboratory, replacing heavy fuel oil (HFO) in large marine vessels with minimally processed, heavy biofuels have potential to reduce emissions of sulfur, CO_2, and criteria emissions; PM reduction is an immediate environmental benefit of oxygenated fuels. Although marine distillate and low-sulfur marine distillate have the potential to reduce sulfur oxides, PM, and black carbon emissions; marine distillate still emits CO_2 and NOx at levels similar to those of HFO. However, in addition to criteria emissions, biofuels also offer the potential to reduce life-cycle CO_2 for marine operations. [61]

Of the current biofuels commercially available, only biodiesel derived from plant oil, used cooking oil or pulping residues and bioethanol are produced at a level where they can supply significant volumes of fuel. There is a potential supply of sustainable renewable diesel produced from hydrotreating and refining vegetable oil. This biofuel can be used in a marine engine without modifications.

Bioethanol can be sustainably produced from waste and lignocellulosic feedstocks, with much higher supply potential, capable of replacing all fossil fuels in the shipping sector, but bioethanol is not compatible with current marine diesels, and cannot be used as a drop-in fuel.[62] However, the development in engine technology has seen the introduction of multifuel engines. These

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[57] Ohio Environmental Protection Agency. "Diesel Mitigation Trust Fund Grant Eligibility: Tug and Ferry Conversions (Only Repower is Eligible)." May 24, 2018.
http://ohioepa.custhelp.com/app/answers/detail/a_id/2957/track/AvOY~wonDv8S~S~~GhAW~yILOv0qhS75Mv9y~zj~PP_7

[58] Birnbaum, Molly, Non-Point Mobile Sources, Department of Air Quality, Alaska Department of Environmental Conservation. Telephone Communication. February 8, 2019.

[59] Boyer, Mike, Senior Diesel Programs Specialist, Air Quality Program, Washington Department of Ecology. Email communication. January 22, 2019.

[60] Environmental Protection Agency. "Clean Diesel National Grants."
https://19january2017snapshot.epa.gov/cleandiesel/clean-diesel-national-grants_.html

[61] ORNL Understanding the Opportunities for Biofuels for Marine Shipping Biofuel,
https://info.ornl.gov/sites/publications/Files/Pub120597.pdf

[62] ORNL Understanding the Opportunities for Biofuels for Marine Shipping Biofuel,
https://info.ornl.gov/sites/publications/Files/Pub120597.pdf

engines can use oil, gas, as well as alcohols (e.g,. methanol or ethanol) in a diesel cycle. Therefore, the use of ethanol may grow significantly in the medium to long term as ships with new engines are introduced.

Utilizing biofuels in the marine sector is not yet common practice. Main barriers to the deployment of marine biofuels include:

1. higher price of biofuels as compared to other marine fuels
2. insufficient logistic support at ports for fuels not compatible with diesel type fuels
3. limited expertise within the shipping sector with the handling of some biofuels, including long-term stability.[63]

There is a need for further evaluation, including the overall compatibility of bio-oils with marine engine combustion and fuel systems and the potential need to remove water (bio-oils are often hydrophilic).

Shore Power

A few U.S. ports have installed shore power to primarily accommodate cruise ships. In 2016 shore power work was completed at the Brooklyn Cruise Terminal allowing cruise ships to plug in at an installation cost of approximately $12 million. Another example is the Port of Seattle where shore power to accommodate cruise ships at two berths came at a cost of approximately $7 million. An example of a shore power installation that accommodates a wide variety of shipping needs is the Port of Oakland which had an estimated combined port and private sector project cost of approximately $70 million for just the shore-side infrastructure. Another example of this type of shore power installation is the Port of Long Beach with a cost of approximately $185 million.

According to EPA's Shore Power Technology Assessment at U.S. Ports, published in March, 2017, ten ports use high voltage systems, to serve cruise, container and refrigerated ("reefer") vessels (Seattle, Tacoma, San Francisco, Oakland, Port Hueneme, Los Angeles, Long Beach and Brooklyn), and 6 ports use low voltage systems, to serve tugs and fishing vessels (Seattle, Los Angeles, Long Beach, Boston, New Bedford, Philadelphia and Baltimore). Alaska currently has installed a shore power connection in Juneau which is Alaska's primary cruise ship destination port. Juneau is considering expanding their port infrastructure to allow greater shore power availability. Though the technology is relatively new in the commercial sector, shore power has been successfully used by the U.S. Navy for decades and is included in the Navy's Incentivized Shipboard Energy Conservation program.

In Washington, Alaska and Pennsylvania, Volkswagen Settlement funds are being used to support the installation of shore power connections for ocean-going vessels.

Cargo Handling Retrofits and Replacement

The Port Authority of NY & NJ has been awarded $1,750,000 in Diesel Emissions Reduction

[63] Biofuels for the Marine Shipping Sector, https://www.ieabioenergy.com/wp-content/uploads/2018/02/Marine-biofuel-report-final-Oct-2017.pdf

Act (DERA) funding for their Truck Replacement Program. The program will replace model year 2006 and older short-haul trucks serving Port Authority facilities, such as Port Newark-Elizabeth, with cleaner 2012 and newer models. This investment will reduce about 246 tons of nitrogen oxides and about 16 tons of fine particles.

The Port of New Orleans (Port NOLA) utilized DERA funds to replace 40 drayage trucks that resulted in an emissions reduction that is greater than the total current emissions from trucking from port operations. Port NOLA has truck traffic that is as high as 1,200 trucks per day at times. Port NOLA hopes to replace another dozen or more drayage trucks using DERA funds, soon. The Port of Houston received $9 million from the EPA's DERA and SmartWay Program and Port Houston contributed an additional $50,000 to replace an average of four trucks per month, or 50 trucks per year.

Emissions Inventory

In 2016, EPA's Office of Transportation and Air Quality and Broward County's Port Everglades announced a voluntary partnership to study mobile source emissions.[64] Through this partnership that has now concluded, EPA and PEV agreed to work together to develop baseline and future year emission inventories and to evaluate various effective technology and operational strategy scenarios for seaports. Port Everglades is the first port to partner with EPA in this way.

The EPA and Port Everglades partnership led to the development of the Port Everglades 2015 Baseline Air Emissions Inventory, as well as documentation of methods, lessons learned, and practical examples that can inform other ports, related agencies, and stakeholders.

5.3 Organizations Focused on Reducing Emissions from Marine Vessels and Ports

EPA's Ports Initiative

EPA's Ports Initiative works in collaboration with the port industry, communities, and all levels of government to improve environmental performance and increase economic prosperity. Through this ports partnership initiative, EPA supports efforts to improve efficiency, enhance energy security, save costs, and reduce harmful health impacts by advancing next-generation, clean technologies and practices at ports.[65]

EPA's Ports Initiative has created a calculator, called the Shore Power Emissions Calculator (SPEC) to help ports determine the potential benefits of creating a shore power infrastructure.

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[64] EPA and Port Everglades Partnership: Emission Inventories and Reduction Strategies, https://www.epa.gov/ports-initiative/epa-and-port-everglades-partnership-emission-inventories-and-reduction-strategies

[65] EPA Port Initiative, https://www.epa.gov/ports-initiative

Green Marine Program

Program Description

The Green Marine Program[66] was voluntarily founded in 2007 by leading marine associations and industry executives in Canada and the United States. The program was originally conceived for the Great Lakes and St. Lawrence corridor around the specific issue of aquatic invasive species, with the founders having no intention of expanding it beyond the region; however, interest throughout the marine industry enabled the program to evolve and be adopted across the east, west and gulf coasts.

Green Marine started out as a one-person organization and now has six full-time employees with offices in Quebec City, Halifax and Seattle. The program's coordination is shared among three program managers. In 2016, Green Marine hired a new East Coast and Great Lakes Program Manager, Thomas Gregoire, who opened Green Marine's east coast office in Halifax, Nova Scotia. The increase in staff was essential to support the rising number and diversity of participants in the program. The membership has more than tripled in the course of the last decade, and now exceeds 130 ship owners, ports, terminals, shipyards, as well as the Seaway corporations, in Canada and the United States.

Some participating members[67] on the east coast include: Port Albany; Global Container Terminals in New York and New Jersey; Waterson Terminals and the Port of Providence in Rhode Island; Ceres Terminals in South Carolina, Maryland and Georgia; Federal Marine Terminals in New York; and Logistec in Connecticut, to name a few. The North Atlantic Ports Association also joined last year as an Association member of Green Marine, pledging to help spread the word of this important sustainability program.

Green Marine's core value of continual improvement has the organization's sights set on further developing both its membership and the criteria that its participants use to address specific environmental issues related to their operational activities.

Certification Program

The Green Marine environmental certification program addresses key environmental issues through 12 performance indicators. Each year, participants benchmark their environmental performance through the program's detailed framework, on a scale of Levels 1 to 5, where Level 1 constitutes monitoring of regulations, and Level 5 indicates leadership and excellence. Some indicators are applicable to vessels, others to landside operations.

- The ship owners' criteria address greenhouse gases, air emissions, oily water, garbage management, and underwater noise.
- The ports, terminal operators and shipyards criteria focuses on greenhouse gases and air pollutants, spill prevention, waste management, environmental leadership, community impacts, and underwater noise.

[66] Green Marine, https://green-marine.org/

[67] Green Marine, https://green-marine.org/members/

The program fills a real need within the marine industry for a thorough but simple framework that guides the Green Marine participants toward reducing their environmental footprint by setting various benchmarks that exceed regulatory compliance and foster a culture of continual improvement. Social license is increasingly sought by industries and shipping is no exception with, for example, a growing number of cruise ships berthing in ports, raising awareness and concern in the neighboring communities for air quality and other impacts.

Certification Process

To receive their annual certification, participants must benchmark their environmental performance through the program's self-evaluation guides, have their results verified by an accredited external verifier and agree to publication of their individual results for each applicable performance indicator on the 1-to-5 scale. This 1-to-5 scale allows anyone outside the industry to easily understand the level of achievement based on the program's criteria. Transparency being a key pillar of Green Marine's philosophy, all of the performance indicators' criteria is available online, for anyone to see what actions a participant had to put in place to reach a specific level.

Using this framework or pathway towards Level 5, like an off-the-shelf environmental management program, Green Marine participants are better equipped to continually improve their environmental performance. The program gives participants a structured plan that identifies concrete actions and the different steps required to achieve a higher level in each performance indicator, therefore serving as a roadmap for continual improvement.

The certification program's framework is rigorous, but welcomes maritime enterprises regardless of size, resources and starting point, if they satisfy current regulations and have a commitment to continual self-improvement. The program's credibility is reinforced by the requirement for all participants to have their self-assessed performance verified by an accredited third-party external verifier, in order to receive certification. This, in turn, allows participants to objectively demonstrate their environmental achievements and commitments.

The Port of Providence is an East Coast port that, although it has a higher degree of merchant vessel traffic, is similar in size and coastal topography to Maine. Waterson Terminal Services, LLC (WTS) is the Port of Providence's exclusive Operator and Manager. In December 2018, WTS joined the Green Marine environmental certification program.[68]

Bay Ferries Limited, a Canadian Maritimes ferry company, is also a Green Marine member that has achieved level 2 for incorporating best practices for reducing SOx, NOx, PM and GHG emissions. In 2020, Bay Ferries Limited plans to operate a ferry between Yarmouth, Nova Scotia and Bar Harbor, Maine.

Northwest Ports Clean Air Strategy – Washington, British Columbia

Northwest Ports Clean Air Strategy is a voluntary program being implemented by the Northwest Seaport Alliance (NWSA) (Ports of Seattle, Tacoma, and Vancouver). By offering sector-

[68] Waterson Terminal Services, Port of Providence, Rhode Island, https://www.provport.com/waterson/environmental.html

specific (ocean-going vessels, drayage vehicles, cargo-handling equipment, etc.) incentives (rewards, including financial), the NWSA is encouraging positive changes to reduce emissions in a myriad of ways: idle-reduction plans for vehicles, opacity testing for vehicles ten years and older in port, repowering of harbor vessels with more current propulsion technology, installation of shore power for more vessels, and fuel-efficiency plans, among others.[69] Alaska is also expected to meet with the NWSA soon.[70] The Port Authority of New York & New Jersey maintains a similar strategy for its ports.[71]

West Coast Collaborative, Marine Vessels & Ports Sector

"The objective of the Marine Vessels and Ports Workgroup is to share information and seek funding for a variety of projects, including: alternative fuel use for vessels and on-shore equipment, equipment retrofits and early retirement, and cold ironing for ocean-going vessels and plug-in power for on-shore equipment."[72]

Port of New York and New Jersey

The Port of New York and New Jersey includes Port Newark, Elizabeth Port Authority Marine Terminal, Port Jersey, Howland Hook Marine Terminal, Brooklyn Marine Terminal, Red Hook Container Terminal, and NY-NJ Rail.

In 2009, the Port Authority worked with its partners to develop a Clean Air Strategy for the Port of NY and NJ. The strategy lays out practical actions that the Port and industry stakeholders can take to reduce diesel and greenhouse (GHG) emissions in advance of potential regulations. These actions can significantly reduce nitrogen oxide (NOx) and particulate matter (PM) pollution, as well as greenhouse gases (GHG). The Port Authority published an implementation Report in 2013 and updated The Clean Air Strategy in 2014.[73]

Emissions sources addressed by the strategy include Ocean Going Vessels, Cargo Handling Equipment, Trucks, Rail and Harbor Craft. Examples of the actions included replacement of the oldest and most polluting trucks serving the port, installation of shore power capability at the Brooklyn Cruise Terminal, retrofit of two switcher locomotives serving the Port's on-dock rail operations with Generator Set systems, and modernization of cargo handling equipment used by terminal operators leasing space from the Port Authority. The strategy also includes developing speed reduction and low sulfur fuel incentive programs

[69] Northwest Seaport Alliance. "Northwest Ports Clean Air Strategy 2015 Implementation Report." https://www.nwseaportalliance.com/sites/default/files/final_2015_implementation_report_version_3-14-2017.pdf
[70] Birnbaum, Molly, Non-Point Mobile Sources, Department of Air Quality, Alaska Department of Environmental Conservation. Telephone Communication. February 8, 2019.
[71] The Port Authority of New York & New Jersey. "Port Environmental Initiatives." https://www.panynj.gov/about/port-initiatives.html
[72] West Coast Collaborative. "Marine Vessels & Ports Sector." https://www.westcoastcollaborative.org/workgroup/wkgrp-marine htm
[73] The Port Authority of New York and New Jersey. Port Environmental Initiatives, https://www.panynj.gov/about/port-initiatives.html

Highlights:

1. The Port Authority of NY & NJ has been awarded $1,750,000 in DERA funding for their Truck Replacement Program. The program will replace model year 2006 and older short-haul trucks serving Port Authority facilities, such as Port Newark-Elizabeth, with cleaner 2012 and newer models. This investment will reduce about 246 tons of nitrogen oxides and about 16 tons of fine particles.

2. The Port of New York and New Jersey began the Clean Vessel Incentive Program in 2013. This program provides qualifying ships with a financial incentive based on the vessel's score achieved on the World Port Climate Initiative's Environmental Ship Index (ESI). Vessels with ESI scores of 20–29 receive $1,500, and greater than 30 receive $2,500 for each vessel call. Vessels that participate in vessel speed reduction, limiting their speed to ten knots on inbound and outbound transits earn an additional five points, which may be added to the ESI score. The program awards ships with Tier II engines an additional $1,000 and those with Tier III engines an additional $2,000.

3. New York City's Brooklyn Cruise Terminal took a major step toward reducing air pollution from port facilities. Brooklyn is only the second Atlantic coast cruise terminal after Halifax, Nova Scotia, to install shore power.

4. Three switching locomotives were each retrofitted by replacing a single large generator set with three small ultra-low-emitting genset engines which are used only as necessary to provide as-needed power. The generator set engines met Tier 3 non-road standards and had exhaust diesel particulate filters, resulting in meeting United States EPA's Tier 4 PM locomotive emissions standards. The retrofits are estimated to reduce PM emissions by 2.8 tons/year and NOx by 47.5 tons/year; an effective more than 99% reduction in PM and 88% reduction in NOx from the pre-retrofitted Tier 0 locomotives.

5. With funding from CMAQ and the Federal Transit Authority, NYC DOT installed diesel oxidation catalysts (DOCs) on over 31 boats and upgraded nine vessels from Tier 0 to Tier 2 engines on BillyBey and Waterway ferries, resulting in approximately 90% emissions reductions compared to non-retrofitted ferries. NYC DOT encouraged all harbor ferries to begin burning ULSD ahead of the mandate of which many did. So far, there has been no cited problem in ULSD fuel availability.

5.4 Maine Initiatives

Clean Marine Engine Program

The Maine Clean Marine Engine Program was developed by the Maine Department of Environmental Protection in 2009 to repower older, dirty diesel engines with funding from the national Diesel Emission Reduction Act (DERA) as administered by the U.S. Environmental Protection Agency. The goal of the Clean Marine Engine Program is to remove unregulated diesel engines from the fleet to improve air quality and provide public health benefits. These older diesel engines emit up to twice the NO_x and diesel particulate as new engines that meet current EPA emission standards.

Figure 5.1. F/V *Providian* (source: Ryan Raber)

The program funds a 40% grant for the purchase and installation of a new engine that meets EPA Tier 3 standards. Eligible projects must have a diesel engine that still has three or more years of useful life and has excessive emissions from high fuel consumption. The vessel must be a registered Maine commercial vessel that operates at least 60% of the time within Maine waters for a minimum continuous five-year period. All work is done at a Maine boatyard to stimulate the local economy.

To date, $2,023,333 has been spent to repower over 100 vessels thereby reducing harmful exhaust emissions by 54.16 tons/year of NO_x and 3.63 tons/year of diesel particulate matter.

Shore power

Shore power is the provision of shoreside electrical power to a ship at berth while its main propulsion and auxiliary engines are shut down. Shore power saves fuel consumption, which would otherwise be used to power vessels while in port, and reduces air pollution associated with fuel combustion. Grant funds from the Diesel Emission Reduction Act (DERA) funded Fore

River Dock and Dredge Company, which specializes in marine construction, to install a ship to shore power at Turners Island in South Portland. The ship to shore power project on the pier eliminates the need for cargo ships and tugs that are unloading cargo or being repaired, to run their main propulsion engines in order to generate power. Grant funds through DERA and Volkswagen Settlement Funds are available for shore power projects.

General Marine Construction installed shore power at Deakes' Wharf, a busy commercial fishing pier on Portland's waterfront. The DERA grant funded 50% of the cost to install ship to shore power to the mid-water trawler, *Providian,* to reduce operating costs and emissions when in port. This project demonstrates a successful public/private partnership to reduce emissions and help the local fishing industry.

Biodiesel/Fueled by French Fries

Since 2014, Casco Bay Lines has used B20, a 20 % biodiesel blended with ultra-low sulfur diesel, to operate the ferry service for the Casco Bay Islands. The biodiesel is manufactured locally in Portland at Maine Standard Biofuels from waste cooking oil from local restaurants. Casco Bay Lines purchases approximately 225,000 gallons of B20 annually to run their five ferries year-round. Any diesel engine can run on biodiesel with no modifications required with no difference in performance or fuel economy. Biodiesel reduces greenhouse gases by 20% compared to petroleum diesel. Casco Bay Lines estimated that they reduced carbon dioxide emissions by 846,092 pounds a year. Casco Bay Lines is finishing the design work on their new car ferry and is considering a plug-in diesel hybrid electric propulsion system for it (and for future vessels).

International Marine Terminal

In 2016, MaineDOT received a USDOT FASTLANE grant to improve utilization and efficiencies at the Port of Portland. The grant included track and crossing upgrades to the railroad serving the Port enabling it to more safely and efficiently connect with the national rail grid. These rail improvements will allow for growth in cargo transported by rail and minimize highway traffic in the northeast. According to MaineDOT improvements in port infrastructure will remove more than 12,000 trucks from the freight highway systems. Included in the project is state-of-the-art technology that will allow for multiple trucks to enter and exit the facility simultaneously limiting idling. The purchase of a second crane, with zero emissions, will allow vessels to be fully loaded and unloaded in nearly half the time. A new rail packer will result in intermodal efficiency gains.

In addition, funds from the Volkswagen Settlement will replace four port drayage trucks with new clean diesel engines.

The CAT

Bay Ferries Limited is a Green Marine Member that has voluntarily incorporated best practices into their ferry operations for reducing NOx, SOx, PM, and GHG emissions. Bay Ferries Limited did operate a ferry across the Gulf of Maine between Yarmouth, Nova Scotia and Portland, Maine. However, that route has ceased operating as they are now reconstructing the terminal in Bar Harbor for the CAT to return next season in 2020.

Section 6. Options for Further Action

Maine is already addressing emissions from marine vessels (see Section 4.3 Maine Initiatives); however, as both cargo and cruise ship activity continue to grow, Maine could consider additional initiatives. Based on the findings from this report, below is a list of potential strategies Maine could undertake to address emissions from marine vessels.

6.1 Monitoring

The Department monitors ambient air concentrations of a range of pollutants throughout the state; however, the Department has not conducted any port-specific monitoring that could indicate how marine vessel emissions impact ambient air quality in the immediate vicinity. While some investigatory analysis of possible cruise ship influence on ambient air quality was completed in 2015 using data from the McFarland Hill monitoring site in Acadia, this monitoring location may be too far removed from the marine vessel activity to detect emissions. To get a better understanding of how marine vessels affect ambient air quality, monitoring studies could be initiated along the coast in areas of high marine vessel activity. Such an undertaking would require research and planning to identify the pollutants of concern, the best methods and locations for measuring them, as well as the funding for instrumentation[74] and staffing needs[75] to conduct a monitoring study. Monitoring of ambient air quality concentrations could lead to a better understanding of the overall impact of marine vessel activity, but it would not specify or differentiate the sources of these pollutants, e.g., which emissions are from local fishing vessels, versus which emissions are from a cargo ship or cruise ship.

6.2 Emissions Inventory Baseline

The marine vessel emissions data presented in Section 1.3 is from EPA's 2014 National Emissions Inventory. While some of this data is based on Maine-specific activity, much of the data used to compile this emissions inventory is based on models. Estimates of local emissions in ports and harbors along Maine's coast would provide the more accurate data and could help define the sources of detected emissions. Other U.S. ports are undertaking comprehensive local emissions inventories (e.g., Port Everglades). Such assessments are typically conducted by an environmental consultant and can be quite costly; however, port-specific data can be gathered for specific activities including cargo ships, cruise ships, and tankers; harbor vessels, such as towboats and yachts; cargo handling equipment, such as cranes, straddle carriers, and forklifts; and on-road vehicles, such as those that transport cruise passengers. A port emissions baseline could also include emissions for electrical power consumption from public and private entities related to port activities.

6.3 Regulating Visible Emissions

Chapter 101, Visible Emissions, does not contain any visible emission standards specifically applicable to marine vessels of any type. The Department should consider revising Chapter 101 to add visible emission standards that would be applicable to emissions from certain types of

[74] The cost of instrumentation to measure SO_2 and PM at one location is approximately $86,500.
[75] The operations or staffing cost for a monitoring station is approximately $75,000.

marine vessels. The Department would need to consider how it would enforce any such visible emission standards, particularly for marine vessels at anchor.

6.4 Biofuels

Biofuels when blended with petroleum fuels reduce sulfur content and offer a potentially lower ash and emission profile. Depending on the biomass feedstock and processing conditions, biofuels can be low in sulfur and nitrogen while also providing a low carbon intensity fuel. Biodiesel produced from plant-based oils or used cooking oil is a drop-in fuel not requiring engine modifications and is more practical for smaller vessels. Biodiesel blends (up to 20%) have been reported as the most promising bio-based alternative fuel for marine vessel operations.

6.5 Green Marine

The Green Marine Program is a voluntary environmental certification program for the North American marine industry. The program seeks commitment from shipowners, ports, terminals, seaway corporations, and shipyards to reduce their environmental footprint from all port operations through measurable actions.

Members receive their certification by evaluating their annual environmental performance through 12 performance indicators in the program's self-evaluation guides, and have their results verified by an accredited external contractor. The members must adopt practices and technologies and measure progress with the help of performance indicators, which are revised yearly, for continuous improvement.

Maine terminals, shipowners, shipyards and ports could learn how to improve efficiencies and achieve measurable results that would certify them as Green Marine members.

6.6 Passenger Fees

Maine received a total of 424,867 cruise ship passengers in 2019. The state could consider requiring a fee charged per cruise ship passenger for possible port improvements. This strategy has been employed by at least one other state, Alaska.[76]

6.7 Shore Power

Although installing shore power infrastructure is expensive, the Portland Cruise Terminal is located at the former Bath Iron Works dry dock facility which may have three-phase power available to lower installation costs. Grid improvements may also be required depending on expected usage and power availability. The cost of the dockside improvements could turn out to be cost prohibitive if there is a low likelihood of shore power utilization. The operational cost is primarily related to electricity costs including demand charges. Grant funding may be available to offset the infrastructure costs.

[76] Due to legal issues raised with the current fees in Alaska, should Maine consider a passenger fee, the intended use of collected funds would need to be clear and directly or indirectly benefit the vessels.

Appendices

Appendix A. Wet Scrubber Systems

Wet scrubber systems utilize an enclosed compartment that allows exhaust gases from the vessels propulsion or auxiliary engines to mix with a liquid medium. The liquid can be water (fresh or sea water) or an alkaline solution that acts to neutralize the acidic nature of the exhaust gases by reacting with pollutants including SO_x and NO_x.

The alkaline solution can be fresh water with added calcium or sodium sorbents (lime or caustic soda). In some cases, the wet scrubber may utilize the water and lime or caustic soda mixture so that sulfur-based salts are produced which are not an environmental threat and can be easily disposed of.

Wet scrubbers have the collateral benefit of controlling particulate matter (PM), including particulate matter with a diameter of less than 10µm (PM_{10}) which is associated with sulfur emissions from coal and petroleum fuel combustion. Wet scrubbers can potentially remove up to 80% of PM_{10} in a combustion exhaust stream.

Wet scrubbers may also have a collateral benefit of reclaiming some of the heat that would be lost out the vessel's exhaust stack. This design includes piping to condense scrubber medium out of the exhaust gas stream after the injection point and in turn capture some of the heat gained during the scrubbing phase of the unit.

After mixing with the exhaust gases, the wet scrubber medium must be collected, treated and subsequently stored or discharged depending on the type of wet scrubber system. Discharged medium falls under the oversight of IMO's MARPOL convention which further classifies wet scrubber systems as either open loop, closed loop or hybrid depending on the scrubber medium and the method used to handle the spent scrubber medium.

1. Open-loop Scrubber System

   An open loop system on a marine vessel utilizes sea water for scrubbing. Figure A.1 is an example of a typical open-loop scrubber that can be found on an ocean-going vessel. Sea water is naturally alkaline, so it readily neutralizes the acidic nature of the exhaust gases. Some scrubber designs incorporate mist eliminators to remove acid mists from the exhaust gas stream. The mist eliminators can be of the mesh or chevron design. The design can also include a packed bed to increase the interaction time between the exhaust gases and scrubber medium.

   After passing through the scrubber, scrubber medium can be treated to remove any sludge but often is simply diluted with a wash water so that the resulting mixture meets the pH standards established by the MARPOL. MARPOL also requires the discharged medium be continually monitored to demonstrate compliance with the pH requirements. After dilution, the medium is simply discharged back into the open sea with a pH of 6.5 pH.

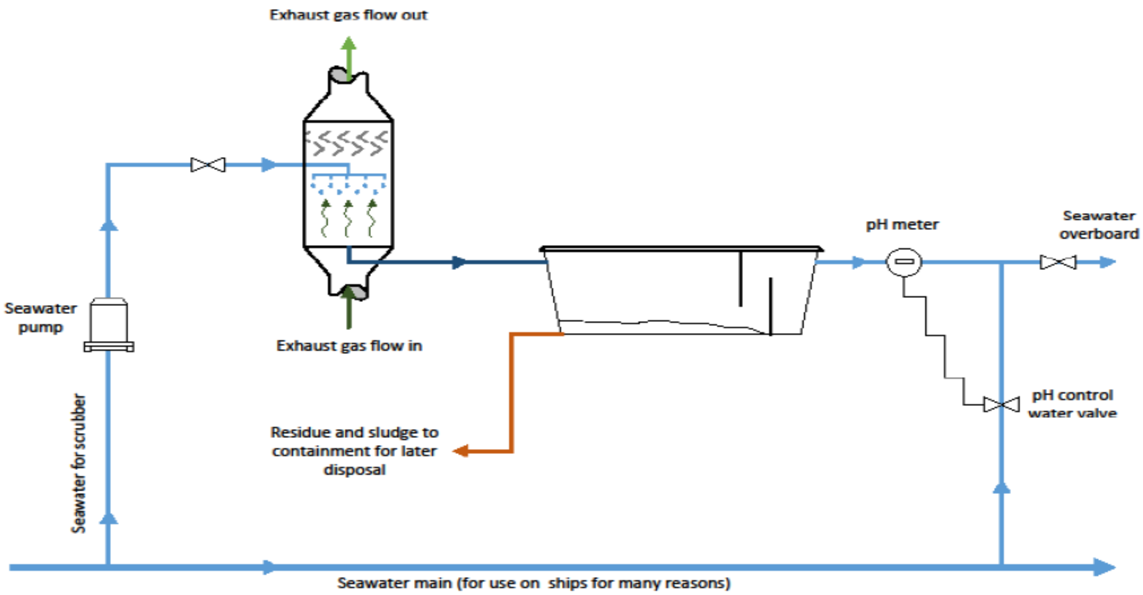

Figure A.1. Open-loop exhaust gas wet scrubber system.

This design requires a large amount of sea water and subsequently requires a large pumping capacity. The alkalinity of sea water varies depending on the body of water and may not be an efficient or effective method in some areas. This design does have the benefit of simplicity and does not require much maintenance attention or a large amount of onboard storage space.

2. Closed-loop Scrubber System

Closed-loop scrubber systems operate very similar to open loop systems but utilize an onboard source of scrubber medium and do not discharge the scrubber effluent to the open sea. Closed-loop systems utilize fresh water treated with caustic soda (sodium hydroxide) to provide alkalinity. Figure A.2 is an example of a closed-loop scrubber that may be found on an ocean-going vessel.

Fresh water for the caustic solution can either come from a fresh water storage tank or generated from sea water with fresh water generators (evaporators). This fresh water source can provide make-up to be mixed with the scrubber medium to maintain an appropriate alkalinity.

After mixing with the scrubber solution, the SO_x from the exhaust gas stream is converted into harmless sodium sulphate. The scrubber medium is drawn from a designated storage tank and then discharged either directly back to the storage tank or to a treatment system to remove dissolved pollutants. The treatment may result in sludge or final waste product that requires storage while the vessel is at sea and eventual removal from the vessel.

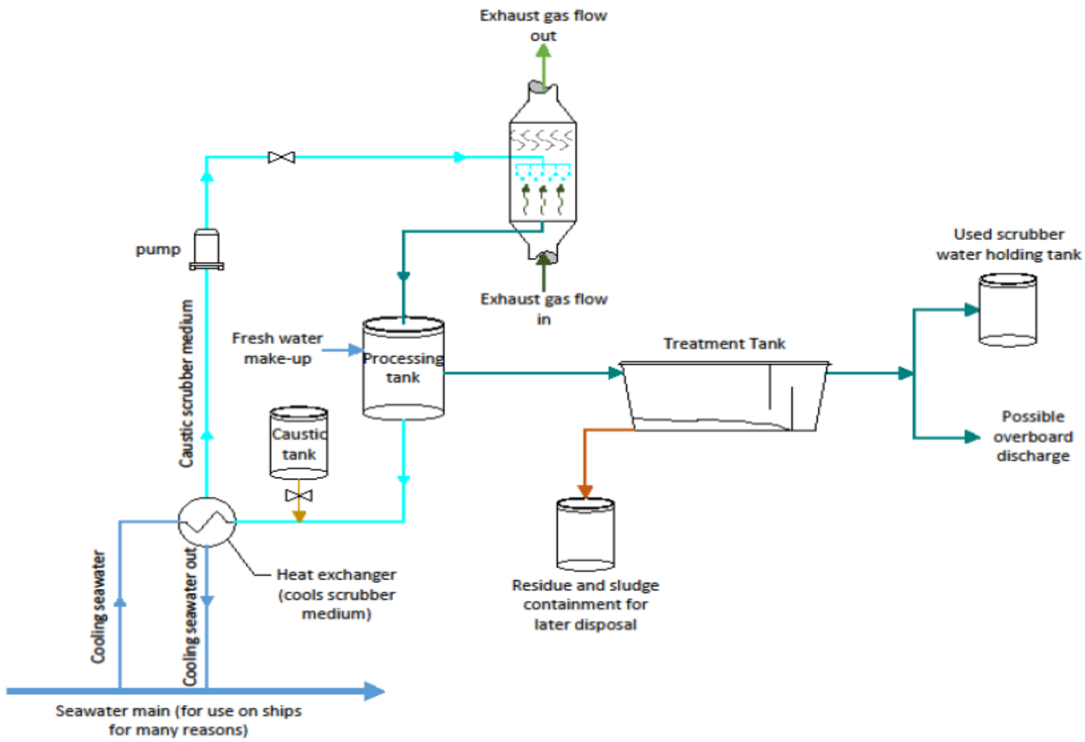

Figure A.2. Closed-loop exhaust gas web scrubber system.

The main benefit of a closed-loop system is that it can be operated independent of the body of water that the vessel is in so there are no environmental impacts from discharge at sea. Because the closed-loop system uses a caustic solution, the system can use much less scrubber medium than is necessary in an open-loop system. However, the system requires more tanks, and pumps than an open-loop system. This closed-loop design requires tanks for caustic soda storage, fresh water storage, scrubber medium mixing and usable scrubber medium storage as well as tanks for used scrubber medium and sludge generated from scrubbing.

3. <u>Hybrid Scrubber Systems</u>

A hybrid system is a combination of the above that can operate as an open-loop system when discharge regulations allow and a closed-loop system when discharges are restricted. This system allows for the bypass of the closed-loop process while at sea and easy return to closed loop while in port and operating at reduced engine loads. Because the system is only operated in closed-loop mode while in port while at reduced engine load, they do not require the large amount of storage for materials that the expressly closed-loop system does.

Dry Scrubber Systems

Although a dry scrubber may resemble a wet scrubber in many ways, a dry scrubber utilizes a scrubbing medium that is not a water-based liquid. Dry scrubbers are designed to have exhaust gas pass through a bulk sorbent material which is either in powder/granulated or pelletized form. High scrubber temperatures give the collateral benefit of burning off soot and oily residuals prior to the exhaust gas release to atmosphere.

Hydrated lime is often used and the calcium in the lime reacts with sulfur dioxide in the exhaust gas to form calcium sulfite which subsequently oxidizes to form calcium sulfate. Calcium sulphate can be mixed with water to make gypsum. In this design, both the fresh dry scrubber lime must be stored onboard until use and the spent material must be stored on board until it is disposed of. This requires space which is very limited on board a marine vessel. However, the spent medium is not considered a waste as the gypsum can eventually be used as fertilizer or construction material. In certain circumstances, the resulting gypsum may be a value-added product.

Dry scrubbers do not require the use of circulator pumps, so they use less power and they do not produce a liquid effluent that requires storage or direct overboard discharge. However, they weigh more than wet scrubber systems and require regular changeover of medium requiring regular attention by vessel maintenance crew. Dry scrubbers provide efficient removal of both SO_x and NO_x.

Appendix B. Diesel Particulate Filters

The combustion of diesel fuel in a diesel engine results in the generation of PM from incomplete combustion (soot) and impurities suspended in the diesel fuel. The PM emitted from a diesel engine can range in size from ultrafine particles (respirable, 0.1 micron in size and smaller), $PM_{2.5}$ (respirable, 2.5 microns and smaller), PM_{10} (10 microns and smaller) to larger visible PM emissions. A particulate filter acts to capture this material on the filters surface.

DPFs can be of the partial or flow-through filter design or wall-flow design. Partial or flow-through filters[77] pass exhaust gases in essentially a straight line through the filter and rely on material adhering to the filter surface area as the gases pass through. Surfaces in this type of filter are rough at a microscopic level and PM impinges on this rough surface area adhering to those surfaces. Partial or flow-through filters may or may not utilize a catalyst material to increase capture efficiency and surface regeneration efficiency.

The higher efficiency wall-flow filters are designed to change the direction of the exhaust gases as they pass through the filter which causes entrained PM to impart its energy on filter surfaces making the PM more likely to drop out of suspension in the exhaust gas stream and adhere to the filter surface and drop.

DPFs must be durable and continue to perform in a high temperature, dirty atmosphere for long periods and heavy engine use. Much like a catalytic converter, DPFs utilize a honeycomb design to allow gases to pass through and provide ample surface area for the PM to adhere to. Material used to construct DPFs can include ceramic material (cordierite) which is relatively affordable, ceramic fibers which are woven together to provides porosity, silicon carbide which has a high melting point (melting point of almost 5,000 ^{o} F), woven metal fibers which allow for an electric current for surface area regeneration and paper which is affordable and disposable. Capture needs and affordability are often the deciding factors in determining the appropriate filter for a certain application.

As the filter's available surface area is used, it is necessary to periodically regenerate it. This is accomplished by oxidizing (burning) the soot that has accumulated on the filter surfaces. Soot burns at temperatures greater than 500 ^{o} F. Soot burning can be accomplished passively by using the heat of the engine's exhaust gas. This process may include adding a catalyst to the filter to increase the rate at which the soot can be combusted. Active strategies to regenerate filter surface areas include alternative methods to heat the engine's exhaust gases to temperatures that ignite the soot and combustible material captured by the filter. These active methods can include microwave energy, electric (resistive) heating coils, increasing exhaust gas temperatures through engine tuning (late fuel injection or fuel injection during the exhaust stroke), introducing a catalyst into the fuel which will react with soot to lower soot combustion temperatures, post turbo fuel burners and catalytic oxidizers to name a few.

[77] MECA Particulate Filters, http://www meca.org/technology/technology-details?id=6

Appendix C. Marine Vapor Recovery Systems

One method of vapor recovery is accomplished by allowing the negative pressure of the unloading tank to draw vapors back to that space. Systems that utilizes this method of vapor capture are called "vapor-balance" systems and are considered "passive" vapor control methods. Other VOC capture methods include adsorption onto the surface of a solid material (called an adsorbent), absorption into a liquid or solid material, incineration either by flare or incinerator, and condensation in which the vapors are cooled to a temperature at which the vapors condense to a liquid. Vapor control systems that utilize these methods are considered "active" vapor control systems.

Many marine vessels whose function is to deliver liquid petroleum-based products in bulk (i.e., tankers) have installed vapor control systems so that the vessel can have the versatility to meet the requirements that may be encountered at ports globally. If a vessel in a U.S. port, including any Maine port, utilizes a vapor control system during the transfer of an applicable liquid or gas product, that vessel's vapor control system must meet the installation and operational standards for that control method as established in federal regulations.

Some states, including New Jersey[78] and California[79], have adopted requirements that apply to loading, lightering, ballasting, and housekeeping events where a marine tank vessel is filled with an organic liquid or petroleum-based product or where a liquid is placed into a marine tank vessel's cargo tanks that had previously held organic liquid or petroleum-based products. These activities potentially generate VOC emissions which would require control methods under these state's requirements. These requirements are designed to address facilities that undertake tank operations but do not meet NESHAP applicability thresholds.

[78] New Jersey's Marine Tank Vessel Operations regulation, https://www.nj.gov/dep/aqm/currentrules/Sub16.pdf
[79] California's Marine Tank Vessel Operations regulation, http://www.aqmd.gov/docs/default-source/rule-book/reg-xi/rule-1142.pdf?sfvrsn=4