CHAPTER 3 EMISSION INVENTORY

CHAPTER 3 Emission Inventory

3.1 Introduction

Ships (i.e., ocean-going vessels) are significant contributors to the total United States (U.S.) mobile source emission inventory. The U.S. ship inventory reported here focuses on Category 3 (C3) vessels, which use C3 engines for propulsion. C3 engines are defined as having displacement above 30 liters per cylinder (L/cyl). The resulting inventory includes emissions from both propulsion and auxiliary engines used on these vessels, as well as those on gas and steam turbine vessels.

Most of the vessels operating in U.S. ports that have propulsion engines less than 30 liters per cylinder are domestic and are already subject to strict national standards affecting NO_X, PM, and fuel sulfur content. As such, the inventory does not include any ships, foreign or domestic, powered by Category 1 or Category 2 (i.e., <30 L/cyl) engines. In addition, as discussed in Sections 3.3.2.5 and 3.3.3.2, this inventory is primarily based on activity data for ships that carry foreign cargo. Category 3 vessels carrying domestic cargo that operate only between U.S. ports are only partially accounted for in this inventory.[1] Emissions due to military vessels are also excluded.

The regional and national inventories for C3 vessels presented in this chapter are sums of independently constructed port and interport emissions inventories. Port inventories were developed for 89 deep water and 28 Great Lake ports in the U.S.[2] While there are more than 117 ports in the U.S., these are the top U.S. ports in terms of cargo tonnage. Port-specific emissions were calculated with a “bottom-up” approach, using data for vessel calls, emission factors, and activity for each port. Interport emissions were obtained using the Waterway Network Ship Traffic, Energy and Environment Model (STEEM).[3,4] STEEM also uses a “bottom-up” approach, estimating emissions from C3 vessels using historical North American shipping activity, ship characteristics, and activity-based emission factors. STEEM was used to quantify and geographically (i.e., spatially) represent interport vessel traffic and emissions for vessels traveling within 200 nautical miles (nm) of the U.S.

The detailed port inventories were spatially merged into the STEEM gridded inventory to create a comprehensive inventory for Category 3 vessels. For the 117 ports, this involved removing the near-port portion of the STEEM inventory and replacing it with the detailed port inventories. For the remaining U.S. ports for which detailed port inventories are not available, the near-port portion of the STEEM inventory was simply retained. This was done for a base year of 2002. Inventories for 2020 were then projected using regional growth rates[5,6] and adjustment factors to account for the International Maritime Organization (IMO) Tier 1 and Tier 2 NO_X standards and NO_X retrofit program.[2] Inventories incorporating additional Tier 3 NO_X and fuel sulfur controls within the proposed Emission Control Area (ECA) were also developed for 2020 and 2030.

This chapter details the methodologies used to create the baseline and future year inventories and presents the resulting inventories for the U.S. Section 3.2 describes the modeling domain and geographic regions used in this analysis. Section 3.3 describes the methodology and results for the 2002 base year inventory. Section 3.4 follows with a discussion of the growth rates and methodology used to create the 2020 and 2030 baseline and control inventories. Section 3.5 presents the estimated contribution of Category 3 vessels to U.S. national and local inventories. Section 3.6 follows with estimates of the projected emission reductions due to the proposed control program. Section 3.7 concludes the chapter by describing the changes in the inventories between the baseline scenarios used for the air quality modeling and the updated baseline scenarios in this proposed rule.

The inventory estimates reported in this chapter include emissions out to 200 nm from the U.S. coastline, including Alaska and Hawaii, but not extending into the Exclusive Economic Zone (EEZ) of neighboring countries. Inventories are presented for the following pollutants: oxides of nitrogen (NO_X), particulate matter ($PM_{2.5}$ and PM_{10}), sulfur dioxide (SO_2), hydrocarbons (HC), carbon monoxide (CO), and carbon dioxide (CO_2). The PM inventories include directly emitted PM only, although secondary sulfates are taken into account in the air quality modeling.

3.2 Modeling Domain and Geographic Regions

The inventories described in this chapter reflect ship operations that occur within the area that extends 200 nautical miles (nm) from the official U.S. baseline, which is recognized as the low-water line along the coast as marked on the official U.S. nautical charts in accordance with the articles of the Law of the Sea. This boundary is roughly equivalent to the border of the U.S Exclusive Economic Zone. The U.S. region was then clipped to the boundaries of the U.S. Exclusive Economic Zone. The boundary was divided into regions using geographic information system (GIS) shapefiles obtained from the National Oceanic and Atmospheric Administration, Office of Coast Survey.[7] The accuracy of the NOAA shapefiles was verified with images obtained from the U.S. Geological Survey. The confirmed NOAA shapefiles were then combined with a shapefile of the U.S. international border from the National Atlas.[8]

The resulting region was further subdivided for this analysis to create regions that were compatible with the geographic scope of the regional growth rates, which are used to project emission inventories for the years 2020 and 2030, as described later in this document.

- The Pacific Coast region was split into separate North Pacific and South Pacific regions along a horizontal line originating from the Washington/Oregon border (Latitude 46° 15’ North).

- The East Coast and Gulf of Mexico regions were divided along a vertical line roughly drawn through Key Largo (Longitude 80° 26’ West).

- The Alaska region was divided into separate Alaska Southeast and Alaska West regions along a straight line intersecting the cities of Naknek and Kodiak. The Alaska Southeast region includes most of the State’s population, and the Alaska West region includes the emissions from ships on a great circle route along the Aleutian Islands between Asia and the U.S. West Coast.

- For the Great Lakes domain, a similar approach was used to create shapefiles containing all the ports and inland waterways in the near port inventory and extending out into the lakes to the international border with Canada. The modeling domain spanned from Lake Superior on the west to the point eastward in the State of New York where the St. Lawrence River parts from U.S. soil.

- The Hawaiian domain was subdivided so that a distance of 200 nm beyond the southeastern islands of Hawaii, Maui, Oahu, Molokai, Niihau, Kauai, Lanai, and Kahoolawe was contained in Hawaii East. The remainder of the Hawaiian Region was then designated Hawaii West.

This methodology resulted in nine separate regional modeling domains that are identified below and shown in Figure 3-1. U.S. territories are not included in this analysis.

- South Pacific (SP)
- North Pacific (NP)
- East Coast (EC)
- Gulf Coast (GC)
- Alaska Southeast (AE)
- Alaska West (AW)
- Hawaii East (HE)
- Hawaii West (HW)
- Great Lakes (GL)

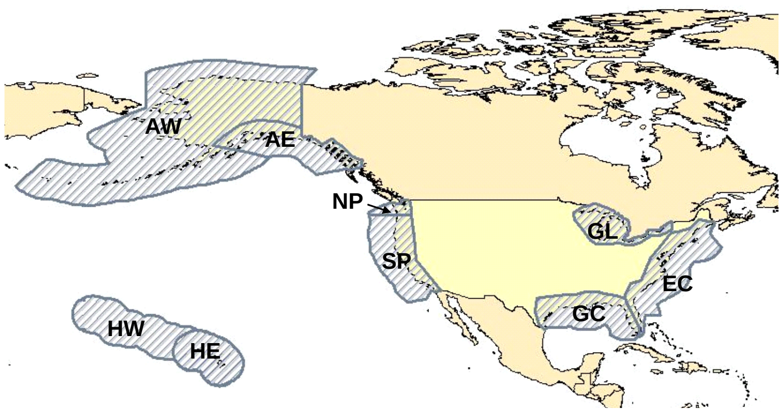

Figure 3-1 Regional Modeling Domains

3.3 Development of 2002 Baseline Inventory

This section describes the methodology and inputs, and presents the resulting inventories for the 2002 baseline calendar year. The first section describes the general methodology. The second section describes the methodology, inputs, and results for near port emissions. The third section describes the methodology and inputs for emissions when operating away from port (also referred to as "interport" emissions). The fourth section describes the method for merging the interport and near port portions of the inventory. Resulting total emissions for the U.S., as well as for nine geographic regions within the U.S., are then presented.

3.3.1 Outline of Methodology

The total inventory was created by summing emissions estimates for ships while at port (near port inventories) and while underway (interport inventories). Near port inventories for calendar year 2002 were developed for 117 U.S. commercial ports that engage in foreign trade. Based on an ICF International analysis,[9] these 117 commercial ports encompass nearly all U.S. C3 vessel calls.[10]

The outer boundaries of the ports are defined as 25 nm from the terminus of the reduced speed zone for deep water ports and 7 nm from the terminus of the reduced speed zone for Great Lake ports. Port emissions are calculated for different modes of operation and then summed. Emissions for each mode are calculated using port-specific information for vessel calls, vessel characteristics, and activity, as well as other inputs that vary instead by vessel or engine type (e.g., emission factors).

The interport inventory was estimated using the Waterway Network Ship Traffic, Energy, and Environmental Model (STEEM).[3,4] The model geographically characterizes emissions from ships traveling along shipping lanes to and from individual ports, in addition to the emissions from vessels transiting near the ports. The shipping lanes were identified from actual ship positioning reports. The model then uses detailed information about ship destinations, ship attributes (e.g., vessel speed and engine horsepower), and emission factors to produce spatially allocated (i.e., gridded) emission estimates for ships engaged in foreign commerce.

The 117 near port inventories are an improvement upon STEEM's near port results in several ways. First, the precision associated with STEEM's use of ship positioning data may be less accurate in some locations, especially as the lanes approach shorelines where ships would need to follow more prescribed paths. Second, the STEEM model includes a maneuvering operational mode (i.e., reduced speed) that is generally assumed to occur for the first and last 20 kilometers of each trip when a ship is leaving or entering a port. In reality, the distance when a ship is traveling at reduced speeds varies by port. Also, the distance a ship traverses at reduced speeds often consists of two operational modes: a reduced speed zone (RSZ) as a ship enters or leaves the port area and actual maneuvering at a very low speed near the dock. Third, the STEEM model assumes that the maneuvering distance occurs at an engine load of 20 percent, which represents a vessel speed of approximately 60 percent of cruise speed. This is considerably faster than ships would maneuver near the docks. The single maneuvering speed assumed by STEEM also does not reflect the fact that the reduced speed zone, and therefore emissions, may vary by port. Fourth, and finally, the STEEM model does not include the emissions from auxiliary engines during hotelling operations at the port. The near-port inventories correct these issues.

The regional emission inventories produced by the current STEEM interport model are most accurate for vessels while cruising in ocean or Great Lakes shipping lanes, and the near port inventories, which use more detailed local port information, are significantly more accurate near the ports. Therefore, the inventories in this analysis are derived by merging together: (1) the near port inventories, which extend 25 nautical miles and 7 nautical miles from the terminus of the RSZ for deep water ports and Great Lake ports, respectively, and (2) the remaining interport portion of the STEEM inventory, which extends from the endpoint of the near port inventories to the 200 nautical mile boundary or international border with Canada, as appropriate. Near some ports, a portion of the underlying STEEM emissions were retained if it was determined that the STEEM emissions included ships traversing the area near a port, but not actually entering or exiting the port.

3.3.2 Near Port Emissions

Near port inventories for calendar year 2002 were developed for ocean-going vessels at 89 deep water and 28 Great Lake ports in the U.S. The inventories include emissions from both propulsion and auxiliary engines on these vessels.

This section first describes the selection of the ports for analysis and then provides the methodology used to develop the near port inventories. This is followed by a description of the key inputs. Total emissions by port and pollutant for 2002 are then presented. The work summarized here was conducted by ICF International under contract to EPA.[2] The ICF documentation provides more detailed information.[2]

3.3.2.1 Selection of Individual Ports to be Analyzed

All 150 deep sea and Great Lake ports in the Principal Ports of the United States dataset[11] were used as a starting point. Thirty ports which had no foreign traffic were eliminated because there is no information in the U.S. Army Corps of Engineers (USACE) entrances and clearances data about domestic traffic. (See Section 3.3.2.5 for a further discussion of domestic traffic and how it is accounted for in this study). In addition, two U.S. Territory ports in Puerto Rico were removed as these were outside the area of interest for this study. Several California ports were added to the principle ports list because ARB provided the necessary data and estimates for those ports. This is discussed in Section 3.3.2.4.1. Also, a conglomerate port in the Puget Sound area was added as discussed in Section 3.3.2.4.2. The final list of 117 deep sea and Great Lake ports, along with their coordinates, is given in the Appendix, Table 3-102.

3.3.2.2 Port Methodology

Near port emissions for each port are calculated for four modes of operation: (1) hotelling, (2) maneuvering, (3) reduced speed zone (RSZ), and (4) cruise. Hotelling, or dwelling, occurs while the vessel is docked or anchored near a dock, and only the auxiliary engine(s) are being used to provide power to meet the ship's energy needs. Maneuvering occurs within a very short distance of the docks. The RSZ varies from port to port, though generally the

RSZ would begin and end when the pilots board or disembark, and typically occurs when the near port shipping lanes reach unconstrained ocean shipping lanes. The cruise mode emissions in the near ports analysis extend 25 nautical miles beyond the end of the RSZ lanes for deep water ports and 7 nautical miles for Great Lake ports.

Emissions are calculated separately for propulsion and auxiliary engines. The basic equation used is as follows:

Equation 3-1

$$Emissions_{\mathrm{mode}[eng]} = (calls) \times (P_{[eng]}) \times (hrs/call_{\mathrm{mode}}) \times (LF_{\mathrm{mode}[eng]}) \times (EF_{[eng]}) \times (Adj) \times (10^{-6}\ tonnes/g)$$

Where:
Emissions$_{\mathrm{mode\ [eng]}}$ = Metric tonnes emitted by mode and engine type
Calls = Round-trip visits (i.e., one entrance and one clearance is considered a call)
$P_{[\mathrm{eng}]}$ = Total engine power by engine type, in kilowatts
hrs/call$_{\mathrm{mode}}$ = Hours per call by mode
$LF_{\mathrm{mode\ [eng]}}$ = Load factor by mode and engine type (unitless)
$EF_{[\mathrm{eng}]}$ = Emission factor by engine type for the pollutant of interest, in g/kW-hr
(these vary as a function of engine type and fuel used, rather than activity mode)
Adj = Low load adjustment factor, unitless (used when the load factor is below 0.20)
10^{-6} = Conversion factor from grams to metric tonnes

Main engine load factors are calculated directly from the propeller curve based upon the cube of actual speed divided by maximum speed (at 100% maximum continuous rating [MCR]). In addition, cruise mode activity is based on cruise distance and speed inputs. The following sections provide the specific equations used to calculate propulsion and auxiliary emissions for each activity mode.

3.3.2.2.1 Cruise

Cruise emissions are calculated for both propulsion (main) and auxiliary engines. The basic equation used to calculate cruise mode emissions for the main engines is:

Equation 3-2

$$Emissions_{cruise[main]} = (calls) \times (P_{[main]}) \times (hrs/call_{cruise}) \times (LF_{cruise[main]}) \times (EF_{[main]}) \times (10^{-6}\ tonnes/g)$$

Where:
Emissions$_{\mathrm{cruise\ [main]}}$ = Metric tonnes emitted from main engines in cruise mode
Calls = Round-trip visits (i.e., one entrance and one clearance is considered a call)
$P_{[\mathrm{main}]}$ = Total main engine power, in kilowatts
hrs/call$_{\mathrm{cruise}}$ = Hours per call for cruise mode
$LF_{\mathrm{cruise\ [main]}}$ = Load factor for main engines in cruise mode (unitless)
$EF_{[\mathrm{main}]}$ = Emission factor for main engines for the pollutant of interest, in g/kW-hr (these vary as a function of engine type and fuel used, rather than activity mode)
10^{-6} = Conversion factor from grams to metric tonnes

In addition, the time in cruise is calculated as follows:

Equation 3-3

$$Hrs/call_{cruise} = Cruise\ Distance[nmiles]/Cruise\ Speed\ [knots] \times 2\ trips/call$$

Where:
Cruise distance = one way distance (25 nautical miles for deep sea ports, and 7 nautical miles for Great Lake ports)
Cruise speed = vessel service speed, in knots
2 trips/call = Used to calculate round trip cruise distance

Main engine load factors are calculated directly from the propeller curve based upon the cube of actual speed divided by maximum speed (at 100% maximum continuous rating [MCR]):

Equation 3-4

$$LoadFactor_{cruise[main]} = \left(Cruise\ Speed[knots]/Maximum\ Speed[knots]\right)^3$$

Since cruise speed is estimated at 94 percent of maximum speed[12], the load factor for main engines at cruise is 0.83.

Substituting Equation 3-3 for time in cruise into Equation 3-2, and using the load factor of 0.83, the equation used to calculate cruise mode emissions for the main engines becomes the following:

Equation 3-5 Cruise Mode Emissions for Main Engines

$$Emissions_{cruise[main]} = (calls) \times (P_{[main]}) \times (Cruise\ Distance/Cruise\ Speed) \times (2\ trips/call) \times 0.83 \times (EF_{[main]}) \times (10^{-6}\ tonnes/g)$$

Where:
$Emissions_{cruise\ [main]}$ = Metric tonnes emitted from main engines in cruise mode
calls = Round-trip visits (i.e., one entrance and one clearance is considered a call)
$P_{[main]}$ = Total main engine power, in kilowatts
Cruise distance = one way distance (25 nautical miles for deep sea ports, and 7 nautical miles for Great Lake ports)
Cruise speed = vessel service speed, in knots
2 trips/call = Used to calculate round trip cruise distance
0.83 = Load factor for main engines in cruise mode, unitless
$EF_{[main]}$ = Emission factor for main engines for the pollutant of interest, in g/kW-hr (these vary as a function of engine type and fuel used, rather than activity mode)
10^{-6} = Conversion factor from grams to metric tonnes

The equation used to calculate cruise mode emissions for the auxiliary engines is:

Equation 3-6 Cruise Mode Emissions for Auxiliary Engines

$$Emissions_{cruise[aux]} = (calls) \times (P_{[aux]}) \times (Cruise\ Distance/Cruise\ Speed) \times (2\ trips/call) \times (LF_{cruise[aux]}) \times (EF_{[aux]}) \times (10^{-6}\ tonnes/g)$$

Where:
$Emissions_{cruise[aux]}$ = Metric tonnes emitted from auxiliary engines in cruise mode
calls = Round-trip visits (i.e., one entrance and one clearance is considered a call)
$P_{[aux]}$ = Total auxiliary engine power, in kilowatts

Cruise distance = one way distance (25 nautical miles for deep sea ports, and 7 nautical miles for Great Lake ports)
Cruise speed = vessel service speed, in knots
2 trips/call = Used to calculate round trip cruise distance
$LF_{cruise\ [aux]}$ = Load factor for auxiliary engines in cruise mode, unitless (these vary by ship type and activity mode)
$EF_{[aux]}$ = Emission factor for auxiliary engines for the pollutant of interest, in g/kW-hr (these vary as a function of engine type and fuel used, rather than activity mode)
10^{-6} = Conversion factor from grams to metric tonnes

The inputs of calls, cruise distance, and vessel speed are the same for main and auxiliary engines. Relative to the main engines, auxiliary engines have separate inputs for engine power, load factor, and emission factors. The activity-related inputs, such as engine power, vessel speed, and calls, can be unique to each ship calling on a port, if ship-specific information is available. For this analysis, as discussed in Section 3.3.2.3.1.1, these inputs were developed by port for bins that varied by ship type, engine type, and dead weight tonnage (DWT) range.

3.3.2.2.2 Reduced Speed Zone

RSZ emissions are calculated for both propulsion (main) and auxiliary engines. The basic equation used to calculate RSZ mode emissions for the main engines is:

Equation 3-7

$$Emissions_{RSZ[main]} = (calls) \times (P_{[main]}) \times (hrs/call_{RSZ}) \times (LF_{RSZ[main]}) \times (EF_{[main]}) \times (Adj) \times (10^{-6}\ tonnes/g)$$

Where:
$Emissions_{RSZ[main]}$ = Metric tonnes emitted from main engines in RSZ mode
calls = Round-trip visits (i.e., one entrance and one clearance is considered a call)
$P_{[main]}$ = Total main engine power, in kilowatts
$hrs/call_{RSZ}$ = Hours per call for RSZ mode
$LF_{RSZ\ [main]}$ = Load factor for main engines in RSZ mode, unitless
$EF_{[main]}$ = Emission factor for main engines for the pollutant of interest, in g/kW-hr (these vary as a function of engine type and fuel used, rather than activity mode)
Adj = Low load adjustment factor, unitless (used when the load factor is below 0.20)
10^{-6} = Conversion factor from grams to metric tonnes

In addition, the time in RSZ mode is calculated as follows:

Equation 3-8

$$Hrs / call_{RSZ} = RSZ\ Distance[nmiles] / RSZ\ Speed[knots] \times 2\,trips / call$$

Load factor during the RSZ mode is calculated as follows:

Equation 3-9

$$LoadFactor_{RSZ\,[main]} = \left(RSZ\ Speed / Maximum\ Speed\right)^3$$

In addition:

Equation 3-10

$$Maximum\,Speed = Cruise\,Speed / 0.94$$

Where:
0.94 = Fraction of cruise speed to maximum speed

Substituting

Equation 3-10 into Equation 3-9, the equation to calculate load factor becomes:

Equation 3-11

$$LoadFactor_{RSZ\,[main]} = \left(RSZ\ Speed \times 0.94 / Cruise\,Speed\right)^3$$

Where:
0.94 = Fraction of cruise speed to maximum speed

Load factors below 2 percent were set to 2 percent as a minimum.

Substituting Equation 3-8 for time in mode and Equation 3-11 for load factor into Equation 3-7 , the expression used to calculate RSZ mode emissions for the main engines becomes:

Equation 3-12 RSZ Mode Emissions for Main Engines

$$Emissions_{RSZ[aux]} = (calls) \times (P_{[aux]}) \times (RSZ Distance / RSZ Speed) \times (2 trips/call) \times \left(RSZ Speed \times 0.94 / Cruise Speed\right)^3 \times (EF_{[aux]}) \times \left(Adj\right) \times (10^{-6}\ tonnes/g)$$

Where:
$Emissions_{RSZ[main]}$ = Metric tonnes emitted from main engines in RSZ mode
calls = Round-trip visits (i.e., one entrance and one clearance is considered a call)
$P_{[main]}$ = Total main engine power, in kilowatts
RSZ distance = one way distance, in nautical miles (specific to each port)
RSZ speed = speed, in knots (specific to each port)
2 trips/call = Used to calculate round trip RSZ distance
Cruise speed = vessel service speed, in knots
$EF_{[main]}$ = Emission factor for main engines for the pollutant of interest, in g/kW-hr (these vary as a function of engine type and fuel used, rather than activity mode)
Adj = Low load adjustment factor, unitless (used when the load factor is below 0.20)
10^{-6} = Conversion factor from grams to tons
0.94 = Fraction of cruise speed to maximum speed

Emission factors are considered to be relatively constant down to about 20 percent load. Below that threshold, emission factors tend to increase significantly as the load decreases. During the RSZ mode, load factors can fall below 20 percent. Low load multiplicative adjustment factors were developed and applied when the load falls below 20 percent (0.20). If the load factor is 0.20 or greater, the low load adjustment factor is set to 1.0.

The equation used to calculate RSZ mode emissions for the auxiliary engines is:

Equation 3-13 RSZ Mode Emissions for Auxiliary Engines

$$Emissions_{RSZ[aux]} = (calls) \times (P_{[aux]}) \times (RSZ\,Distance / RSZ\,Speed) \times (2\,trips/call) \times (LF_{RSZ[aux]}) \times (EF_{[aux]}) \times (10^{-6}\ tonnes/g)$$

Where:
$Emissions_{RSZ[aux]}$ = Metric tonnes emitted from auxiliary engines in RSZ mode
calls = Round-trip visits (i.e., one entrance and one clearance is considered a call)
$P_{[aux]}$ = Total auxiliary engine power, in kilowatts
RSZ distance = one way distance, in nautical miles (specific to each port)
RSZ speed = speed, in knots (specific to each port)
2 trips/call = Used to calculate round trip cruise distance
$LF_{RSZ\ [aux]}$ = Load factor for auxiliary engines in RSZ mode, unitless (these vary by ship type and activity mode)
$EF_{[aux]}$ = Emission factor for auxiliary engines for the pollutant of interest, in g/kW-hr (these vary as a function of engine type and fuel used, rather than activity mode)
10^{-6} = Conversion factor from grams to metric tonnes

Unlike main engines, there is no need for a low load adjustment factor for auxiliary engines, because of the way they are generally operated. When only low loads are needed, one or more engines are shut off, allowing the remaining engines to maintain operation at a more efficient level.

The inputs of calls, RSZ distance, and RSZ speed are the same for main and auxiliary engines. Relative to the main engines, auxiliary engines have separate inputs for engine power, load factor, and emission factors. The RSZ distances vary by port rather than vessel or engine type. Some RSZ speeds vary by ship type, while others vary by DWT. Mostly, however, RSZ speed is constant for all ships entering the harbor area. All Great Lake ports have reduced speed zone distances of three nautical miles occurring at halfway between cruise speed and maneuvering speed.

3.3.2.2.3 Maneuvering

Maneuvering emissions are calculated for both propulsion (main) and auxiliary engines. The basic equation used to calculate maneuvering mode emissions for the main engines is:

Equation 3-14

$$Emissions_{man[main]} = (calls) \times (P_{[main]}) \times (hrs/call_{man}) \times (LF_{man[main]}) \times (EF_{[main]}) \times (Adj) \times (10^{-6}\ tonnes/g)$$

Where:
$Emissions_{man[main]}$ = Metric tonnes emitted from main engines in maneuvering mode
calls = Round-trip visits (i.e., one entrance and one clearance is considered a call)
$P_{[main]}$ = Total main engine power, in kilowatts
$hrs/call_{man}$ = Hours per call for maneuvering mode
$LF_{man\ [main]}$ = Load factor for main engines in maneuvering mode, unitless
$EF_{[main]}$ = Emission factor for main engines for the pollutant of interest, in g/kW-hr (these vary as a function of engine type and fuel used, rather than activity mode)
Adj = Low load adjustment factor, unitless (used when the load factor is below 0.20)
10^{-6} = Conversion factor from grams to metric tonnes

Maneuvering time-in-mode is estimated based on the distance a ship travels from the breakwater or port entrance to the pier/wharf/dock (PWD). Maneuvering times also include shifts from one PWD to another or from one port within a greater port area to another. Average maneuvering speeds vary from 3 to 8 knots depending on direction and ship type. For consistency, maneuvering speeds were assumed to be the dead slow setting of approximately 5.8 knots.

Load factor during maneuvering is calculated as follows:

Equation 3-15

$$LoadFactor_{man[main]} = \left(Man\,Speed[knots] / Maximum\,Speed[knots]\right)^3$$

In addition:

Equation 3-16

$$Maximum\,Speed = Cruise\,Speed[knots] / 0.94$$

Where:
0.94 = Fraction of cruise speed to maximum speed

Also, the maneuvering speed is 5.8 knots. Substituting Equation 3-16 into Equation 3-15, and using a maneuvering speed of 5.8 knots, the equation to calculate load factor becomes:

Equation 3-17

$$LoadFactor_{man[main]} = \left(5.45 / Cruise\,Speed\right)^3$$

Load factors below 2 percent were set to 2 percent as a minimum.

Substituting Equation 3-17 for load factor into Equation 3-14, the expression used to calculate maneuvering mode emissions for the main engines becomes:

Equation 3-18 Maneuvering Mode Emissions for Main Engines

$$Emissions_{man[main]} = (calls) \times (P_{[main]}) \times (hrs/call_{man}) \times (5.45/Cruise\,Speed)^3 \times (EF_{[main]}) \times (Adj) \times (10^{-6}\ tonnes/g)$$

Where:
$Emissions_{man[main]}$ = Metric tonnes emitted from main engines in maneuvering mode
calls = Round-trip visits (i.e., one entrance and one clearance is considered a call)
$P_{[main]}$ = Total main engine power, in kilowatts
$hrs/call_{man}$ = Hours per call for maneuvering mode
Cruise speed = Vessel service speed, in knots
$EF_{[main]}$ = Emission factor for main engines for the pollutant of interest, in g/kW-hr (these vary as a function of engine type and fuel used, rather than activity mode)
Adj = Low load adjustment factor, unitless (used when the load factor is below 0.20)
10^{-6} = Conversion factor from grams to metric tonnes

Since the load factor during maneuvering usually falls below 20 percent, low load adjustment factors are also applied accordingly. Maneuvering times are not readily available for all 117 ports. For this analysis, maneuvering times and load factors available for a subset of the ports were used to calculate maneuvering emissions for the remaining ports. This is discussed in more detail in Section 3.3.2.3.8.

The equation used to calculate maneuvering mode emissions for the auxiliary engines is:

Equation 3-19 Maneuvering Mode Emissions for Auxiliary Engines

$$Emissions_{man[aux]} = (calls) \times (P_{[aux]}) \times (hrs/call_{man}) \times (LF_{man[aux]}) \times (EF_{[aux]}) \times (10^{-6}\ tonnes/g)$$

Where:
$Emissions_{man[aux]}$ = Metric tonnes emitted from auxiliary engines in maneuvering mode
calls = Round-trip visits (i.e., one entrance and one clearance is considered a call)
$P_{[aux]}$ = Total auxiliary engine power, in kilowatts
$hrs/call_{man}$ = Hours per call for maneuvering mode
$LF_{man\ [aux]}$ = Load factor for auxiliary engines in maneuvering mode, unitless (these vary by ship type and activity mode)
$EF_{[aux]}$ = Emission factor for auxiliary engines for the pollutant of interest, in g/kW-hr (these vary as a function of engine type and fuel used, rather than activity mode)
10^{-6} = Conversion factor from grams to metric tonnes

Low load adjustment factors are not applied for auxiliary engines.

3.3.2.2.4 Hotelling

Hotelling emissions are calculated for auxiliary engines only, as main engines are not operational during this mode. The equation used to calculate hotelling mode emissions for the auxiliary engines is:

Equation 3-20 Hotelling Mode Emissions for Auxiliary Engines

$$Emissions_{hotel[aux]} = (calls) \times (P_{[aux]}) \times (hrs/call_{hotel}) \times (LF_{hotel[aux]}) \times (EF_{[aux]}) \times (10^{-6}\ tonnes/g)$$

Where:
$Emissions_{hotel[aux]}$ = Metric tonnes emitted from auxiliary engines in hotelling mode
calls = Round-trip visits (i.e., one entrance and one clearance is considered a call)
$P_{[aux]}$ = Total auxiliary engine power, in kilowatts
$hrs/call_{hotel}$ = Hours per call for hotelling mode
$LF_{hotel\ [aux]}$ = Load factor for auxiliary engines in hotelling mode, unitless (these vary by ship type and activity mode)
$EF_{[aux]}$ = Emission factor for auxiliary engines for the pollutant of interest, in g/kW-hr (these vary as a function of engine type and fuel used, rather than activity mode)
10^{-6} = Conversion factor from grams to metric tonnes

Hotelling times are not readily available for all 117 ports. For this analysis, hotelling times available for a subset of the ports were used to calculate hotelling emissions for the remaining ports. This is discussed in more detail in Section 3.3.2.3.8.

3.3.2.3 Inputs for Port Emission Calculations

From a review of the equations described in Section 3.3.2.2, the following inputs are required to calculate emissions for the four modes of operation (cruise, RSZ, maneuvering, and hotelling):

- Number of calls
- Main engine power
- Cruise (vessel service) speed
- Cruise distance
- RSZ distance for each port
- RSZ speed for each port
- Auxiliary engine power
- Auxiliary load factors
- Main and auxiliary emission factors
- Low load adjustment factors for main engines
- Maneuvering time-in-mode (hours/call)
- Hotelling time-in-mode (hours/call)

Note that load factors for main engines are not listed explicitly, since they are calculated as a function of mode and/or cruise speed. This section describes the inputs in more detail, as well as the sources for each input.

3.3.2.3.1 Calls and Ship Characteristics (Propulsion Engine Power and Cruise Speed)

For this analysis, U.S. Army Corps of Engineers (USACE) entrance and clearance data for 2002,[13] together with Lloyd's data for ship characteristics,[14] were used to calculate average ship characteristics and calls by ship type for each port. Information for number of calls, propulsion engine power, and cruise speed were obtained from these data.

3.3.2.3.1.1 Bins by Ship Type, Engine Type, and DWT Range

The records from the USACE entrances and clearances data base were matched with Lloyd's data on ship characteristics for each port. Calls by vessels that have either Category 1 or 2 propulsion engines were eliminated from the data set. The data was then binned by ship type, engine type and dead weight tonnage (DWT) range. The number of entrances and clearances in each bin are counted, summed together and divided by two to determine the number of calls (i.e., one entrance and one clearance was considered a call). For Great Lake ports, there is a larger frequency of ships either entering the port loaded and leaving unloaded (light) or entering the port light and leaving loaded. In these cases, there would only be one record (the loaded trip into or out of the port) that would be present in the data. For Great Lake ports, clearances were matched with entrances by ship name. If there was not a reasonable match, the orphan entrance or clearance was treated as a call.

Propulsion power and vessel cruise speed are also averaged for each bin. While each port is analyzed separately, the various bins and national average ship characteristics are given in Table 3-1 for deep sea ports and Table 3-2 for Great Lake ports. Auxiliary engine power was computed from the average propulsion power using the auxiliary power to propulsion power ratios discussed in Section 3.3.2.3.4.

Table 3-1 Bins and Average Ship Characteristics for Deep Sea Ports

Ship Type	Main Engine [a]	DWT Range	Calls	Engine Power (kW) Main	Engine Power (kW) Auxiliary	Cruise Speed (kts)	DWT
AUTO CARRIER	MSD	< 10,000	35	6,527	1,736	16.0	6,211
		10,000 – 20,000	224	10,499	2,793	18.2	13,003
		20,000 – 30,000	28	6,620	1,761	13.0	22,268
	MSD Total		286	9,640	2,564	17.4	13,063
	SSD	<10,000	84	7,927	2,109	17.7	8,845
		10,000 – 20,000	2,316	10,899	2,899	18.7	14,959
		20,000 – 30,000	621	13,239	3,522	19.5	24,860
	SSD Total		3,020	11,298	3,005	18.8	16,826
AUTO CARRIER Total			3,306	11,155	2,967	18.7	16,500
BARGE CARRIER	MSD	< 25,000	1	4,461	1,200	13.3	4,393
	MSD Total		1	4,461	1,200	13.3	4,393
	SSD	< 25,000	1	3,916	1,053	14.0	11,783
		35,000 – 45,000	20	19,463	5,236	18.0	44,799
		45,000 – 90,000	19	25,041	6,736	20.0	48,093
	SSD Total		40	21,724	5,844	18.9	45,538
	ST	35,000 – 45,000	5	24,196	6,509	21.7	41,294
	ST Total		5	24,196	6,509	21.7	41,294
BARGE CARRIER Total			45	21,779	5,859	19.1	44,657
BULK CARRIER	MSD	< 25,000	213	4,867	1,080	14.0	15,819
		25,000 – 35,000	6	8,948	1,986	14.0	29,984
		35,000 – 45,000	44	9,148	2,031	15.2	39,128
		45,000 – 90,000	51	9,705	2,155	14.3	71,242
		> 90,000	1	16,109	3,576	15.8	105,550
	MSD Total		314	6,360	1,412	14.2	28,621

Table 3-1 Bins and Average Ship Characteristics for Deep Sea Ports (continued)

Ship Type	Main Engine [a]	DWT Range	Calls	Engine Power (kW)		Cruise Speed (kts)	DWT
				Main	Auxiliary		
BULK CARRIER	SSD	< 25,000	1,194	5,650	1,254	14.2	19,913
		25,000 – 35,000	2,192	7,191	1,596	14.6	29,323
		35,000 – 45,000	1,742	8,515	1,890	14.7	39,875
		45,000 – 90,000	3,733	9,484	2,105	14.4	62,573
		> 90,000	352	14,071	3,124	14.5	112,396
	SSD Total		9,212	8,434	1,872	14.5	46,746
	ST	< 25,000	72	6,290	1,396	15.0	18,314
		25,000 – 35,000	3	8,948	1,986	15.0	33,373
	ST Total		75	6,379	1,416	15.0	18,819
BULK CARRIER Total			9,600	8,350	1,854	14.5	45,936
CONTAINER SHIP	MSD	< 25,000	1,005	6,846	1,506	17.2	8,638
		25,000 – 35,000	53	22,304	4,907	20.6	28,500
		35,000 – 45,000	59	26,102	5,742	22.3	39,932
		45,000 – 90,000	248	37,650	8,283	24.0	56,264
	MSD Total		1,365	13,878	3,053	18.8	19,419
	SSD	< 25,000	2,054	12,381	2,724	19.1	18,776
		25,000 – 35,000	2,360	19,247	4,234	20.5	31,205
		35,000 – 45,000	2,443	24,755	5,446	21.8	40,765
		45,000 – 90,000	6,209	36,151	7,953	23.3	58,604
		> 90,000	98	57,325	12,612	25.0	105,231
	SSD Total		13,163	27,454	6,040	21.9	44,513
	ST	< 25,000	46	20,396	4,487	20.8	19,963
		25,000 – 35,000	89	21,066	4,635	21.0	30,804
		35,000 – 45,000	41	23,562	5,184	21.0	40,949
	ST Total		176	21,472	4,724	21.0	30,334
CONTAINER SHIP Total			14,703	26,122	5,747	21.6	42,014
GENERAL CARGO	MSD	< 25,000	2,937	5,080	1,316	15.1	8,268
		25,000 – 35,000	38	9,458	2,450	15.4	30,746
		35,000 – 45,000	1	13,728	3,556	14.3	40,910
		45,000 – 90,000	9	11,932	3,090	16.0	50,250
	MSD Total		2,984	5,159	1,336	15.1	8,688
	SSD	< 25,000	2,357	6,726	1,742	15.4	14,409
		25,000 – 35,000	500	7,575	1,962	14.9	29,713
		35,000 – 45,000	1,122	9,269	2,401	15.2	41,568
		45,000 – 90,000	405	9,336	2,418	15.1	47,712
		> 90,000	6	10,628	2,753	14.5	134,981
	SSD Total		4,389	7,718	1,999	15.3	26,326
	ST	< 25,000	18	17,897	4,635	21.0	22,548
	ST Total		18	17,897	4,635	21.0	22,548
GENERAL CARGO Total			7,391	6,709	1,738	15.2	19,196

Table 3-1 Bins and Average Ship Characteristics for Deep Sea Ports (continued)

Ship Type	Main Engine [a]	DWT Range	Calls	Engine Power (kW) Main	Engine Power (kW) Auxiliary	Cruise Speed (kts)	DWT
MISCELLANEOUS	MSD	All	51	9,405	2,530	12.7	6,083
	MSD Total		51	9,405	2,530	12.7	6,083
	MSD-ED	All	6	16,968	4,565	12.7	15,795
	MSD-ED Total		6	16,968	4,565	12.7	15,795
	SSD	All	7	4,659	1,253	14.2	8,840
	SSD Total		7	4,659	1,253	14.2	8,840
	ST	All	1	12,871	3,462	21.0	16,605
	ST Total		1	12,871	3,462	21.0	16,605
MISCELLANEOUS Total			64	9,564	2,573	13.0	7,311
PASSENGER	MSD	<10,000	1,011	22,024	6,123	20.2	5,976
		10,000 - 20,000	24	96,945	26,951	28.5	15,521
	MSD Total		1,035	23,762	6,606	20.4	6,197
	MSD-ED	<10,000	1,964	39,095	10,868	20.9	7,345
		10,000 - 20,000	228	53,236	14,800	22.0	10,924
	MSD-ED Total		2,192	40,566	11,277	21.1	7,717
	SSD	<10,000	189	23,595	6,559	20.1	6,235
	SSD Total		189	23,595	6,559	20.1	6,235
	GT-ED	10,000 - 20,000	143	44,428	12,351	24.0	11,511
	GT-ED Total		143	44,428	12,351	24.0	11,511
	ST	<10,000	13	16,858	4,687	21.2	6,981
		10,000 - 20,000	52	29,982	8,335	18.0	13,960
	ST Total		65	27,357	7,605	18.6	12,564
PASSENGER Total			3,623	34,800	9,674	20.9	7,443
REEFER	MSD	<10,000	122	4,829	1,961	16.3	5,646
		10,000 - 20,000	60	12,506	5,077	20.0	11,632
	MSD Total		182	7,360	2,988	17.5	7,619
	SSD	<10,000	464	6,539	2,655	18.0	7,267
		10,000 - 20,000	801	12,711	5,161	20.8	13,138
	SSD Total		1,265	10,449	4,242	19.7	10,986
REEFER Total			1,447	10,060	4,084	19.5	10,562
RORO	MSD	<10,000	892	7,840	2,031	15.5	6,641
		10,000 - 20,000	286	9,312	2,412	17.0	11,338
		> 30,000	31	22,386	5,798	21.0	31,508
	MSD Total		1,208	8,561	2,217	16.0	8,389
	SSD	<10,000	132	7,240	1,875	15.0	4,695
		10,000 - 20,000	208	9,062	2,347	16.9	14,293
		20,000 - 30,000	31	12,781	3,310	18.9	22,146
		> 30,000	555	20,362	5,274	18.9	42,867
	SSD Total		925	15,702	4,067	17.9	30,321
	GT	> 30,000	1	47,076	12,193	24.0	36,827
	GT Total		1	47,076	12,193	24.0	36,827
	ST	10,000 – 20,000	2	22,373	5,795	25.0	16,144
		20,000 – 30,000	1	22,373	5,795	25.0	22,501
	ST Total		3	22,373	5,795	25.0	18,687
RORO Total			2,137	11,687	3,027	16.8	17,910

Table 3-1 Bins and Average Ship Characteristics for Deep Sea Ports (continued)

Ship Type	Main Engine [a]	DWT Range	Calls	Engine Power (kW)		Cruise Speed (kts)	DWT
				Main	Auxiliary		
TANKER	MSD	<30,000	650	4,888	1,031	14.3	11,415
		30,000 - 60,000	181	10,533	2,222	15.3	42,153
		60,000 - 90,000	148	9,782	2,064	14.7	74,245
		90,000 - 120,000	3	15,139	3,194	14.1	113,957
	MSD Total		981	6,697	1,413	14.6	26,847
	SSD	<30,000	3,050	6,303	1,330	14.6	17,145
		30,000 - 60,000	3,752	9,021	1,903	14.9	41,677
		60,000 - 90,000	1,766	10,310	2,175	14.6	74,595
		90,000 - 120,000	2,835	12,318	2,599	14.6	101,116
		120,000 - 150,000	258	15,840	3,342	14.7	144,405
		> 150,000	487	16,888	3,563	15.2	166,394
	SSD Total		12,147	9,755	2,058	14.7	61,353
	GT-ED	30,000 - 60,000	13	7,592	1,602	14.5	39,839
	GT-ED Total		13	7,592	1,602	14.5	39,839
	ST	< 30,000	2	13,534	2,856	18.0	27,235
		30,000 - 60,000	87	15,818	3,338	17.9	43,982
		60,000 - 90,000	73	26,848	5,665	18.9	70,108
		90,000 - 120,000	4	17,660	3,726	16.3	91,868
		120,000 - 150,000	3	19,125	4,035	16.0	122,409
		> 150,000	2	20,785	4,386	14.3	190,111
	ST Total		170	20,678	4,363	18.2	58,616
TANKER Total			13,310	9,667	2,040	14.8	58,754
TUG	MSD	All	48	7,579	2,039	14.5	626
	MSD Total		48	7,579	2,039	14.5	626
TUG Total			48	7,579	2,039	14.5	626
Grand Total			55,672	15,212	3,593	17.4	38,083

Note:
[a] Engine Types: MSD = medium speed engine; SSD = slow speed engine; ST = steam turbine; GT = gas turbine

Table 3-2 Bins and Average Ship Characteristics for Great Lake Ports

Ship Type	Main Engine [a]	DWT Range	Calls	Engine Power (kW) Main	Engine Power (kW) Auxiliary	Cruise Speed (kts)	DWT
BULK CARRIER	MSD	10,000 - 20,000	9	4,413	980	15.3	11,693
		20,000 - 30,000	4	8,826	1,959	14.0	28,481
		30,000 - 40,000	11	6,001	1,332	13.5	32,713
	MSD Total		24	5,876	1,305	14.2	24,125
	SSD	10,000 - 20,000	18	4,844	1,075	13.6	14,392
		20,000 - 30,000	208	6,995	1,553	14.6	27,486
		30,000 - 40,000	223	8,284	1,839	14.1	34,172
	SSD Total		449	7,549	1,676	14.3	30,282
	ST	20,000 - 30,000	23	6,910	1,534	15.5	26,513
	ST Total		23	6,910	1,534	15.5	26,513
BULK CARRIER Total			496	7,438	1,651	14.4	29,809
SELF UNLOADING BULK CARRIER	MSD	10,000 - 20,000	5	3,114	691	10.5	12,513
		20,000 - 30,000	12	6,436	1,429	15.0	28,591
		30,000 - 40,000	771	6,881	1,528	13.2	33,531
		> 40,000	67	12,140	2,695	13.5	65,089
	MSD Total		855	7,265	1,613	13.3	35,812
	SSD	20,000 - 30,000	275	6,659	1,478	15.0	26,504
		30,000 - 40,000	122	7,574	1,681	14.9	34,476
	SSD Total		397	6,940	1,541	14.9	28,954
	ST	< 10,000	26	3,236	718	12.3	4,538
		10,000 - 20,000	93	4,750	1,055	13.6	16,830
		20,000 - 30,000	79	6,679	1,483	16.6	28,847
	ST Total		198	5,321	1,181	14.6	20,011
SELF UNLOADING BULK CARRIER Total			1,450	6,910	1,534	13.9	31,776
GENERAL CARGO	MSD	< 10,000	87	4,436	847	15.1	6,755
		10,000 - 20,000	6	5,939	1,134	16.5	12,497
	MSD Total		93	4,533	866	15.2	7,125
	SSD	< 10,000	3	4,763	910	16.4	6,708
		10,000 - 20,000	7	6,280	1,199	14.1	16,993
		20,000 - 30,000	1	7,099	1,356	16.0	24,432
		30,000 - 40,000	6	8,827	1,686	15.0	30,900
	SSD Total		17	6,959	1,329	14.9	20,524
GENERAL CARGO Total			110	4,908	937	15.1	9,196
INTEGRATED TUG-BARGE	MSD	All	24	5,364	1,443	13.8	672
	MSD Total		24	5,364	1,443	13.8	672
INTEGRATED TUG-BARGE Total			24	5,364	1,443	13.8	672
TANKER	MSD	10,000 - 20,000	42	3,972	838	13.5	10,475
	MSD Total		42	3,972	838	13.5	10,475
	SSD	10,000 - 20,000	5	5,160	1,089	14.3	13,735
	SSD Total		5	5,160	1,089	14.3	13,735
TANKER Total			47	4,098	865	13.6	10,822
Grand Total			2,127	6,850	1,515	14.1	29,336

Note:

[a] Engine Types: MSD = medium speed engine; SSD = slow speed engine; ST = steam turbine

3.3.2.3.1.2 Removal of Category 1 and 2 Ships

Since these inventories were intended to cover ships with Category 3 propulsion engines only, the ships with Category 1 and 2 propulsion engines were eliminated. This was accomplished by matching all ship calls with information from Lloyd's Data, which is produced by Lloyd's Register-Fairplay Ltd.[14] Over 99.9 percent of the calls in the entrances and clearances data were directly matched with Lloyd's data. The remaining 0.1 percent was estimated based upon ships of similar type and size.

Engine category was determined from engine make and model. Engine bore and stroke were found in the Marine Engine 2005 Guide[15] and displacement per cylinder was calculated. Ships with Category 1 or 2 propulsion engines were eliminated from the data.

Many passenger ships and tankers have either diesel-electric or gas turbine-electric engines that are used for both propulsion and auxiliary purposes. Both were included in the current inventory.

3.3.2.3.1.3 Treatment of Electric-Drive Ships

Many passenger ships and tankers have either diesel-electric or gas turbine-electric engines that are used for both propulsion and auxiliary purposes. Both were included in the current inventory.

Lloyds clearly calls out these types of engines in their database and that information was used to distinguish them from direct and geared drive systems. Generally the power Lloyds lists is the total power. To separate out propulsion from auxiliary power for purposes of calculating emissions, the total power listed in the Lloyds data was divided by 1 plus the ratio of auxiliary to propulsion power (given in Table 3-3) to obtain the propulsion power portion of the total. The remaining portion was considered auxiliary engine power. In addition, no low load adjustment factor was applied to diesel and gas turbine electric engines for loads below 20 percent MCR because several engines are used to generate power, and some can be shut down to allow others to operate at a more efficient setting.

3.3.2.3.2 Cruise Distance

Cruise mode emissions are calculated assuming a 25 nautical mile distance into and out of the port for deep sea ports and 7 nautical miles into and out of the port for Great Lake ports outside of the reduced speed and maneuvering zones.

3.3.2.3.3 RSZ Distances and Speeds by Port

Reduced speed zone (RSZ) distance and speed were determined for each port. For deep sea ports, the RSZ distances were developed from shipping lane information contained in the U.S. Army Corps of Engineers National Waterway Network.[16] The NWN is a geographic database of navigable waterways in and around the U.S. The database defines waterways as links or line segments that, for the purposes of this study, represent actual shipping lanes (i.e., channels, intracoastal waterways, sea lanes, and rivers). The geographic locations of the waterways that were directly associated with each of the 117 ports were viewed using geographic information system computer software. The sea-side endpoint for the RSZ was selected as the point along the line segment that was judged to be far enough into the ocean where ship movements were unconstrained by the coastline or other vessel traffic. These RSZ sea-side endpoints typically coincided with estimates provided by the pilots for the major ports as reported in earlier work. The resulting RSZ distance was then measured for each deep sea port. The final RSZ distances and endpoints for each port are listed in the Appendix, Table 3-103. The RSZ for each Great Lake port was fixed at three nautical miles, as previously discussed in Section 3.3.2.2.2.

The RSZ speeds were primarily taken from previous studies by ICF[17,18] or from an ENVIRON report[19] based upon discussions with pilots. A few of the RSZ speeds were also modified based upon newer information obtained from conversations with pilots. The final RSZ speeds for each port are listed in the Appendix, Table 3-103. The RSZ speeds for the Great Lake ports vary by vessel type and are the average of the vessel service speed and the maneuvering speed.

3.3.2.3.4 Auxiliary Engine Power and Load Factors

Since hotelling emissions are a large part of port inventories, it is important to distinguish propulsion engine emissions from auxiliary engine emissions. In the methodology used in this analysis, auxiliary engine maximum continuous rating power and load factors were calculated separately from propulsion engines and different emission factors (EFs) applied. All auxiliary engines were treated as Category 2 medium-speed diesel (MSD) engines for purposes of this analysis.

Auxiliary engine power is not contained in the USACE database and is only sparsely populated in the Lloyd's database; as a result, it must be estimated. The approach taken was to derive ratios of average auxiliary engine power to propulsion power based on survey data. The California Air Resources Board (ARB) conducted an Oceangoing Ship Survey of 327 ships in January 2005 that was principally used for this analysis.[20] Average auxiliary engine power to propulsion power ratios were estimated by ship type and are presented in Table 3-3. These ratios by ship type were applied to the propulsion power data to derive auxiliary power for the ship types at each port.

Table 3-3 Auxiliary Engine Power Ratios (ARB Survey, except as noted)

Ship Type	Average Propulsion Engine (kW)	Average Auxiliary Engines: Number	Power Each (kW)	Total Power (kW)	Engine Speed	Auxiliary to Propulsion Ratio
Auto Carrier	10,700	2.9	983	2,850	Medium	0.266
Bulk Carrier	8,000	2.9	612	1,776	Medium	0.222
Container Ship	30,900	3.6	1,889	6,800	Medium	0.220
Passenger Ship[a]	39,600	4.7	2,340	11,000	Medium	0.278
General Cargo	9,300	2.9	612	1,776	Medium	0.191
Miscellaneous[b]	6,250	2.9	580	1,680	Medium	0.269
RORO	11,000	2.9	983	2,850	Medium	0.259
Reefer	9,600	4.0	975	3,900	Medium	0.406
Tanker	9,400	2.7	735	1,985	Medium	0.211

Notes:

[a] Many passenger ships typically use a different engine configuration known as diesel-electric. These vessels use large generator sets for both propulsion and ship-board electricity. The figures for passenger ships above are estimates taken from the Starcrest Vessel Boarding Program.

[b] Miscellaneous ship types were not provided in the ARB methodology, so values from the Starcrest Vessel Boarding Program were used.

Load factors for auxiliary engines vary by ship type and operating mode. It was previously thought that power generation was provided by propulsion engines in all modes but hotelling. Starcrest's Vessel Boarding Program[12] showed that auxiliary engines are on all of the time, except when using shoreside power during hotelling. Table 3-4 shows the auxiliary engine load factors by ship type determined by Starcrest, through interviews conducted with ship captains, chief engineers, and pilots during its vessel boarding programs. Auxiliary load factors were used in conjunction with total auxiliary power. Auxiliary load factors listed in Table 3-4 are used together with the total auxiliary engine power (determined from total propulsion power and the ratios from Table 3-3) to calculate auxiliary engine emissions.

Table 3-4 Auxiliary Engine Load Factor Assumptions

Ship-Type	Cruise	RSZ	Maneuver	Hotel
Auto Carrier	0.13	0.30	0.67	0.24
Bulk Carrier	0.17	0.27	0.45	0.22
Container Ship	0.13	0.25	0.50	0.17
Passenger Ship	0.80	0.80	0.80	0.64
General Cargo	0.17	0.27	0.45	0.22
Miscellaneous	0.17	0.27	0.45	0.22
RORO	0.15	0.30	0.45	0.30
Reefer	0.20	0.34	0.67	0.34
Tanker	0.13	0.27	0.45	0.67

3.3.2.3.5 Fuel Types and Fuel Sulfur Levels

There are primarily three types of fuel used by marine engines: residual marine (RM), marine diesel oil (MDO), and marine gas oil (MGO), with varying levels of fuel sulfur.[5] MDO and MGO are generally described as distillate fuels. For this analysis, RM and MDO fuels are assumed to be used. Since PM and SO_2 emission factors are dependent on the fuel sulfur level, calculation of port inventories requires information about the fuel sulfur levels associated with each fuel type, as well as which fuel types are used by propulsion and auxiliary engines.

An ARB survey[20] found that almost all ships used RM in their main propulsion engines, and that only 29 percent of all ships (except passenger ships) used distillate in their auxiliary engines, with the remaining 71 percent using RM. However, only 8 percent of passenger ships used distillate in their auxiliary engines, while the other 92 percent used RM. We used the results of this survey as reasonable approximations for calculations of emission factors. However, their accuracy for years other than those of the ARB survey may be affected by fuel prices, since as fuel prices increase, more ships will use RM in their auxiliary engines.

Based on the ARB survey, average fuel sulfur level for residual marine was set to 2.5 percent for the west coast and 2.7 percent for the rest of the country. A sulfur content of 1.5 percent was used for MDO.[21] While a more realistic value for MDO used in the U.S. appears to be 0.4 percent, given the small proportion of distillate fuel used by ships relative to RM, the difference should not be significant. Sulfur levels in other areas of the world can be significantly higher for RM. Table 3-5 provides the assumed mix of fuel types used for propulsion and auxiliary engines by ship type.

Table 3-5 Estimated Mix of Fuel Types Used by Ships

Ship Type	Fuel Used	
	Propulsion	Auxiliary
Passenger	100% RM	92% RM/8% MDO
Other	100% RM	71% RM/29% MDO

3.3.2.3.6 Propulsion and Auxiliary Engine Emission Factors

An analysis of emission data was prepared and published in 2002 by Entec.[21] The resulting Entec emission factors include individual factors for three speeds of diesel engines (slow-speed diesel (SSD), medium-speed diesel (MSD), and high-speed diesel (HSD)), steam turbines (ST), gas turbines (GT), and two types of fuel used here (RM and MDO). Table 3-6 lists the propulsion engine emission factors for NO_X and HC that were used for the 2002 port inventory development. The CO, PM, SO_2 and CO_2 emission factors shown in the table come from other data sources as explained below.

Table 3-6 Emission Factors for OGV Main Engines using RM, g/kWh

Engine	All Ports				West Coast Ports			Other Ports		
	NO_X	CO	HC	CO_2	PM_{10}	$PM_{2.5}$	SO_2	PM_{10}	$PM_{2.5}$	SO_2
SSD	18.1	1.40	0.60	620.62	1.4	1.3	9.53	1.4	1.3	10.29
MSD	14.0	1.10	0.50	668.36	1.4	1.3	10.26	1.4	1.3	11.09
ST	2.1	0.20	0.10	970.71	1.4	1.3	14.91	1.5	1.4	16.10
GT	6.1	0.20	0.10	970.71	1.4	1.3	14.91	1.5	1.4	16.10

CO emission factors were developed from information provided in the Entec appendices because they are not explicitly stated in the text. . HC and CO emission factors were confirmed with a recent EPA review.[22]

PM_{10} values were determined by EPA based on existing engine test data in consultation with ARB.[23] GT PM_{10} emission factors were not part of the EPA analysis but assumed here to be equivalent to ST PM_{10} emission factors. Test data shows PM_{10} emission rates as dependent upon fuel sulfur levels, with base PM_{10} emission rates of 0.23 g/kw-hr with distillate fuel (0.24% sulfur) and 1.35 g/kw-hr with residual fuel (2.46% sulfur).[24] The equation used to generate emission factors based on sulfur content is shown below.

Equation 3-21 Calculation of PM_{10} Emission Factors Based on Fuel Sulfur Levels

$$PM_{EF} = PM_{Nom} + [(S_{Act} - S_{Nom}) \times BSFC \times FSC \times MWR \times 0.0001]$$

Where:

PM_{EF} = PM emission factor adjusted for fuel sulfur

PM_{Nom}= PM emission rate at nominal fuel sulfur level

= 0.23 g/kW-hr for distillate fuel, 1.35 g/kW-hr for residual fuel

S_{Act}= Actual fuel sulfur level (weight percent)
S_{Nom}= nominal fuel sulfur level (weight percent)
= 0.24 for distillate fuel, 2.46 for residual fuel
BSFC= fuel consumption in g/kW-hr
= 200 g/kW-hr used for this analysis
FSC= percentage of sulfur in fuel that is converted to direct sulfate PM
= 2.247% used for this analysis
MWR= molecular weight ratio of sulfate PM to sulfur
= 224/32 = 7 used for this analysis

The PM_{10} to $PM_{2.5}$ conversion factor used here is 0.92. While the NONROAD model uses 0.97 for such conversion based upon low sulfur fuels, a reasonable value seems to be closer to 0.92 because higher sulfur fuels in medium and slow speed engines would tend to produce larger particulates than high speed engines on low sulfur fuels.

SO_2 emission factors were based upon a fuel sulfur to SO_2 conversion formula which was supplied by ENVIRON.[25] Emission factors for SO_2 emissions were calculated using the formula assuming that 97.753 percent of the fuel sulfur was converted to SO_2.[26] The brake specific fuel consumption (BSFC)[A] that was used for SSDs was 195 g/kWh, while the BSFC that was used for MSDs was 210 g/kWh based upon Lloyds 1995. The BSFC that was used for STs and GTs was 305 g/kWh based upon Entec.[21]

Equation 3-22 Calculation of SO_2 Emission Factors, g/kWh

$$SO_2\ EF = BSFC \times 2 \times 0.97753 \times \text{Fuel Sulfur Fraction}$$

CO_2 emission factors were calculated from the BSFC assuming a fuel carbon content of 86.7 percent by weight[21] and a ratio of molecular weights of CO_2 and C at 3.667.

Equation 3-23 Calculation of CO_2 Emission Factors, g/kWh

$$CO_2\ EF = BSFC \times 3.667 \times 0.867$$

Fuel consumption was calculated from CO_2 emissions based on a 1:3.183 ratio. 3.183 tons of CO_2 emissions are assumed produced from one metric ton of fuel.

The most current set of auxiliary engine emission factors comes from Entec except as noted below. Table 3-7 provides these auxiliary engine emission factors.

Table 3-7 Auxiliary Engine Emission Factors by Fuel Type, g/kWh

Engine	Fuel	All Ports				West Coast Ports			Other Ports		
		NO_X	CO	HC	CO_2	PM_{10}	$PM_{2.5}$	SO_2	PM_{10}	$PM_{2.5}$	SO_2
MSD	RM	14.70	1.10	0.40	668.36	1.4	1.3	10.26	1.4	1.3	11.09
	MDO	13.90	1.10	0.40	668.36	0.6	0.55	6.16	0.6	0.55	6.16

[A] Brake specific fuel consumption is sometimes called specific fuel oil consumption (SFOC).

It should be noted that Entec used 2.7 percent fuel sulfur content for RM, and 1.0 percent for MDO which is consistent with the RM assumptions made in this analysis for other than West Coast ports. For MDO, there is a slight discrepancy between the 1.0 percent used by Entec versus the 1.5 percent estimate used for this analysis. SO_2 emission factors were calculated based upon the assumed sulfur levels and the methodology suggested by ENVIRON[25] while PM emissions were determined by EPA based on existing engine test data in consultation with ARB.[23]

Using the ratios of RM versus MDO use determined by the ARB study[20] as given in Table 3-5 together with the emission factors shown in Table 3-7, the auxiliary engine emission factor averages by ship type are listed in Table 3-8. As discussed above, this fuel sulfur level may be too high for the U.S. However, we do not believe this emission factor has a significant effect on the total emission inventory estimates.

If the fuel sulfur level for MDO is correctly adjusted from 1.5 percent to 1.0 percent, the effect on SO_2 emissions is still less than 7 percent, due to the high percentage of RM fuel used in auxiliary engines. The difference for PM is within the round off error of the emission factor.

Table 3-8 Auxiliary Engine Emission Factors by Ship Type, g/kWh

Ship Type	All Ports				West Coast Ports			Other Ports		
	NO_X	CO	HC	CO_2	PM_{10}	$PM_{2.5}$	SO_2	PM_{10}	$PM_{2.5}$	SO_2
Passenger	14.64	1.10	0.40	668.36	1.3	1.2	9.93	1.4	1.3	10.70
Others	14.47	1.10	0.40	668.36	1.1	1.0	9.07	1.2	1.1	9.66

3.3.2.3.7 Low Load Adjustment Factors for Propulsion Engines

Emission factors are considered to be constant down to about 20 percent load. Below that threshold, emission factors tend to increase as the load decreases. This trend results because diesel engines are less efficient at low loads and the BSFC tends to increase. Thus, while mass emissions (grams per hour) decrease with low loads, the engine power tends to decrease more quickly, thereby increasing the emission factor (grams per engine power) as load decreases. Energy and Environmental Analysis Inc. (EEA) demonstrated this effect in a study prepared for EPA in 2000.[27] In the EEA report, various equations have been developed for the various emissions. The low-load emission factor adjustment factors were developed based upon the concept that the BSFC increases as load decreases below about 20 percent load. For fuel consumption, EEA developed the following equation:

Equation 3-24

$$\text{Fuel Consumption (g/kWh)} = 14.1205\ (1/\text{Fractional Load}) + 205.7169$$

In addition, based upon test data, they developed algorithms to calculate emission factors at reduced load. These equations are noted below:

Equation 3-25

$$\text{Emission Rate (g/kWh)} = a\,(\text{Fractional Load})^{-x} + b$$

For SO_2 emissions, however, EEA developed a slightly different equation:

Equation 3-26

$$\text{Emission Rate (g/kWh)} = a\,(\text{Fuel Consumption x Fuel Sulfur Fraction}) + b$$

The coefficients for the above equations are given in Table 3-9 below.

Table 3-9 Emission Factor Algorithm Coefficients for OGV Main Engines using RM

Coefficient	NO_X	HC	CO	PM	SO_2	CO_2
a	0.1255	0.0667	0.8378	0.0059	2.3735	44.1
x	1.5	1.5	1.0	1.5	n/a	1.0
b	10.4496	0.3859	0.1548	0.2551	-0.4792	648.6

The underlying database used to calculate these coefficients includes primarily tests on engines rated below 10,000 kW, using diesel fuel. This introduces uncertainty regarding the use of these coefficients for Category 3 engines using residual fuel; however, these are the best estimates currently available.

Using these algorithms, fuel consumption and emission factors versus load were calculated. By normalizing these emission factors to 20% load, the low-load multiplicative adjustment factors presented in Table 3-10 are calculated. SO_2 adjustment factors were calculated using 2.7% sulfur. The SO_2 multiplicative adjustment factors at 2.5 percent sulfur are not significantly different.

Table 3-10 Calculated Low Load Multiplicative Adjustment Factors

Load (%)	NO_X	HC	CO	PM	SO_2	CO_2
1	11.47	59.28	19.32	19.17	5.99	5.82
2	4.63	21.18	9.68	7.29	3.36	3.28
3	2.92	11.68	6.46	4.33	2.49	2.44
4	2.21	7.71	4.86	3.09	2.05	2.01
5	1.83	5.61	3.89	2.44	1.79	1.76
6	1.60	4.35	3.25	2.04	1.61	1.59
7	1.45	3.52	2.79	1.79	1.49	1.47
8	1.35	2.95	2.45	1.61	1.39	1.38
9	1.27	2.52	2.18	1.48	1.32	1.31
10	1.22	2.20	1.96	1.38	1.26	1.25
11	1.17	1.96	1.79	1.30	1.21	1.21
12	1.14	1.76	1.64	1.24	1.18	1.17
13	1.11	1.60	1.52	1.19	1.14	1.14
14	1.08	1.47	1.41	1.15	1.11	1.11
15	1.06	1.36	1.32	1.11	1.09	1.08
16	1.05	1.26	1.24	1.08	1.07	1.06
17	1.03	1.18	1.17	1.06	1.05	1.04
18	1.02	1.11	1.11	1.04	1.03	1.03
19	1.01	1.05	1.05	1.02	1.01	1.01
20	1.00	1.00	1.00	1.00	1.00	1.00

There is no need for a low load adjustment factor for auxiliary engines, because they are generally operated in banks. When only low loads are needed, one or more engines are shut off, allowing the remaining engines to operate at an efficient level.

3.3.2.3.8 Use of Detailed Typical Port Data for Other Inputs

There is currently not enough information to readily calculate time-in-mode (hours/call) for all 117 ports during the maneuvering and hotelling modes of operation. As a result, it was necessary to review and select available detailed emission inventories that have been estimated for selected ports to date. These ports are referred to as typical ports. The typical port information for maneuvering and hotelling time-in-mode (as well as maneuvering load factors for the propulsion engines) was then used for the typical ports and also assigned to the other modeled ports. A modeled port is the port in which emissions are to be estimated. The methodology that was used to select the typical ports and match these ports to the other modeled ports is briefly described in this section, and more fully described in the ICF documentation.[2]

3.3.2.3.8.1 Selection of Typical Ports

In 1999, EPA published two guidance documents[17,18] to calculate marine vessel activity at ports. These documents contained detailed port inventories of eight deep sea ports, two Great

Lake ports and two inland river ports. The detailed inventories were developed by obtaining ship call data from Marine Exchanges/Port Authorities (MEPA) at the various ports for 1996 and matching the various ship calls to data from Lloyds Maritime Information Services to provide ship characteristics. The ports for which detailed inventories were developed are shown in Table 3-11 for deep sea ports and Table 3-12 for Great Lake ports along with the level of detail of shifts for each port. Most ports provided the ship name, Lloyd's number, the vessel type, the date and time the vessel entered and left the port, and the vessel flag. Inland river ports were developed from U.S. Army Corps of Engineers (USACE) Waterborne Commerce Statistics Center data.

Table 3-11 Deep Sea MEPA Vessel Movement and Shifting Details

MEPA Area and Ports	MEPA Data Includes
Lower Mississippi River including the ports of New Orleans, South Louisiana, Plaquemines, and Baton Rouge	Information on the first and last pier/wharf/dock (PWD) for the vessel (gives information for at most one shift per vessel). No information on intermediate PWDs, the time of arrival at the first destination PWD, or the time of departure from the River.
Consolidated Port of New York and New Jersey and other ports on the Hudson and Elizabeth Rivers	All PWDs or anchorages for shifting are named. Shifting arrival and departure times are not given. Hotelling time is based upon the entrance and clearance times and dates, subtracting out maneuvering times. Maneuvering times were calculated based upon the distance the ship traveled at a given maneuvering speed.
Delaware River Ports including the ports of Philadelphia, Camden, Wilmington and others	All PWDs or anchorages for shifting are named. Shifting arrival and departure times are not given. Hotelling time is based upon the entrance and clearance times and dates, subtracting out maneuvering times. Maneuvering times were calculated based upon the distance the ship traveled at a given maneuvering speed.
Puget Sound Area Ports including the ports of Seattle, Tacoma, Olympia, Bellingham, Anacortes, and Grays Harbor	All PWDs or anchorages for shifting are named. Arrival and departure dates and times are noted for all movements, allowing calculation of maneuvering and hotelling both for individual shifts and the overall call on port.
The Port of Corpus Christi, TX	Only has information on destination PWD and date and time in and out of the port area. No shifting details.
The Port of Coos Bay, OR	Only has information on destination PWD and date and time in and out of the port area. No shifting details.
Patapsco River Ports including the port of Baltimore Harbor, MD	All PWDs or anchorages for shifting are named. Shifting arrival and departure times are not given. Hotelling time is based upon the entrance and clearance times and dates, subtracting out maneuvering times. Maneuvering times were calculated based upon the distance the ship traveled at a given maneuvering speed.
The Port of Tampa, FL	All PWDs or anchorages for shifting are named. Arrival and departure dates and times are noted for all movements, allowing calculation of maneuvering and hotelling both for individual shifts and the overall call.

Table 3-12 Great Lake MEPA movements and shifts

MEPA Area and Ports	MEPA Data Includes
Port of Cleveland, OH	Information on the first and last PWD for the vessel (gives information for at most one shift per vessel). No information on intermediate PWDs..
Port of Burns Harbor, IN	No shifting details, No PWDs listed..

Since 1999, several new detailed emissions inventories have been developed and were reviewed for use as additional or replacement typical ports: These included:

- Port of Los Angeles[12,28]
- Puget Sound Ports[29]
- Port of New York/New Jersey[30]
- Port of Houston/Galveston[31]
- Port of Beaumont/Port Arthur[32]
- Port of Corpus Christi[33]
- Port of Portland[34]
- Ports of Cleveland, OH and Duluth-Superior, MN&WI[35]

Based on the review of these newer studies, some of the previous typical ports were replaced with newer data and an additional typical port was added. Data developed for Cleveland and Duluth-Superior for LADCO was used in lieu of the previous typical port data for Cleveland and Burns Harbor because it provided more detailed information and better engine category definitions. The Port of Houston/Galveston inventory provided enough data to add an additional typical port. All three port inventories were adjusted to reflect the current methodology used in this study.

The information provided in the current inventory for Puget Sound Ports[29] was used to calculate RSZ speeds, load factors, and times for all Puget Sound ports. As described in Section 3.3.2.4.2, an additional modeled port was also added to account for the considerable amount of Jones Act tanker ship activity in the Puget Sound area that is not contained in the original inventory.

The newer Port of New York/New Jersey inventory provided a check against estimates made using the 1996 data. All other new inventory information was found to lack sufficient detail to prepare the detailed typical port inventories needed for this project.

The final list of nine deep sea and two Great Lake typical ports used in this analysis and their data year is as follows:

- Lower Mississippi River Ports [1996]

- Consolidated Ports of New York and New Jersey and Hudson River [1996]
- Delaware River Ports [1996]
- Puget Sound Area Ports [1996]
- Corpus Christi, TX [1996]
- Houston/Galveston Area Ports [1997]
- Ports on the Patapsco River [1996]
- Port of Coos Bay, OR [1996]
- Port of Tampa, FL [1996]
- Port of Cleveland, OH on Lake Erie [2005]
- Duluth-Superior, MN & WI on Lake Michigan [2005]

The maneuvering and hotelling time-in-modes, as well as the maneuvering load factors for these typical ports, were binned by ship type, engine type, and DWT type, using the same bins described in Section 3.3.2.3.1.1.

3.3.2.3.8.2 Matching Typical Ports to Modeled Ports

The next step in the process was to match the ports to be modeled with the typical port which was most like it. Three criteria were used for matching a given port to a typical port: regional differences,[B] maximum vessel draft, and the ship types that call on a specific port. One container port, for instance, may have much smaller bulk cargo and reefer ships number of calls on that port than another. Using these three criteria and the eleven typical ports that are suitable for port matching, the 89 deep sea ports and 28 Great Lake ports were matched to the typical ports. For a typical port, the modeled and typical port is the same (i.e., the port simply represents itself). For California ports, we used data provided by ARB as discussed in Section 3.3.2.4. The matched ports for the deep sea ports are provided in Table 3-13.

Table 3-13 Matched Ports for the Deep Sea Ports

Modeled Port Name	Typical Like Port
Anacortes, WA	Puget Sound
Barbers Point, HI	Puget Sound
Everett, WA	Puget Sound
Grays Harbor, WA	Puget Sound
Honolulu, HI	Puget Sound
Kalama, WA	Puget Sound
Longview, WA	Puget Sound
Olympia, WA	Puget Sound

[B] The region in which a port was located was used to group top ports as it was considered a primary influence on the characteristics (size and installed power) of the vessels calling at those ports.

Modeled Port Name	Typical Like Port
Port Angeles, WA	Puget Sound
Portland, OR	Puget Sound
Seattle, WA	Puget Sound
Tacoma, WA	Puget Sound
Vancouver, WA	Puget Sound
Valdez, AK	Puget Sound
Other Puget Sound	Puget Sound
Anchorage, AK	Coos Bay
Coos Bay, OR	Coos Bay
Hilo, HI	Coos Bay
Kahului, HI	Coos Bay
Nawiliwili, HI	Coos Bay
Nikishka, AK	Coos Bay
Beaumont, TX	Houston
Freeport, TX	Houston
Galveston, TX	Houston
Houston, TX	Houston
Port Arthur, TX	Houston
Texas City, TX	Houston
Corpus Christi, TX	Corpus Christi
Lake Charles, LA	Corpus Christi
Mobile, AL	Corpus Christi
Brownsville, TX	Tampa
Gulfport, MS	Tampa
Manatee, FL	Tampa
Matagorda Ship	Tampa
Panama City, FL	Tampa
Pascagoula, MS	Tampa
Pensacola, FL	Tampa
Tampa, FL	Tampa
Everglades, FL	Tampa
New Orleans, LA	Lower Mississippi
Baton Rouge, LA	Lower Mississippi
South Louisiana, LA	Lower Mississippi
Plaquemines, LA	Lower Mississippi
Albany, NY	New York/New Jersey
New York/New Jersey	New York/New Jersey
Portland, ME	New York/New Jersey
Georgetown, SC	Delaware River
Hopewell, VA	Delaware River
Marcus Hook, PA	Delaware River

Modeled Port Name	Typical Like Port
Morehead City, NC	Delaware River
Paulsboro, NJ	Delaware River
Chester, PA	Delaware River
Fall River, MA	Delaware River
New Castle, DE	Delaware River
Penn Manor, PA	Delaware River
Providence, RI	Delaware River
Brunswick, GA	Delaware River
Canaveral, FL	Delaware River
Charleston, SC	Delaware River
New Haven, CT	Delaware River
Palm Beach, FL	Delaware River
Bridgeport, CT	Delaware River
Camden, NJ	Delaware River
Philadelphia, PA	Delaware River
Wilmington, DE	Delaware River
Wilmington, NC	Delaware River
Richmond, VA	Delaware River
Jacksonville, FL	Delaware River
Miami, FL	Delaware River
Searsport, ME	Delaware River
Boston, MA	Delaware River
New Bedford/Fairhaven, MA	Delaware River
Baltimore, MD	Patapsco River
Newport News, VA	Patapsco River
Savannah, GA	Patapsco River
Catalina, CA	ARB Supplied
Carquinez, CA	ARB Supplied
El Segundo, CA	ARB Supplied
Eureka, CA	ARB Supplied
Hueneme, CA	ARB Supplied
Long Beach, CA	ARB Supplied
Los Angeles, CA	ARB Supplied
Oakland, CA	ARB Supplied
Redwood City, CA	ARB Supplied
Richmond, CA	ARB Supplied
Sacramento, CA	ARB Supplied
San Diego, CA	ARB Supplied
San Francisco, CA	ARB Supplied
Stockton, CA	ARB Supplied

Great Lake ports were matched to either Cleveland or Duluth as shown in Table 3-14.

Table 3-14 Great Lake Match Ports

Port Name	Typical Like Port
Alpena, MI	Cleveland
Buffalo, NY	Cleveland
Burns Waterway, IN	Cleveland
Calcite, MI	Cleveland
Cleveland, OH	Cleveland
Dolomite, MI	Cleveland
Erie, PA	Cleveland
Escanaba, MI	Cleveland
Fairport, OH	Cleveland
Gary, IN	Cleveland
Lorain, OH	Cleveland
Marblehead, OH	Cleveland
Milwaukee, WI	Cleveland
Muskegon, MI	Cleveland
Presque Isle, MI	Cleveland
St Clair, MI	Cleveland
Stoneport, MI	Cleveland
Two Harbors, MN	Cleveland
Ashtabula, OH	Duluth-Superior
Chicago, IL	Duluth-Superior
Conneaut, OH	Duluth-Superior
Detroit, MI	Duluth-Superior
Duluth-Superior, MN&WI	Duluth-Superior
Indiana, IN	Duluth-Superior
Inland Harbor, MI	Duluth-Superior
Manistee, MI	Duluth-Superior
Sandusky, OH	Duluth-Superior
Toledo, OH	Duluth-Superior

Once a modeled port was matched to a typical port, the maneuvering and hotelling time-in-mode values, as well as the maneuvering load factors by bin for the typical ports, were used directly for the modeled ports, with no adjustments. The other inputs used for both the typical and modeled ports are as described in Section 3.3.2.3.

3.3.2.3.8.3 Bin Mismatches

In some cases, the specific DWT range bin at the modeled port was not in the typical like port data. In those cases, the next nearest DWT range bin was used for the calculations. In a few cases, the engine type for a given ship type might not be in the typical like port data. In these cases, the closest engine type at the typical like port was used. Also in a few cases, a specific ship type in the modeled port data was not in the typical like port data. In this case, the nearest like ship type at the typical port was chosen to calculate emissions at the modeled port.

3.3.2.4 Stand Alone Ports

In a few cases, the USACE entrances and clearances data was not used to calculate emissions at the modeled port. These include the California ports for which we received data from ARB, the Port of Valdez, Alaska, and a conglomerate port within the Puget Sound area, as described below.

3.3.2.4.1 California Ports

The California Air Resources Board (ARB) supplied inventories for 14 California ports for 2002. The data received from ARB for the California ports were modified to provide consistent PM and SO_2 emissions to those calculated in this report. In addition, cruise and RSZ emissions were calculated directly based upon average ship power provided in the ARB methodology document[36] and number of calls, because ARB did not calculate cruise emissions, and transit (RSZ) emissions were allocated to counties instead of ports. ARB provided transit distances for each port to calculate the RSZ emissions. Ship propulsion and auxiliary engine power were calculated based upon the methodology in Section 3.3.2.3.1.3 for use in computing cruise and RSZ emissions. For maneuvering and hotelling emissions, the ARB values were used and adjusted as discussed below. The data supplied by ARB included domestic traffic as well as foreign cargo traffic.

For PM emission calculations, ARB used an emission factor of 1.5 g/kWh to calculate total PM emissions and factors of 0.96 and 0.937 to convert total PM to PM_{10} and $PM_{2.5}$ respectively. Since an emission factor of 1.4 g/kWh was used in our calculations for PM_{10} and an emission factor of 1.3 g/kWh for $PM_{2.5}$, ARB PM_{10} and $PM_{2.5}$ emissions were multiplied by factors of 0.972 and 0.925, respectively to get consistent PM_{10} and $PM_{2.5}$ emissions for propulsion engines.

For auxiliary engines, ARB used the same emission factors as above, while we used PM_{10} and $PM_{2.5}$ emission factors of 1.3 and 1.2 g/kWh, respectively for passenger ships and 1.1 and 1.0 g/kWh, respectively for all other ships. In the ARB inventory, all passenger ships are treated as electric drive and all emissions are allocated to auxiliary engines. ARB auxiliary engine emissions were thus multiplied by factors of 0.903 and 0.854 respectively for passenger ships and 0.764 and 0.711 respectively for other ships to provide consistent PM emission calculations.

SO_2 emissions were also different between the ARB and these analyses. ARB used a composite[C] propulsion engine SO_2 emission factor of 10.55 g/kWh while we used a composite SO_2 emission factor of 9.57 g/kWh. Thus, ARB SO_2 propulsion emissions were multiplied by a factor of 0.907 to be consistent with our emission calculations. For auxiliary engines, ARB used SO_2 emission factors of 11.48 and 9.34 g/kWh, respectively for passenger and other ships, while we use emission factors of 9.93 and 9.07 g/kWh, respectively. Thus, ARB auxiliary SO_2 emissions were multiplied by factors of 0.865 and 0.971, respectively for passenger and other ships to provide consistent SO_2 emissions.

3.3.2.4.2 Port in Puget Sound

In the newest Puget Sound inventory[29], it was found that a considerable amount of tanker ships stop at Cherry Point, Ferndale, March Point and other areas which are not within the top 89 U.S. deep sea ports analyzed in this analysis. In addition, since they are ships carrying U.S. cargo (oil from Alaska) from one U.S. port to another, they are not documented in the USACE entrances and clearances data. To compensate for this anomaly, an additional port was added which encompassed these tanker ships stopping within the Puget Sound area but not at one of the Puget Sound ports analyzed in this analysis. Ship calls in the 1996 typical port data to ports other than those in the top 89 U.S. deep sea ports were analyzed separately. There were 363 ship calls by tankers to those areas in 1996. In the inventory report for 2005, there were 468 calls. For 2002, it was estimated there were 432 calls. The same ship types and ship characteristics were used as in the 1996 data, but the number of calls was proportionally increased to 432 calls to represent these ships. The location of the "Other Puget Sound" port was approximately at Cherry Point near Aberdeen.

3.3.2.4.3 Port of Valdez

In a recent Alaska port inventory,[37] it was found that significant Category 3 domestic tanker traffic enters and leaves the Port of Valdez on destination to West Coast ports. Since the USACE entrances and clearances data did not contain any tanker calls at Valdez in 2002, the recent Alaska inventory data was used to calculate emissions at that port. In this case, the number of calls and ship characteristics for 2002 were taken directly from the Alaska inventory and used in determining emissions for the modeled port with the Puget Sound area typical port being used as the like port.

3.3.2.5 Domestic Traffic

One of the concerns with using USACE entrances and clearances data is that it only contains foreign cargo movements moved by either a foreign flag vessel or a U.S. flag vessel. The Maritime Administration (MARAD) maintains the Foreign Traffic Vessel Entrances and Clearances database, which contains statistics on U.S. foreign maritime trade. Data are compiled during the regular processing of statistics on foreign imports and exports. The database contains information on the type of vessel, commodities, weight, customs districts and ports, and origins and destinations of goods. Thus domestic traffic, i.e., U.S. ships delivering cargo from one U.S.

[C] Based upon ARB assuming 95 percent of the engines were SSD and 5 percent were MSD. The composite SO_2 EF of 9.57 g/kW-hr was calculated using this weighting, along with the SSD and MSD SO_2 EFs for the West Coast ports reported in Table 3-6.

port to another U.S. port, is covered under the Jones Act and is not accounted for in the database. However, U.S. flagged ships carrying cargo from a foreign port to a U.S. port or from a U.S. port to a foreign port are accounted for in the USACE entrances and clearances database, as these are considered foreign cargo movements.

Under the Jones Act, domestic cargo movements from one U.S. port to another U.S. port must be carried by a U.S. flag ship. The Jones Act also requires ships traveling between United States ports to be constructed by United States companies and owned by a United States company or citizen. Members of the ships' crews must be United States citizens or legal aliens. Because of the use of USACE data, in the present baseline and future year inventories, only limited Jones Act ships were counted. These ships included those servicing California ports, those serving the Port of Valdez and those serving other Puget Sound ports. At all other ports, Jones Act ships were not counted.

ICF conducted an analysis to estimate the amount of Category 3 Jones Act ships calling at the 117 U.S. ports. This was done by analyzing marine exchange data obtained from port authorities for eleven typical ports and using this information to estimate the Jones Act ship contribution for the remaining ports. Based on this limited analysis, Jones Act ships are estimated to account for 9.2% of the total installed power calling on U.S. ports. Approximately 30% of these ships, largely in the Alaska and Pacific regions, have been included in the 2002 baseline inventory. Based on this analysis, Jones Act ships excluded from this inventory constitute roughly 6.5% of total installed power.[38] This results in an underestimation of the port ship inventory and therefore the benefits of the coordinated program reported in this chapter are also underestimated.

3.3.2.6 2002 Near Port Inventories

This section presents a summary of the baseline near port inventories for 2002. Individual port inventories are presented separately for deep sea ports and Great Lake ports because of the difference in ship types between the two. This is followed by totals for the summed port inventories, provided by engine type (propulsion and auxiliary), mode of operation, and ship type.

3.3.2.6.1 Deep Sea Ports

Emission inventories for the 89 deep sea ports are presented here. Total emissions (propulsion and auxiliary) by ports are given in Table 3-15. Auxiliary only emissions by ports are given in Table 3-16. Emissions by mode are given in Table 3-17 for cruise, Table 3-18 for reduced speed zone, Table 3-19 for maneuvering, and Table 3-20 for hotelling. Emissions by ship type by port are given in Table 3-21 through Table 3-31. Ports that are missing from those lists had no emissions related to that ship type during 2002.

For deep sea ports, auxiliary emissions are responsible for roughly 47% of the NO_X and PM emissions, primarily due to emissions during the hotelling mode. Container and Tanker ships combined are responsible for approximately half the total emissions, followed by Passenger ships and Bulk Carrier ships.

3.3.2.6.2 Great Lake Ports

Emissions inventories for 28 Great Lake ports were developed and are presented here. Great Lake ships include self-unloading bulk carriers (Bulk Carrier, SU) which tend to operate within the Great Lakes only. Other ships travel down the St. Lawrence River from the open ocean. Integrated tug-barges (ITB) are also used on the Great Lakes.

Total emissions by port for Great Lakes Ports are shown in Table 3-32. Auxiliary engine emissions for Great Lake ports are shown in Table 3-33. Emissions by mode for Great Lake ports are shown in Table 3-34 for cruise, Table 3-35 for reduced speed zone, Table 3-36 for maneuvering, and Table 3-37 for hotelling. Emissions by ship type are shown in Table 3-38 through Table 3-42.

Table 3-15 Total Emissions by Deep Sea Port in 2002

Port Name	Installed Power (MW)	Metric Tonnes						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Anacortes, WA	545	403	32	29	14	32	225	15,462
Barbers Point, HI	472	122	10	9	4	10	71	5,034
Everett, WA	186	82	7	6	3	7	46	3,125
Grays Harbor, WA	360	50	4	4	2	4	30	2,066
Honolulu, HI	8,037	1,268	116	102	47	102	800	54,385
Kalama, WA	1,190	359	30	26	13	30	210	14,555
Longview, WA	1,619	413	34	30	15	35	239	16,495
Olympia, WA	97	56	4	4	2	4	31	2,047
Port Angeles, WA	556	151	13	11	5	12	89	6,042
Portland, OR	11,198	2,307	206	182	117	223	1,320	90,558
Seattle, WA	26,292	6,669	573	513	265	551	3,789	253,190
Tacoma, WA	19,130	5,742	477	428	217	464	3,211	215,754
Vancouver, WA	1,946	446	37	33	17	39	259	17,821
Valdez, AK	6,676	343	37	33	11	27	299	20,789
Other Puget Sound	5,678	2,111	219	197	71	169	1,745	118,629
Anchorage, AK	537	221	18	16	7	17	133	8,236
Coos Bay, OR	399	46	4	3	2	4	27	1,810
Hilo, HI	4,514	929	77	70	27	72	626	44,368
Kahului, HI	2,323	474	39	35	14	37	312	22,094
Nawiliwili, HI	591	122	10	9	4	9	83	5,884
Nikishka, AK	1,110	270	26	24	8	21	209	13,794
Beaumont, TX	12,699	2,106	261	240	91	189	1,972	83,736
Freeport, TX	7,411	714	92	85	25	54	716	28,422
Galveston, TX	6,572	1,014	118	102	35	69	873	43,643
Houston, TX	47,147	4,625	546	491	158	347	4,136	183,952
Port Arthur, TX	3,531	436	52	47	17	37	388	17,342
Texas City, TX	7,382	970	127	117	33	74	986	38,575
Corpus Christi, TX	11,452	1,758	143	132	59	401	1,090	70,240
Lake Charles, LA	6,382	850	80	74	35	239	594	38,409
Mobile, AL	8,200	1,144	95	88	39	303	724	46,155
Brownsville, TX	1,213	175	14	13	6	14	108	7,057
Gulfport, MS	3,556	607	51	46	20	48	414	26,382
Manatee, FL	2,903	667	56	49	22	53	450	28,904
Matagorda Ship	2,504	389	32	28	14	33	239	15,827
Panama City, FL	662	70	6	5	2	6	44	2,789
Pascagoula, MS	3,566	518	44	40	17	42	344	22,223
Pensacola, FL	351	40	3	3	1	3	27	1,726
Tampa, FL	10,941	1,507	129	109	50	121	988	63,033
Everglades, FL	38,304	4,287	402	372	134	334	3,123	198,127
New Orleans, LA	27,575	6,603	556	513	221	536	4,245	272,794
Baton Rouge, LA	4,627	1,985	160	148	63	155	1,223	78,568
South Louisiana, LA	18,366	6,428	519	479	203	502	3,976	257,346
Plaquemines, LA	4,230	1,045	85	78	33	82	658	43,258
Albany, NY	396	103	9	8	4	9	65	4,167
New York/New Jersey	86,980	7,364	622	575	274	621	4,620	296,780
Portland, ME	3,968	722	60	55	23	57	466	30,836
Georgetown, SC	609	89	7	7	3	7	152	3,668
Hopewell, VA	185	45	4	3	2	4	211	1,764

Table 3-15 Total Emissions by Deep Sea Port in 2002 (continued)

Port Name	Installed Power (MW)	Metric Tonnes						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Marcus Hook, PA	2,754	965	79	73	30	76	2,462	40,563
Morehead City, NC	967	121	10	9	4	10	94	5,196
Paulsboro, NJ	3,272	668	55	50	22	54	2,103	26,676
Chester, PA	1,467	196	16	15	7	16	411	7,648
Fall River, MA	290	35	3	3	1	3	52	1,748
New Castle, DE	765	199	16	15	6	16	394	8,257
Penn Manor, PA	721	174	14	13	6	14	656	6,878
Providence, RI	1,097	198	16	15	6	16	334	8,222
Brunswick, GA	5,184	670	54	50	22	53	1,297	26,273
Canaveral, FL	17,801	3,060	281	261	89	233	2,279	139,768
Charleston, SC	46,233	3,809	311	288	133	310	4,519	150,424
New Haven, CT	1,801	287	23	22	9	22	207	12,116
Palm Beach, FL	2,277	219	19	18	7	17	162	9,869
Bridgeport, CT	1,452	247	20	19	8	19	164	10,692
Camden, NJ	4,209	994	82	76	34	83	1,625	41,540
Philadelphia, PA	7,644	1,684	140	129	55	140	3,363	70,523
Wilmington, DE	4,444	627	52	48	23	54	1,011	25,319
Wilmington, NC	4,888	641	53	49	22	52	956	26,264
Richmond, VA	596	86	7	7	3	8	206	3,333
Jacksonville, FL	13,908	1,507	125	116	51	122	1,652	62,457
Miami, FL	57,415	7,155	650	602	218	551	5,340	322,880
Searsport, ME	543	110	9	8	3	9	124	4,769
Boston, MA	13,290	1,647	146	135	53	131	1,572	74,625
New Bedford/Fairhaven, MA	181	39	3	3	1	3	33	1,700
Baltimore, MD	25,197	6,412	519	481	212	502	3,918	244,560
Newport News, VA	5,529	505	41	38	17	41	316	19,760
Savannah, GA	37,523	3,594	289	267	126	291	2,174	137,046
Catalina, CA	928	78	7	7	2	6	53	3,639
Carquinez, CA	3,442	537	39	36	17	42	309	20,535
El Segundo, CA	1,685	192	14	13	6	15	108	7,095
Eureka, CA	409	82	6	5	2	6	51	3,486
Hueneme, CA	3,334	319	22	21	10	280	190	12,820
Long Beach, CA	56,935	5,303	389	357	166	417	3,141	213,005
Los Angeles, CA	50,489	4,793	352	324	150	378	2,839	192,430
Oakland, CA	48,762	3,022	222	205	100	239	1,638	110,003
Redwood City, CA	456	107	8	7	3	8	64	4,317
Richmond, CA	3,956	484	35	33	15	37	277	18,361
Sacramento, CA	455	138	10	9	4	11	81	5,417
San Diego, CA	8,255	840	68	63	25	65	536	36,609
San Francisco, CA	6,260	684	53	49	21	53	419	28,356
Stockton, CA	1,210	332	24	22	10	26	192	12,830
Total Port Emissions	863,191	121,606	10,530	9,631	4,148	10,635	93,908	4,995,871
Total Port Emissions (short tons)		***134,047***	***11,608***	***10,616***	***4,572***	***11,723***	***103,515***	***5,507,005***

Table 3-16 Auxiliary Engine Emissions by Deep Sea Port in 2002

Port Name	Installed Power (MW)	Metric Tonnes						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Anacortes, WA	115	147	11	10	4	11	92	6,798
Barbers Point, HI	101	77	6	5	2	6	48	3,568
Everett, WA	40	21	2	1	1	2	13	977
Grays Harbor, WA	73	25	2	2	1	2	16	1,176
Honolulu, HI	2,043	793	67	61	22	60	522	36,366
Kalama, WA	260	172	13	12	5	13	108	7,930
Longview, WA	346	183	14	13	5	14	115	8,445
Olympia, WA	21	9	1	1	0	1	6	410
Port Angeles, WA	111	42	3	3	1	3	26	1,922
Portland, OR	2,560	924	70	64	26	70	580	42,675
Seattle, WA	5,947	1,472	116	106	41	112	939	67,795
Tacoma, WA	4,305	1,279	97	88	35	97	802	59,093
Vancouver, WA	427	182	14	13	5	14	114	8,402
Valdez, AK	1,411	256	20	18	7	19	161	11,836
Other Puget Sound	1,198	951	72	66	26	72	596	43,927
Anchorage, AK	158	99	8	7	3	8	63	3,683
Coos Bay, OR	78	21	2	2	1	2	14	949
Hilo, HI	1,251	815	64	58	23	64	529	38,048
Kahului, HI	642	412	32	29	12	32	267	19,178
Nawiliwili, HI	164	108	8	8	3	8	70	5,023
Nikishka, AK	235	132	10	9	4	10	83	5,623
Beaumont, TX	2,415	873	149	135	31	63	1,188	40,334
Freeport, TX	1,342	321	58	53	11	24	461	14,819
Galveston, TX	1,645	674	89	75	24	42	660	31,135
Houston, TX	8,410	1,827	305	268	64	129	2,352	84,373
Port Arthur, TX	640	173	29	25	6	12	220	8,002
Texas City, TX	1,414	418	78	71	15	31	626	19,301
Corpus Christi, TX	2,486	770	64	59	21	59	514	35,563
Lake Charles, LA	1,347	457	38	35	13	35	305	21,105
Mobile, AL	1,816	423	35	32	12	32	282	19,529
Brownsville, TX	260	84	7	6	2	6	56	3,899
Gulfport, MS	878	415	34	30	11	31	292	19,017
Manatee, FL	902	491	41	35	13	37	343	22,448
Matagorda Ship	535	202	17	14	6	15	131	9,318
Panama City, FL	130	28	2	2	1	2	19	1,315
Pascagoula, MS	795	277	23	20	8	21	187	12,772
Pensacola, FL	87	20	2	1	1	1	14	906
Tampa, FL	2,639	777	67	51	21	59	534	35,735
Everglades, FL	9,813	3,032	277	256	84	230	2,158	140,039
New Orleans, LA	6,376	3,426	295	271	95	260	2,343	158,234
Baton Rouge, LA	988	813	67	62	22	62	543	37,544
South Louisiana, LA	3,988	2,969	246	226	82	226	1,982	137,151
Plaquemines, LA	919	607	50	46	17	46	406	28,058
Albany, NY	85	46	4	3	1	3	31	2,111
New York/New Jersey	20,036	3,467	294	270	96	263	2,343	159,839
Portland, ME	883	477	40	37	13	36	320	22,034
Georgetown, SC	129	42	3	3	1	3	28	1,960
Hopewell, VA	40	16	1	1	0	1	11	757

Table 3-16 Auxiliary Engine Emissions by Deep Sea Port in 2002 (continued)

Port Name	Installed Power (MW)	Metric Tonnes						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Marcus Hook, PA	583	617	51	47	17	47	412	28,518
Morehead City, NC	203	74	6	6	2	6	49	3,421
Paulsboro, NJ	701	294	25	23	8	22	198	13,584
Chester, PA	318	63	5	5	2	5	42	2,897
Fall River, MA	61	17	2	2	1	2	15	1,035
New Castle, DE	164	120	10	9	3	9	80	5,532
Penn Manor, PA	159	69	6	5	2	5	46	3,204
Providence, RI	236	118	10	9	3	9	79	5,436
Brunswick, GA	1,302	263	22	20	7	20	176	12,160
Canaveral, FL	4,916	2,486	225	209	68	187	1,804	113,582
Charleston, SC	10,277	1,630	136	124	45	124	1,093	75,271
New Haven, CT	379	188	16	14	5	14	125	8,664
Palm Beach, FL	506	132	11	10	4	10	89	6,082
Bridgeport, CT	522	187	15	14	5	14	125	8,625
Camden, NJ	1,286	579	48	44	16	44	387	26,754
Philadelphia, PA	1,803	976	81	74	27	74	652	45,081
Wilmington, DE	1,155	303	25	23	8	23	202	13,982
Wilmington, NC	1,045	333	28	25	9	25	223	15,397
Richmond, VA	130	26	2	2	1	2	18	1,216
Jacksonville, FL	3,242	776	64	59	21	59	516	35,693
Miami, FL	14,504	5,171	462	428	142	389	3,711	236,659
Searsport, ME	116	73	6	6	2	6	49	3,380
Boston, MA	3,100	1,105	94	87	30	84	759	50,846
New Bedford/Fairhaven, MA	53	28	2	2	1	2	19	1,280
Baltimore, MD	5,924	1,632	137	126	45	52	1,111	75,309
Newport News, VA	1,216	170	14	13	5	13	122	8,063
Savannah, GA	8,297	1,035	83	76	29	79	691	47,804
Catalina, CA	257	45	4	4	1	3	28	2,043
Carquinez, CA	772	193	13	11	5	15	128	8,706
El Segundo, CA	355	47	3	3	1	4	32	2,117
Eureka, CA	88	59	4	4	2	5	38	2,661
Hueneme, CA	1,010	177	11	10	5	47	115	7,955
Long Beach, CA	13,007	2,632	178	162	72	205	1,704	119,333
Los Angeles, CA	11,535	2,356	160	145	65	184	1,525	106,855
Oakland, CA	10,759	860	57	52	24	67	551	39,102
Redwood City, CA	101	59	4	3	2	5	39	2,665
Richmond, CA	866	164	11	10	5	13	109	7,403
Sacramento, CA	95	61	4	4	2	5	40	2,754
San Diego, CA	2,164	483	37	34	13	37	311	21,942
San Francisco, CA	1,480	345	25	23	9	27	224	15,630
Stockton, CA	259	125	8	7	3	10	82	5,673
Total Auxiliary Emissions	197,430	57,317	5,052	4,597	1,615	4,306	41,232	2,635,436
Total Auxiliary Emissions (short tons)		***63,181***	***5,569***	***5,067***	***1,781***	***4,746***	***45,450***	***2,905,071***

Table 3-17 Cruise Emissions by Deep Sea Port in 2002

Port Name	Installed Power (MW)	Metric Tonnes						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Anacortes, WA	545	50	4	4	2	4	29	1,871
Barbers Point, HI	472	28	2	2	1	2	16	1,039
Everett, WA	186	9	1	1	0	1	6	385
Grays Harbor, WA	360	15	1	1	1	1	10	627
Honolulu, HI	8,037	300	28	26	10	23	206	13,469
Kalama, WA	1,190	72	6	6	2	6	45	2,949
Longview, WA	1,619	89	8	7	3	7	55	3,597
Olympia, WA	97	5	0	0	0	0	3	184
Port Angeles, WA	556	27	2	2	1	2	17	1,134
Portland, OR	11,198	424	40	37	15	33	291	19,040
Seattle, WA	26,292	775	74	69	27	59	544	35,599
Tacoma, WA	19,130	622	59	55	22	49	428	28,010
Vancouver, WA	1,946	88	8	7	3	7	56	3,650
Valdez, AK	6,676	45	8	8	2	4	75	4,904
Other Puget Sound	5,678	197	24	22	7	15	202	13,218
Anchorage, AK	537	22	2	2	1	2	14	934
Coos Bay, OR	399	21	2	2	1	2	12	758
Hilo, HI	4,514	108	14	13	4	9	109	7,278
Kahului, HI	2,323	58	7	6	2	5	51	3,382
Nawiliwili, HI	591	14	2	2	1	1	15	984
Nikishka, AK	1,110	32	4	4	1	3	34	2,220
Beaumont, TX	12,699	665	52	48	22	51	384	23,253
Freeport, TX	7,411	362	28	26	12	28	209	12,624
Galveston, TX	6,572	283	23	22	9	22	175	10,741
Houston, TX	47,147	2,180	173	161	72	169	1,290	78,115
Port Arthur, TX	3,531	184	15	13	6	14	108	6,521
Texas City, TX	7,382	386	30	28	13	30	224	13,579
Corpus Christi, TX	11,452	584	46	43	19	45	341	20,702
Lake Charles, LA	6,382	266	25	23	9	21	195	11,811
Mobile, AL	8,200	402	33	30	13	31	247	14,961
Brownsville, TX	1,213	69	5	5	2	5	40	2,453
Gulfport, MS	3,556	148	13	12	5	12	95	5,765
Manatee, FL	2,903	132	11	10	4	10	82	4,991
Matagorda Ship	2,504	143	11	10	5	11	83	5,021
Panama City, FL	662	35	3	3	1	3	20	1,240
Pascagoula, MS	3,566	181	15	14	6	15	118	7,155
Pensacola, FL	351	16	1	1	1	1	10	635
Tampa, FL	10,941	539	45	42	18	42	341	20,705
Everglades, FL	38,304	1,348	131	121	45	104	1,038	62,951
New Orleans, LA	27,575	1,249	102	94	41	97	761	46,164
Baton Rouge, LA	4,627	238	19	17	8	18	139	8,439
South Louisiana, LA	18,366	961	75	70	32	74	557	33,789
Plaquemines, LA	4,230	221	17	16	7	17	128	7,766
Albany, NY	396	20	2	2	1	2	12	734
New York/New Jersey	86,980	3,266	261	242	108	253	1,940	117,641
Portland, ME	3,968	195	16	15	6	15	118	7,131
Georgetown, SC	609	31	3	2	1	2	19	1,153
Hopewell, VA	185	10	1	1	0	1	6	356

Table 3-17 Cruise Emissions by Deep Sea Port in 2002 (continued)

Port Name	Installed Power (MW)	Metric Tonnes						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Marcus Hook, PA	2,754	143	11	10	5	11	82	4,974
Morehead City, NC	967	44	4	3	1	3	28	1,687
Paulsboro, NJ	3,272	166	13	12	5	13	97	5,887
Chester, PA	1,467	63	5	5	2	5	37	2,261
Fall River, MA	290	13	1	1	0	1	9	540
New Castle, DE	765	41	3	3	1	3	23	1,415
Penn Manor, PA	721	38	3	3	1	3	22	1,351
Providence, RI	1,097	58	4	4	2	4	33	2,007
Brunswick, GA	5,184	222	17	16	7	17	129	7,816
Canaveral, FL	17,801	665	54	50	22	52	501	30,423
Charleston, SC	46,233	1,702	133	123	56	132	986	59,738
New Haven, CT	1,801	92	7	7	3	7	54	3,259
Palm Beach, FL	2,277	83	8	7	3	6	60	3,623
Bridgeport, CT	1,452	58	4	4	2	5	34	2,073
Camden, NJ	4,209	191	15	14	6	15	113	6,874
Philadelphia, PA	7,644	326	26	24	11	25	194	11,761
Wilmington, DE	4,444	178	14	13	6	14	104	6,283
Wilmington, NC	4,888	213	17	16	7	16	125	7,597
Richmond, VA	596	25	2	2	1	2	15	891
Jacksonville, FL	13,908	571	46	43	19	44	349	21,139
Miami, FL	57,415	2,068	173	161	70	161	1,497	90,831
Searsport, ME	543	27	2	2	1	2	17	1,018
Boston, MA	13,290	465	41	38	16	36	340	20,603
New Bedford/Fairhaven, MA	181	8	1	1	0	1	5	331
Baltimore, MD	25,197	1,013	81	75	34	78	600	36,410
Newport News, VA	5,529	214	17	16	7	17	125	7,560
Savannah, GA	37,523	1,400	110	102	46	108	815	49,371
Catalina, CA	928	36	4	3	1	3	26	1,700
Carquinez, CA	3,442	171	13	12	6	13	92	6,025
El Segundo, CA	1,685	87	7	6	3	7	47	3,068
Eureka, CA	409	19	2	1	1	1	11	699
Hueneme, CA	3,334	137	11	10	5	11	74	4,862
Long Beach, CA	56,935	2,093	168	156	69	162	1,165	76,254
Los Angeles, CA	50,489	1,856	149	138	62	144	1,033	67,622
Oakland, CA	48,762	1,676	131	122	55	130	900	58,866
Redwood City, CA	456	24	2	2	1	2	13	851
Richmond, CA	3,956	197	15	14	7	15	106	6,936
Sacramento, CA	455	23	2	2	1	2	13	821
San Diego, CA	8,255	336	30	28	11	26	217	14,243
San Francisco, CA	6,260	273	23	21	9	21	162	10,632
Stockton, CA	1,210	63	5	5	2	5	34	2,216
Total Cruise Emissions	863,191	34,193	2,826	2,623	1,141	2,651	21,186	1,314,146
Total Cruise Emissions (short tons)		***37,691***	***3,115***	***2,891***	***1,258***	***2,922***	***23,353***	***1,448,598***

Table 3-18 Reduced Speed Zone Emissions by Deep Sea Port in 2002

Port Name	Installed Power (MW)	Metric Tonnes						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Anacortes, WA	545	191	15	14	6	15	103	6,773
Barbers Point, HI	472	3	0	0	0	0	2	125
Everett, WA	186	49	4	4	2	4	27	1,785
Grays Harbor, WA	360	3	0	0	0	0	2	109
Honolulu, HI	8,037	75	7	6	3	6	48	3,223
Kalama, WA	1,190	101	8	7	4	9	57	3,800
Longview, WA	1,619	125	10	9	5	11	70	4,645
Olympia, WA	97	43	3	3	1	3	23	1,509
Port Angeles, WA	556	77	6	6	3	6	45	2,924
Portland, OR	11,198	969	86	79	58	108	539	36,288
Seattle, WA	26,292	4,289	349	323	151	347	2,402	157,988
Tacoma, WA	19,130	3,685	290	269	121	285	2,023	133,271
Vancouver, WA	1,946	175	14	13	7	16	100	6,661
Valdez, AK	6,676	33	5	5	1	3	46	3,044
Other Puget Sound	5,678	963	112	104	32	75	942	61,929
Anchorage, AK	537	121	10	9	4	10	71	3,721
Coos Bay, OR	399	5	0	0	0	1	3	123
Hilo, HI	4,514	27	2	2	1	2	18	339
Kahului, HI	2,323	14	1	1	0	1	9	156
Nawiliwili, HI	591	4	0	0	0	0	2	47
Nikishka, AK	1,110	117	12	12	4	9	99	5,979
Beaumont, TX	12,699	771	81	75	45	88	574	29,868
Freeport, TX	7,411	28	2	2	1	2	18	1,016
Galveston, TX	6,572	101	10	9	4	8	73	3,958
Houston, TX	47,147	656	57	53	22	50	429	24,233
Port Arthur, TX	3,531	97	10	9	6	11	71	3,760
Texas City, TX	7,382	181	16	14	6	14	117	6,581
Corpus Christi, TX	11,452	419	33	31	14	293	250	15,432
Lake Charles, LA	6,382	175	20	19	13	185	124	7,805
Mobile, AL	8,200	352	29	27	12	239	219	13,537
Brownsville, TX	1,213	23	2	1	1	2	12	879
Gulfport, MS	3,556	50	4	3	2	5	27	2,070
Manatee, FL	2,903	78	7	4	3	7	36	3,183
Matagorda Ship	2,504	55	5	3	3	6	27	2,117
Panama City, FL	662	7	1	0	0	1	4	263
Pascagoula, MS	3,566	68	6	5	2	6	40	2,788
Pensacola, FL	351	5	0	0	0	0	3	225
Tampa, FL	10,941	329	29	16	12	28	159	13,321
Everglades, FL	38,304	71	7	7	3	7	52	3,225
New Orleans, LA	27,575	2,670	224	208	98	227	1,678	103,988
Baton Rouge, LA	4,627	1,091	87	80	36	85	648	40,082
South Louisiana, LA	18,366	2,897	229	212	95	225	1,712	105,846
Plaquemines, LA	4,230	244	19	18	8	19	144	8,910
Albany, NY	396	48	4	4	2	5	30	1,845
New York/New Jersey	86,980	881	83	76	54	105	547	34,706
Portland, ME	3,968	48	4	4	2	4	30	1,839
Georgetown, SC	609	16	1	1	1	1	105	615
Hopewell, VA	185	22	2	2	1	2	196	781

Table 3-18 Reduced Speed Zone Emissions by Deep Sea Port in 2002(continued)

Port Name	Installed Power (MW)	Metric Tonnes						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Marcus Hook, PA	2,754	245	20	18	9	20	1,996	9,058
Morehead City, NC	967	2	0	0	0	0	16	75
Paulsboro, NJ	3,272	254	21	19	9	21	1,841	9,527
Chester, PA	1,467	86	7	7	3	8	343	3,292
Fall River, MA	290	5	0	0	0	0	29	231
New Castle, DE	765	45	4	3	1	4	295	1,671
Penn Manor, PA	721	82	7	6	3	7	598	3,045
Providence, RI	1,097	26	2	2	1	2	225	971
Brunswick, GA	5,184	215	17	16	7	17	1,015	7,867
Canaveral, FL	17,801	73	7	7	2	6	94	3,316
Charleston, SC	46,233	539	44	41	22	50	2,504	20,265
New Haven, CT	1,801	4	0	0	0	0	27	146
Palm Beach, FL	2,277	5	0	0	0	0	14	235
Bridgeport, CT	1,452	2	0	0	0	0	6	98
Camden, NJ	4,209	346	29	27	14	32	1,208	13,693
Philadelphia, PA	7,644	505	43	40	19	48	2,603	19,709
Wilmington, DE	4,444	206	17	16	10	20	747	7,996
Wilmington, NC	4,888	110	9	9	5	10	620	4,169
Richmond, VA	596	44	4	3	2	4	180	1,688
Jacksonville, FL	13,908	206	17	16	8	19	820	8,030
Miami, FL	57,415	182	17	16	6	15	331	8,194
Searsport, ME	543	11	1	1	0	1	59	442
Boston, MA	13,290	135	13	12	6	13	514	6,009
New Bedford/Fairhaven, MA	181	4	0	0	0	0	10	158
Baltimore, MD	25,197	4,325	347	321	142	336	2,596	159,626
Newport News, VA	5,529	131	11	10	5	11	86	4,998
Savannah, GA	37,523	1,333	107	99	46	110	802	49,492
Catalina, CA	928	11	1	1	0	1	8	523
Carquinez, CA	3,442	183	14	13	6	14	100	6,591
El Segundo, CA	1,685	58	5	4	2	5	32	2,093
Eureka, CA	409	4	0	0	0	0	2	165
Hueneme, CA	3,334	8	1	1	0	256	5	251
Long Beach, CA	56,935	748	62	58	30	69	436	29,056
Los Angeles, CA	50,489	755	63	58	30	69	440	29,305
Oakland, CA	48,762	524	43	40	23	53	272	18,380
Redwood City, CA	456	25	2	2	1	2	14	905
Richmond, CA	3,956	123	10	9	4	10	67	4,427
Sacramento, CA	455	58	5	4	2	4	32	2,088
San Diego, CA	8,255	98	9	8	3	8	63	4,198
San Francisco, CA	6,260	101	8	8	3	8	61	4,015
Stockton, CA	1,210	156	12	11	5	12	85	5,586
Total RSZ Emissions	863,191	34,427	2,887	2,657	1,280	3,804	35,148	1,318,897
Total RSZ Emissions (short tons)		***37,949***	***3,182***	***2,929***	***1,410***	***4,193***	***38,744***	***1,453,835***

Table 3-19 Maneuvering Emissions by Deep Sea Port in 2002

Port Name	Installed Power (MW)	Metric Tonnes						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Anacortes, WA	545	50	5	3	3	5	23	1,610
Barbers Point, HI	472	25	2	2	1	2	12	806
Everett, WA	186	9	1	1	1	1	4	301
Grays Harbor, WA	360	12	1	1	1	1	6	412
Honolulu, HI	8,037	360	36	28	19	32	194	13,248
Kalama, WA	1,190	63	6	4	4	6	31	2,122
Longview, WA	1,619	72	7	5	4	7	35	2,411
Olympia, WA	97	3	0	0	0	0	2	109
Port Angeles, WA	556	19	2	1	1	2	10	666
Portland, OR	11,198	501	49	37	33	50	232	16,173
Seattle, WA	26,292	980	100	76	70	98	445	30,829
Tacoma, WA	19,130	810	81	62	57	82	368	25,644
Vancouver, WA	1,946	75	7	5	4	8	37	2,538
Valdez, AK	6,676	55	8	6	3	5	46	3,156
Other Puget Sound	5,678	252	29	22	13	25	163	11,182
Anchorage, AK	537	1	0	0	0	0	1	54
Coos Bay, OR	399	1	0	0	0	0	0	26
Hilo, HI	4,514	12	1	1	1	1	8	557
Kahului, HI	2,323	6	1	1	0	1	4	283
Nawiliwili, HI	591	1	0	0	0	0	1	73
Nikishka, AK	1,110	2	0	0	0	0	1	90
Beaumont, TX	12,699	49	14	12	2	4	95	1,909
Freeport, TX	7,411	23	7	6	1	2	45	898
Galveston, TX	6,572	40	12	5	1	3	38	1,676
Houston, TX	47,147	169	47	31	6	13	255	6,754
Port Arthur, TX	3,531	17	5	3	1	1	25	683
Texas City, TX	7,382	28	8	7	1	2	59	1,063
Corpus Christi, TX	11,452	112	11	10	8	14	68	4,385
Lake Charles, LA	6,382	54	6	5	4	6	38	2,414
Mobile, AL	8,200	70	7	6	5	8	44	2,835
Brownsville, TX	1,213	8	1	1	1	1	7	323
Gulfport, MS	3,556	27	3	2	2	3	20	1,025
Manatee, FL	2,903	33	3	3	2	4	25	1,301
Matagorda Ship	2,504	16	2	1	1	2	13	609
Panama City, FL	662	4	0	0	0	0	3	144
Pascagoula, MS	3,566	20	2	2	1	2	18	829
Pensacola, FL	351	2	0	0	0	0	2	68
Tampa, FL	10,941	66	7	6	4	8	95	2,637
Everglades, FL	38,304	233	24	23	12	23	163	10,273
New Orleans, LA	27,575	192	19	17	13	22	118	7,540
Baton Rouge, LA	4,627	35	3	3	2	4	21	1,371
South Louisiana, LA	18,366	143	14	12	10	18	87	5,606
Plaquemines, LA	4,230	33	3	3	2	4	20	1,297
Albany, NY	396	3	0	0	0	0	2	120
New York/New Jersey	86,980	455	46	42	36	54	265	17,069
Portland, ME	3,968	37	4	3	2	4	23	1,472
Georgetown, SC	609	3	0	0	0	0	2	126
Hopewell, VA	185	1	0	0	0	0	1	39

Table 3-19 Maneuvering Emissions by Deep Sea Port in 2002 (continued)

Port Name	Installed Power (MW)	Metric Tonnes						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Marcus Hook, PA	2,754	22	2	2	2	3	14	874
Morehead City, NC	967	5	0	0	0	1	3	204
Paulsboro, NJ	3,272	24	2	2	2	3	15	953
Chester, PA	1,467	5	1	1	0	1	3	204
Fall River, MA	290	1	0	0	0	0	1	60
New Castle, DE	765	5	0	0	0	1	3	196
Penn Manor, PA	721	4	0	0	0	0	2	159
Providence, RI	1,097	7	1	1	0	1	4	269
Brunswick, GA	5,184	25	2	2	2	3	15	974
Canaveral, FL	17,801	70	7	6	3	6	50	3,118
Charleston, SC	46,233	199	20	19	17	24	112	7,263
New Haven, CT	1,801	11	1	1	1	1	7	435
Palm Beach, FL	2,277	9	1	1	1	1	6	388
Bridgeport, CT	1,452	10	1	1	1	1	6	419
Camden, NJ	4,209	27	3	2	2	3	17	1,090
Philadelphia, PA	7,644	46	4	4	3	6	28	1,790
Wilmington, DE	4,444	22	2	2	2	3	13	861
Wilmington, NC	4,888	24	2	2	2	3	14	922
Richmond, VA	596	2	0	0	0	0	1	79
Jacksonville, FL	13,908	66	6	6	5	8	40	2,587
Miami, FL	57,415	241	25	23	14	24	164	10,379
Searsport, ME	543	4	0	0	0	0	2	147
Boston, MA	13,290	65	7	6	4	7	44	2,812
New Bedford/Fairhaven, MA	181	1	0	0	0	0	1	52
Baltimore, MD	25,197	130	13	12	10	15	76	4,931
Newport News, VA	5,529	25	3	2	2	3	14	929
Savannah, GA	37,523	164	17	15	14	20	91	5,936
Catalina, CA	928	10	1	1	0	1	6	455
Carquinez, CA	3,442	23	1	1	1	1	11	740
El Segundo, CA	1,685	9	1	1	0	1	4	287
Eureka, CA	409	4	0	0	0	0	2	133
Hueneme, CA	3,334	9	0	0	0	1	4	294
Long Beach, CA	56,935	272	15	13	6	15	120	8,669
Los Angeles, CA	50,489	242	13	12	5	13	106	7,687
Oakland, CA	48,762	241	10	9	5	11	89	6,472
Redwood City, CA	456	3	0	0	0	0	1	83
Richmond, CA	3,956	26	2	1	1	2	12	838
Sacramento, CA	455	3	0	0	0	0	1	84
San Diego, CA	8,255	80	6	6	2	6	46	3,409
San Francisco, CA	6,260	54	4	4	1	4	29	2,105
Stockton, CA	1,210	7	0	0	0	0	3	220
Total Maneuver Emissions	863,191	7,383	758	625	440	724	4,356	266,262
Total Maneuver Emissions (short tons)		***8,138***	***835***	***689***	***485***	***799***	***4,802***	***293,504***

Table 3-20 Hotelling Emissions by Deep Sea Port in 2002

Port Name	Installed Power (MW)	Metric Tonnes						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Anacortes, WA	545	113	9	8	3	9	71	5,207
Barbers Point, HI	472	66	5	5	2	5	42	3,064
Everett, WA	186	14	1	1	0	1	9	653
Grays Harbor, WA	360	20	2	1	1	2	12	918
Honolulu, HI	8,037	533	45	41	15	40	352	24,445
Kalama, WA	1,190	123	9	9	3	9	77	5,684
Longview, WA	1,619	126	10	9	3	10	79	5,842
Olympia, WA	97	5	0	0	0	0	3	245
Port Angeles, WA	556	29	2	2	1	2	18	1,319
Portland, OR	11,198	413	31	29	11	31	259	19,057
Seattle, WA	26,292	625	49	45	17	47	399	28,774
Tacoma, WA	19,130	624	47	43	17	47	391	28,829
Vancouver, WA	1,946	108	8	7	3	8	67	4,972
Valdez, AK	6,676	210	16	15	6	16	132	9,685
Other Puget Sound	5,678	699	53	48	19	53	438	32,299
Anchorage, AK	537	76	6	5	2	6	47	3,527
Coos Bay, OR	399	20	1	1	1	1	12	903
Hilo, HI	4,514	784	60	54	22	60	491	36,194
Kahului, HI	2,323	396	30	27	11	30	248	18,273
Nawiliwili, HI	591	103	8	7	3	8	65	4,780
Nikishka, AK	1,110	119	9	8	3	9	75	5,505
Beaumont, TX	12,699	622	114	105	22	46	919	28,707
Freeport, TX	7,411	301	55	51	11	22	445	13,884
Galveston, TX	6,572	590	73	67	21	36	587	27,267
Houston, TX	47,147	1,621	269	246	57	115	2,162	74,850
Port Arthur, TX	3,531	138	23	21	5	10	184	6,379
Texas City, TX	7,382	376	73	67	13	28	585	17,352
Corpus Christi, TX	11,452	643	53	49	18	49	430	29,720
Lake Charles, LA	6,382	355	29	27	10	27	237	16,379
Mobile, AL	8,200	321	27	24	9	24	214	14,822
Brownsville, TX	1,213	74	6	6	2	6	49	3,402
Gulfport, MS	3,556	382	31	29	10	29	272	17,521
Manatee, FL	2,903	425	35	32	12	32	307	19,428
Matagorda Ship	2,504	175	15	13	5	13	117	8,080
Panama City, FL	662	25	2	2	1	2	16	1,141
Pascagoula, MS	3,566	248	21	19	7	19	168	11,451
Pensacola, FL	351	17	1	1	0	1	12	797
Tampa, FL	10,941	573	49	45	16	43	392	26,370
Everglades, FL	38,304	2,634	240	222	73	200	1,870	121,678
New Orleans, LA	27,575	2,492	211	194	69	189	1,688	115,102
Baton Rouge, LA	4,627	621	51	47	17	47	414	28,676
South Louisiana, LA	18,366	2,427	201	185	67	185	1,620	112,104
Plaquemines, LA	4,230	547	45	42	15	42	365	25,286
Albany, NY	396	32	3	2	1	2	21	1,467
New York/New Jersey	86,980	2,762	234	215	76	210	1,867	127,364
Portland, ME	3,968	442	37	34	12	34	296	20,394
Georgetown, SC	609	38	3	3	1	3	26	1,773
Hopewell, VA	185	13	1	1	0	1	9	589

Table 3-20 Hotelling Emissions by Deep Sea Port in 2002 (continued)

Port Name	Installed Power (MW)	Metric Tonnes						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Marcus Hook, PA	2,754	555	46	42	15	42	371	25,657
Morehead City, NC	967	70	6	5	2	5	47	3,230
Paulsboro, NJ	3,272	223	19	17	6	17	150	10,309
Chester, PA	1,467	41	3	3	1	3	27	1,891
Fall River, MA	290	15	2	2	1	2	13	918
New Castle, DE	765	108	9	8	3	8	72	4,975
Penn Manor, PA	721	50	4	4	1	4	34	2,323
Providence, RI	1,097	108	9	8	3	8	72	4,975
Brunswick, GA	5,184	208	17	16	6	16	139	9,616
Canaveral, FL	17,801	2,252	213	198	62	169	1,634	102,912
Charleston, SC	46,233	1,368	114	105	38	104	917	63,159
New Haven, CT	1,801	179	15	14	5	14	120	8,276
Palm Beach, FL	2,277	122	10	9	3	9	82	5,623
Bridgeport, CT	1,452	175	15	13	5	13	117	8,102
Camden, NJ	4,209	430	36	33	12	33	287	19,882
Philadelphia, PA	7,644	807	67	61	22	61	539	37,262
Wilmington, DE	4,444	220	18	17	6	17	147	10,180
Wilmington, NC	4,888	294	24	22	8	22	196	13,576
Richmond, VA	596	15	1	1	0	1	10	675
Jacksonville, FL	13,908	665	55	51	18	51	444	30,702
Miami, FL	57,415	4,665	434	402	128	351	3,348	213,476
Searsport, ME	543	68	6	5	2	5	46	3,163
Boston, MA	13,290	982	85	78	27	74	673	45,202
New Bedford/Fairhaven, MA	181	25	2	2	1	2	17	1,160
Baltimore, MD	25,197	944	79	73	26	72	646	43,593
Newport News, VA	5,529	136	11	10	4	10	91	6,274
Savannah, GA	37,523	698	55	50	19	53	466	32,248
Catalina, CA	928	21	2	2	1	2	13	961
Carquinez, CA	3,442	159	10	9	4	13	107	7,178
El Segundo, CA	1,685	37	2	2	1	3	25	1,646
Eureka, CA	409	55	4	3	2	4	36	2,489
Hueneme, CA	3,334	164	11	10	5	13	107	7,413
Long Beach, CA	56,935	2,189	144	130	60	172	1,420	99,027
Los Angeles, CA	50,489	1,941	127	116	53	152	1,259	87,816
Oakland, CA	48,762	581	37	34	16	46	376	26,285
Redwood City, CA	456	55	4	3	2	4	36	2,479
Richmond, CA	3,956	137	9	8	4	11	92	6,160
Sacramento, CA	455	54	3	3	1	4	35	2,424
San Diego, CA	8,255	326	23	21	9	25	209	14,758
San Francisco, CA	6,260	257	18	16	7	20	167	11,604
Stockton, CA	1,210	107	7	6	3	8	70	4,808
Total Hotel Emissions	863,191	45,603	4,060	3,726	1,287	3,456	33,218	2,096,566
Total Hotel Emissions (short tons)		***50,268***	***4,475***	***4,107***	***1,419***	***3,809***	***36,617***	***2,311,068***

Table 3-21 Auto Carrier Deep Sea Port Emissions in 2002

Port Name	Installed Power (MW)	Metric Tonnes						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Honolulu, HI	539	59	5	5	3	5	35	2,397
Port Angeles, WA	6	1	0	0	0	0	1	47
Portland, OR	2,331	416	38	33	21	42	246	16,911
Seattle, WA	9	3	0	0	0	0	2	109
Tacoma, WA	2,123	733	61	55	27	59	414	27,690
Vancouver, WA	278	48	4	4	2	5	28	1,946
Beaumont, TX	31	4	1	1	0	0	4	195
Galveston, TX	560	59	6	5	2	4	43	2,372
Houston, TX	1,141	122	12	11	4	8	92	5,019
Mobile, AL	692	72	6	6	2	16	47	2,993
Manatee, FL	4	0	0	0	0	0	0	14
Matagorda Ship	16	1	0	0	0	0	1	48
Pensacola, FL	169	13	1	1	0	1	8	520
Tampa, FL	284	24	2	2	1	2	15	994
Everglades, FL	136	22	2	2	1	2	14	938
New Orleans, LA	225	50	4	4	2	4	32	2,089
South Louisiana, LA	16	3	0	0	0	0	2	129
New York/New Jersey	4,588	361	30	28	15	32	218	13,923
Morehead City, NC	35	3	0	0	0	0	2	102
Chester, PA	9	2	0	0	0	0	4	65
Brunswick, GA	3,350	368	30	28	12	29	499	14,351
Canaveral, FL	53	4	0	0	0	0	3	153
Charleston, SC	1,922	182	15	14	6	14	169	7,234
Bridgeport, CT	40	3	0	0	0	0	2	133
Camden, NJ	0	0	0	0	0	0	0	0
Philadelphia, PA	111	16	1	1	1	1	27	604
Wilmington, DE	1,012	126	10	10	5	11	180	5,014
Jacksonville, FL	4,420	389	32	29	14	32	362	15,430
Miami, FL	131	10	1	1	0	1	7	395
Boston, MA	744	62	5	5	2	5	54	2,495
Baltimore, MD	5,458	1,290	103	95	43	101	768	48,152
Newport News, VA	270	27	2	2	1	2	20	1,127
Savannah, GA	644	76	6	6	3	6	46	2,898
Carquinez, CA	682	84	6	6	3	6	49	3,246
Hueneme, CA	2,036	125	9	8	4	157	71	4,650
Long Beach, CA	1,068	96	7	6	3	7	55	3,681
Los Angeles, CA	947	87	6	6	3	7	50	3,339
Oakland, CA	10	1	0	0	0	0	1	42
Richmond, CA	468	51	4	3	2	4	30	1,986
San Diego, CA	1,374	131	9	9	4	10	77	5,123
San Francisco, CA	20	2	0	0	0	0	1	81
Total Auto Carrier	37,954	5,125	421	384	185	577	3,676	198,637
Total Auto Carrier (short tons)		***5,649***	***464***	***424***	***204***	***636***	***4,052***	***218,960***

Table 3-22 Barge Carrier Deep Sea Port Emissions in 2002

Port Name	Installed Power (MW)	Metric Tonnes						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Mobile, AL	2	0	0	0	0	0	0	17
New Orleans, LA	472	87	8	7	3	8	57	3,738
Morehead City, NC	73	6	1	1	0	0	5	330
Charleston, SC	420	55	4	4	2	4	78	2,279
Total Barge Carrier	967	148	13	12	5	12	141	6,364
Total Barge Carrier (short tons)		***163***	***14***	***13***	***6***	***14***	***156***	***7,015***

Table 3-23 Bulk Carrier Deep Sea Port Emissions in 2002

Port Name	Installed Power (MW)	Metric Tonnes						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Anacortes, WA	67	28	2	2	1	2	15	1,033
Barbers Point, HI	82	14	1	1	1	1	9	599
Everett, WA	71	33	3	2	1	3	18	1,206
Grays Harbor, WA	140	24	2	2	1	2	14	974
Honolulu, HI	158	29	2	2	1	2	17	1,188
Kalama, WA	1,007	233	19	17	8	20	136	9,408
Longview, WA	1,142	265	22	19	10	22	154	10,659
Olympia, WA	73	45	4	3	2	4	24	1,628
Port Angeles, WA	72	22	2	2	1	2	12	848
Portland, OR	2,351	633	51	46	23	53	364	25,061
Seattle, WA	523	244	19	18	8	19	135	9,103
Tacoma, WA	872	445	35	32	15	35	247	16,617
Vancouver, WA	1,003	256	21	19	9	22	147	10,127
Valdez, AK	7	1	0	0	0	0	1	59
Anchorage, AK	52	22	2	2	1	2	12	763
Coos Bay, OR	87	10	1	1	0	1	6	389
Hilo, HI	31	3	0	0	0	0	2	125
Kahului, HI	34	4	0	0	0	0	2	145
Nikishka, AK	246	74	6	5	2	6	41	2,609
Beaumont, TX	1,055	185	19	16	9	18	129	6,998
Freeport, TX	392	35	4	3	1	3	25	1,347
Galveston, TX	1,063	114	11	9	4	8	78	4,285
Houston, TX	5,996	655	66	54	22	48	446	24,640
Port Arthur, TX	890	106	11	9	4	9	74	4,025
Texas City, TX	481	60	6	5	2	4	40	2,221
Corpus Christi, TX	3,359	460	37	34	16	121	278	17,665
Lake Charles, LA	1,116	147	13	12	6	46	91	5,870
Mobile, AL	2,752	401	32	30	14	115	241	15,258
Brownsville, TX	685	106	9	8	3	8	65	4,234
Gulfport, MS	120	21	2	2	1	2	13	834
Manatee, FL	322	60	5	4	2	5	36	2,364
Matagorda Ship	586	118	10	9	4	10	71	4,713
Panama City, FL	79	13	1	1	0	1	8	515
Pascagoula, MS	586	116	9	8	4	9	70	4,586
Pensacola, FL	25	4	0	0	0	0	3	178
Tampa, FL	3,380	604	49	43	20	48	365	23,968
Everglades, FL	626	109	9	8	3	9	70	4,652
New Orleans, LA	8,311	2,511	202	187	79	196	1,550	100,577

Table 3-23 Bulk Carrier Deep Sea Port Emissions in 2002 (continued)

Port Name	Installed Power (MW)	Metric Tonnes						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Baton Rouge, LA	1,668	722	58	53	23	56	439	28,070
South Louisiana, LA	11,606	4,014	323	298	127	313	2,470	159,561
Plaquemines, LA	2,714	665	54	50	21	52	417	27,385
Albany, NY	280	79	6	6	3	7	49	3,152
New York/New Jersey	3,168	482	41	37	16	39	317	20,791
Portland, ME	470	62	5	5	2	5	38	2,458
Georgetown, SC	408	63	5	5	2	5	116	2,606
Hopewell, VA	127	30	2	2	1	2	144	1,167
Marcus Hook, PA	243	54	4	4	2	4	192	2,146
Morehead City, NC	130	17	1	1	1	1	13	692
Paulsboro, NJ	168	38	3	3	1	3	57	1,522
Chester, PA	35	7	1	1	0	1	26	289
Fall River, MA	127	13	2	1	1	1	30	792
New Castle, DE	240	51	4	4	2	4	37	2,080
Penn Manor, PA	659	161	13	12	5	13	637	6,326
Providence, RI	511	78	6	6	3	6	154	3,157
Brunswick, GA	370	75	6	6	2	6	276	2,934
Canaveral, FL	464	59	5	4	2	5	54	2,453
Charleston, SC	1,589	238	19	18	8	19	449	9,729
New Haven, CT	424	55	4	4	2	4	43	2,282
Palm Beach, FL	83	11	1	1	0	1	9	442
Bridgeport, CT	98	13	1	1	0	1	10	547
Camden, NJ	775	176	14	13	6	14	714	6,918
Philadelphia, PA	473	105	8	8	3	8	296	4,161
Wilmington, DE	345	66	5	5	2	5	215	2,611
Wilmington, NC	422	68	5	5	2	5	160	2,718
Richmond, VA	11	3	0	0	0	0	18	117
Jacksonville, FL	1,394	203	17	15	6	16	337	8,436
Miami, FL	122	16	1	1	1	1	17	653
Searsport, ME	37	6	0	0	0	0	9	227
Boston, MA	450	59	5	5	2	5	90	2,652
Baltimore, MD	2,851	1,273	102	95	41	99	773	48,126
Newport News, VA	692	118	10	9	4	9	78	4,815
Savannah, GA	1,474	334	27	25	11	26	205	13,237
Carquinez, CA	717	172	12	11	5	13	103	6,934
Eureka, CA	114	28	2	2	1	2	18	1,201
Long Beach, CA	2,297	468	33	30	14	36	283	19,185
Los Angeles, CA	2,037	423	29	27	13	33	255	17,295
Oakland, CA	280	40	3	3	1	3	23	1,568
Redwood City, CA	437	103	7	7	3	8	61	4,155
Richmond, CA	385	82	6	5	2	6	50	3,371
Sacramento, CA	218	72	5	5	2	6	42	2,842
San Diego, CA	350	64	4	4	2	5	39	2,638
San Francisco, CA	498	101	7	6	3	8	61	4,139
Stockton, CA	638	198	14	13	6	15	116	7,780
Total Bulk Carrier	82,437	19,373	1,570	1,431	633	1,732	14,945	767,825
Total Bulk Carrier (short tons)		***21,355***	***1,731***	***1,577***	***697***	***1,909***	***16,474***	***846,382***

Table 3-24 Container Ship Deep Sea Port Emissions in 2002

Port Name	Installed Power (MW)	Metric Tonnes						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Everett, WA	24	6	0	0	0	0	3	210
Honolulu, HI	2,190	308	30	25	15	27	181	12,403
Port Angeles, WA	14	2	0	0	0	0	1	78
Portland, OR	5,227	879	85	74	59	96	486	33,142
Seattle, WA	21,749	5,230	445	396	218	441	2,857	191,094
Tacoma, WA	15,446	3,109	264	236	124	253	1,741	116,552
Vancouver, WA	7	4	0	0	0	0	2	143
Freeport, TX	1,575	74	6	6	2	6	46	2,679
Galveston, TX	427	22	2	2	1	2	14	792
Houston, TX	13,441	698	59	55	23	53	446	25,617
Corpus Christi, TX	24	2	0	0	0	0	1	84
Lake Charles, LA	36	4	0	0	0	1	2	135
Mobile, AL	39	4	0	0	0	1	2	155
Gulfport, MS	1,538	181	15	14	7	15	110	7,411
Everglades, FL	7,732	658	56	52	23	53	426	27,826
New Orleans, LA	5,756	788	65	60	35	76	482	30,940
South Louisiana, LA	36	5	0	0	0	1	3	197
Plaquemines, LA	12	1	0	0	0	0	1	41
New York/New Jersey	56,253	3,246	268	248	130	281	1,934	122,010
Morehead City, NC	24	2	0	0	0	0	1	58
Chester, PA	1,140	139	11	10	5	11	306	5,313
Charleston, SC	37,982	2,691	219	202	97	222	3,001	103,968
New Haven, CT	14	1	0	0	0	0	1	34
Palm Beach, FL	752	44	4	4	2	3	32	1,861
Philadelphia, PA	2,696	306	25	23	13	28	671	11,715
Wilmington, DE	1,999	197	16	15	8	18	379	7,555
Wilmington, NC	1,779	130	11	10	5	12	162	5,115
Richmond, VA	539	74	6	6	3	7	182	2,807
Jacksonville, FL	3,997	279	24	22	11	24	279	11,419
Miami, FL	20,834	1,310	107	99	46	105	961	51,282
Boston, MA	5,016	325	27	25	13	28	305	12,667
Baltimore, MD	9,224	1,411	112	104	49	113	828	51,462
Newport News, VA	3,797	251	20	19	9	20	148	9,311
Savannah, GA	28,209	2,088	168	156	77	173	1,230	76,805
Carquinez, CA	27	3	0	0	0	0	2	105
Eureka, CA	55	6	0	0	0	0	4	245
Hueneme, CA	82	6	0	0	0	6	4	250
Long Beach, CA	42,292	3,434	244	225	109	272	1,986	134,894
Los Angeles, CA	37,505	3,097	221	203	99	247	1,791	121,601
Oakland, CA	47,109	2,833	208	192	94	224	1,532	102,880
Richmond, CA	165	15	1	1	0	1	8	571
San Diego, CA	385	30	2	2	1	2	17	1,168
San Francisco, CA	1,209	102	7	7	3	8	59	4,003
Total Container Ship	378,355	33,990	2,733	2,494	1,282	2,833	22,628	1,288,596
Total Container Ship (short tons)		***37,468***	***3,012***	***2,749***	***1,413***	***3,123***	***24,944***	***1,420,434***

Table 3-25 General Cargo Ship Deep Sea Port Emissions in 2002

Port Name	Installed Power (MW)	Metric Tonnes						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Anacortes, WA	23	5	0	0	0	0	3	218
Everett, WA	58	19	2	1	1	1	11	764
Grays Harbor, WA	220	26	2	2	1	2	16	1,093
Honolulu, HI	43	6	1	1	0	1	4	294
Kalama, WA	116	15	1	1	1	1	8	568
Longview, WA	441	61	5	5	2	5	35	2,376
Olympia, WA	24	11	1	1	0	1	6	419
Port Angeles, WA	390	90	7	7	3	7	49	3,291
Portland, OR	771	123	11	9	5	11	71	4,812
Seattle, WA	841	261	21	19	9	21	145	9,653
Tacoma, WA	264	105	9	8	4	8	61	4,096
Vancouver, WA	514	73	6	6	3	7	43	2,924
Valdez, AK	6	1	0	0	0	0	1	39
Anchorage, AK	4	1	0	0	0	0	1	48
Coos Bay, OR	312	36	3	3	1	3	21	1,421
Hilo, HI	5	1	0	0	0	0	0	21
Kahului, HI	7	1	0	0	0	0	0	29
Nikishka, AK	24	7	1	0	0	1	4	247
Beaumont, TX	744	113	12	12	5	11	89	4,691
Freeport, TX	238	22	2	2	1	2	16	845
Galveston, TX	111	12	1	1	0	1	9	486
Houston, TX	5,806	560	59	52	19	42	439	23,458
Port Arthur, TX	890	100	11	9	4	9	77	4,085
Texas City, TX	46	6	1	1	0	0	4	232
Corpus Christi, TX	188	20	2	2	1	5	14	876
Lake Charles, LA	670	71	7	6	3	22	49	3,150
Mobile, AL	2,529	297	25	23	10	85	190	11,928
Brownsville, TX	206	23	2	2	1	2	15	949
Gulfport, MS	496	51	4	4	2	4	32	2,048
Manatee, FL	301	36	3	3	1	3	22	1,430
Matagorda Ship	27	2	0	0	0	0	2	104
Panama City, FL	545	52	4	4	2	4	33	2,070
Pascagoula, MS	466	45	4	4	2	4	30	1,915
Pensacola, FL	71	7	1	1	0	1	5	287
Tampa, FL	986	118	10	9	4	9	75	4,784
Everglades, FL	1,813	197	18	16	6	16	138	9,057
New Orleans, LA	2,925	601	50	46	20	48	384	24,538
Baton Rouge, LA	356	111	10	9	4	9	73	4,624
South Louisiana, LA	810	216	18	16	7	17	134	8,502
Plaquemines, LA	178	29	2	2	1	2	19	1,192
Albany, NY	83	15	1	1	1	1	10	639
New York/New Jersey	1,841	153	13	12	6	13	95	5,957
Georgetown, SC	202	26	2	2	1	2	35	1,062
Hopewell, VA	44	12	1	1	0	1	42	444
Marcus Hook, PA	39	7	1	1	0	1	16	299
Morehead City, NC	387	40	3	3	1	3	30	1,684
Paulsboro, NJ	22	3	0	0	0	0	2	145
Chester, PA	237	40	3	3	1	3	71	1,679

Table 3-25 General Cargo Ship Deep Sea Port Emissions in 2002 (continued)

Port Name	Installed Power (MW)	Metric Tonnes						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Fall River, MA	139	17	2	1	1	1	16	774
Penn Manor, PA	56	12	1	1	0	1	18	500
Providence, RI	32	4	0	0	0	0	7	158
Brunswick, GA	1,066	168	14	12	6	14	475	6,535
Canaveral, FL	549	61	5	5	2	5	52	2,509
Charleston, SC	1,814	223	18	17	7	18	343	9,045
New Haven, CT	382	43	4	3	1	3	30	1,791
Palm Beach, FL	722	76	7	6	2	6	54	3,524
Camden, NJ	974	180	15	14	6	15	349	7,471
Philadelphia, PA	960	164	14	13	6	14	315	6,907
Wilmington, DE	185	28	2	2	1	2	43	1,165
Wilmington, NC	1,178	155	13	12	5	12	237	6,288
Richmond, VA	38	7	1	1	0	1	5	322
Jacksonville, FL	1,419	152	13	12	5	12	160	6,422
Miami, FL	2,941	354	31	29	11	28	272	16,024
Searsport, ME	3	0	0	0	0	0	1	17
Boston, MA	122	14	1	1	0	1	13	606
Baltimore, MD	2,275	673	56	52	22	52	430	26,796
Newport News, VA	568	74	6	6	2	6	47	3,033
Savannah, GA	2,521	415	34	32	14	32	261	16,543
Carquinez, CA	39	8	1	1	0	1	5	331
Eureka, CA	183	42	3	3	1	3	26	1,750
Hueneme, CA	77	7	0	0	0	10	4	262
Long Beach, CA	996	158	11	10	5	12	94	6,364
Los Angeles, CA	883	143	10	9	4	11	85	5,742
Oakland, CA	462	43	3	3	1	3	23	1,579
Redwood City, CA	19	4	0	0	0	0	2	163
Richmond, CA	67	13	1	1	0	1	8	530
Sacramento, CA	202	58	4	4	2	5	34	2,292
San Diego, CA	867	144	10	9	4	11	87	5,901
San Francisco, CA	453	82	6	5	2	6	50	3,375
Stockton, CA	202	55	4	4	2	4	32	2,147
Total General Cargo	49,711	7,402	630	576	251	684	6,208	302,338
Total General Cargo (short tons)		***8,159***	***694***	***635***	***277***	***754***	***6,843***	***333,270***

Table 3-26 Miscellaneous Ship Deep Sea Port Emissions in 2002

Port Name	Installed Power (MW)	Metric Tonnes						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Honolulu, HI	16	4	0	0	0	0	2	149
Portland, OR	21	7	1	0	0	0	4	269
Seattle, WA	9	5	0	0	0	0	3	180
Anchorage, AK	58	22	2	2	1	2	15	992
Kahului, HI	1	0	0	0	0	0	0	11
Houston, TX	13	1	0	0	0	0	1	49
Corpus Christi, TX	119	16	2	1	1	5	12	759
Lake Charles, LA	3	0	0	0	0	0	0	18
Mobile, AL	604	83	8	7	3	24	62	3,903
Pensacola, FL	65	11	1	1	0	1	8	497
New Orleans, LA	12	7	1	1	0	1	4	281
New York/New Jersey	26	7	1	1	0	1	5	325
Baltimore, MD	23	14	1	1	0	1	10	674
Newport News, VA	6	2	0	0	0	0	2	103
Total Miscellaneous	976	179	16	15	6	35	128	8,209
Total Miscellaneous (short tons)		***197***	***18***	***17***	***7***	***39***	***141***	***9,049***

Table 3-27 Passenger Ship Deep Sea Port Emissions in 2002

Port Name	Installed Power (MW)	Metric Tonnes						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Honolulu, HI	4,359	637	58	53	19	48	427	28,546
Portland, OR	60	12	1	1	1	1	8	558
Seattle, WA	3,017	739	72	66	23	54	540	35,669
Valdez, AK	31	2	0	0	0	0	2	110
Anchorage, AK	200	66	5	5	2	5	43	2,495
Hilo, HI	4,467	923	76	70	27	72	622	44,123
Kahului, HI	2,256	466	38	35	14	36	307	21,755
Nawiliwili, HI	583	120	10	9	4	9	82	5,810
Galveston, TX	3,248	644	76	64	23	42	559	28,782
Houston, TX	751	143	19	15	5	9	131	6,539
Corpus Christi, TX	113	21	2	2	1	3	14	954
Mobile, AL	330	80	7	6	2	11	52	3,538
Manatee, FL	634	66	7	5	2	5	52	3,064
Tampa, FL	3,599	352	34	25	12	28	271	16,166
Everglades, FL	22,083	2,447	244	227	73	187	1,897	117,326
New Orleans, LA	5,401	1,133	110	102	37	91	835	51,550
New York/New Jersey	6,841	745	74	68	25	59	551	34,382
Portland, ME	380	31	3	3	1	2	25	1,523
Paulsboro, NJ	126	30	3	3	1	2	23	1,395
Fall River, MA	11	1	0	0	0	0	1	63
Canaveral, FL	15,756	2,758	256	238	80	209	2,044	126,856
Charleston, SC	758	101	9	9	3	8	75	4,652
Palm Beach, FL	146	15	1	1	0	1	11	684
Philadelphia, PA	44	11	1	1	0	1	8	508
Miami, FL	28,808	4,919	463	430	142	373	3,712	230,290
Boston, MA	2,878	431	41	38	13	33	327	20,219
New Bedford/Fairhaven, MA	16	2	0	0	0	0	2	94
Baltimore, MD	1,058	427	42	39	13	33	320	19,829
Savannah, GA	16	5	1	0	0	0	4	243
Catalina, CA	919	78	7	7	2	6	53	3,608
Eureka, CA	57	6	1	1	0	0	4	290
Hueneme, CA	29	2	0	0	0	4	1	100
Long Beach, CA	5,756	567	52	48	17	43	382	26,353
Los Angeles, CA	5,105	516	47	43	16	40	348	23,970
San Diego, CA	5,172	456	42	38	14	35	307	21,178
San Francisco, CA	2,241	214	19	18	7	16	144	9,935
Total Passenger	127,251	19,165	1,819	1,668	578	1,470	14,184	893,157
Total Passenger (short tons)		***21,126***	***2,005***	***1,838***	***638***	***1,620***	***15,635***	***984,538***

Table 3-28 Refrigerated Cargo Ship Deep Sea Port Emissions in 2002

Port Name	Installed Power (MW)	Metric Tonnes						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Honolulu, HI	6	3	0	0	0	0	2	113
Port Angeles, WA	3	1	0	0	0	0	1	57
Seattle, WA	55	30	2	2	1	2	17	1,203
Anchorage, AK	140	62	5	4	2	5	36	2,256
Galveston, TX	532	87	9	8	3	6	70	3,724
Houston, TX	78	13	1	1	0	1	11	563
Corpus Christi, TX	97	21	2	2	1	3	13	897
Mobile, AL	22	5	0	0	0	1	3	209
Gulfport, MS	374	56	5	4	2	4	37	2,320
Manatee, FL	1,277	453	37	33	14	36	307	19,845
Pascagoula, MS	232	54	5	4	2	4	38	2,387
Pensacola, FL	2	0	0	0	0	0	0	13
Tampa, FL	245	38	3	3	1	3	25	1,599
Everglades, FL	116	71	6	5	2	5	47	3,223
New Orleans, LA	163	109	9	8	3	9	72	4,907
New York/New Jersey	1,575	195	16	15	7	16	123	8,151
Morehead City, NC	6	1	0	0	0	0	1	56
Paulsboro, NJ	4	1	0	0	0	0	1	53
Brunswick, GA	158	32	3	2	1	2	20	1,373
Canaveral, FL	525	96	8	7	3	7	63	4,212
Charleston, SC	82	16	1	1	0	1	10	684
Bridgeport, CT	1,086	188	15	14	6	15	121	8,196
Camden, NJ	2,088	531	44	41	19	45	341	22,716
Philadelphia, PA	833	206	17	16	7	18	132	8,874
Wilmington, DE	733	171	14	13	6	14	110	7,319
Jacksonville, FL	173	34	3	3	1	3	22	1,483
Miami, FL	742	130	11	10	4	10	84	5,666
Searsport, ME	5	1	0	0	0	0	1	44
New Bedford/Fairhaven, MA	69	15	1	1	0	1	10	682
Baltimore, MD	45	58	5	4	2	4	38	2,641
Hueneme, CA	963	161	11	10	5	81	99	6,839
Long Beach, CA	662	94	6	6	3	7	56	3,884
Los Angeles, CA	587	84	6	5	2	7	51	3,494
San Diego, CA	48	9	1	1	0	1	5	378
Total Reefer	13,724	3,027	247	226	98	313	1,968	130,060
Total Reefer (short tons)		***3,337***	***273***	***249***	***108***	***345***	***2,170***	***143,367***

Table 3-29 Roll-On/Roll-Off Ship Deep Sea Port Emissions in 2002

Port Name	Installed Power (MW)	Metric Tonnes						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Barbers Point, HI	4	0	0	0	0	0	0	3
Everett, WA	27	2	0	0	0	0	1	64
Honolulu, HI	39	3	0	0	0	0	2	129
Longview, WA	5	1	0	0	0	0	1	39
Portland, OR	110	8	1	1	0	1	5	325
Seattle, WA	11	4	0	0	0	0	2	150
Tacoma, WA	148	45	4	3	2	4	25	1,654
Vancouver, WA	11	2	0	0	0	0	1	81
Anchorage, AK	5	2	0	0	0	0	1	75
Beaumont, TX	62	13	1	1	1	1	9	521
Galveston, TX	59	7	1	1	0	0	5	290
Houston, TX	810	99	10	9	3	7	75	4,089
Corpus Christi, TX	6	1	0	0	0	0	1	33
Lake Charles, LA	6	1	0	0	0	0	1	33
Mobile, AL	69	11	1	1	0	2	7	454
Gulfport, MS	1,028	299	26	23	9	23	222	13,769
Manatee, FL	3	1	0	0	0	0	1	36
Pensacola, FL	18	5	0	0	0	0	4	231
Tampa, FL	166	48	4	4	1	4	36	2,230
Everglades, FL	3,734	285	27	25	10	23	209	13,387
New Orleans, LA	783	132	11	10	5	12	81	5,237
South Louisiana, LA	4	1	0	0	0	0	1	34
Albany, NY	6	1	0	0	0	0	1	50
New York/New Jersey	3,323	290	24	22	11	25	176	11,292
Portland, ME	305	28	3	2	1	2	20	1,316
Morehead City, NC	27	2	0	0	0	0	2	104
Chester, PA	47	8	1	1	0	1	5	302
Penn Manor, PA	6	1	0	0	0	0	1	53
Brunswick, GA	219	23	2	2	1	2	14	880
Canaveral, FL	75	9	1	1	0	1	6	418
Charleston, SC	455	43	4	3	1	3	28	1,777
New Haven, CT	32	3	0	0	0	0	2	163
Palm Beach, FL	423	49	4	4	2	4	35	2,302
Bridgeport, CT	23	3	0	0	0	0	2	110
Camden, NJ	22	4	0	0	0	0	3	178
Philadelphia, PA	175	31	3	3	1	3	22	1,456
Wilmington, DE	10	1	0	0	0	0	1	48
Wilmington, NC	342	35	3	3	1	3	22	1,390
Richmond, VA	8	2	0	0	0	0	1	87
Jacksonville, FL	855	102	9	8	3	8	71	4,617
Miami, FL	3,646	380	33	30	12	30	258	16,915
Boston, MA	301	37	3	3	1	3	26	1,734
Baltimore, MD	3,284	841	65	60	28	65	495	30,930
Newport News, VA	77	12	1	1	0	1	8	532
Savannah, GA	2,578	281	22	20	9	22	169	10,774
Hueneme, CA	52	5	0	0	0	8	3	173
Long Beach, CA	483	67	5	4	2	5	39	2,617

Table 3-29 Roll-On/Roll-Off Ship Deep Sea Port Emissions in 2002 (Continued)

Port Name	Installed Power (MW)	Metric Tonnes						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Los Angeles, CA	428	61	4	4	2	5	36	2,379
Oakland, CA	901	104	8	7	3	8	59	3,935
Total RoRo	25,210	3,391	281	259	113	278	2,193	139,396
Total RoRo (short tons)		***3,738***	***310***	***286***	***125***	***306***	***2,418***	***153,658***

Table 3-30 Tanker Ship Deep Sea Port Emissions in 2002

Port Name	Installed Power (MW)	Metric Tonnes						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Anacortes, WA	455	370	29	26	13	29	207	14,211
Barbers Point, HI	387	108	9	8	4	9	62	4,432
Everett, WA	6	23	2	2	1	2	13	881
Honolulu, HI	687	221	18	16	8	18	130	9,165
Kalama, WA	67	112	9	8	4	9	66	4,579
Longview, WA	30	86	7	6	3	7	49	3,421
Port Angeles, WA	72	34	3	3	1	3	25	1,721
Portland, OR	309	222	19	17	8	18	133	9,246
Seattle, WA	74	152	12	11	5	12	87	5,952
Tacoma, WA	277	1,306	104	94	45	105	723	49,146
Vancouver, WA	133	64	5	5	2	5	37	2,600
Valdez, AK	6,632	338	36	32	11	27	296	20,581
Other Puget Sound	5,678	2,111	219	197	71	169	1,745	118,629
Anchorage, AK	78	45	4	3	2	4	25	1,608
Hilo, HI	11	2	0	0	0	0	1	99
Kahului, HI	9	2	0	0	0	0	1	77
Nawiliwili, HI	8	2	0	0	0	0	1	74
Nikishka, AK	840	189	19	18	6	15	165	10,938
Beaumont, TX	10,807	1,791	228	210	76	159	1,742	71,331
Freeport, TX	5,206	584	80	74	20	45	630	23,551
Galveston, TX	552	68	12	11	2	5	93	2,832
Houston, TX	19,096	2,334	319	294	80	178	2,494	93,908
Port Arthur, TX	1,751	230	31	28	9	19	237	9,232
Texas City, TX	6,856	905	121	111	31	69	942	36,122
Corpus Christi, TX	7,498	1,213	99	91	40	263	752	48,747
Lake Charles, LA	4,544	627	60	55	26	168	450	29,166
Mobile, AL	1,114	187	15	14	6	46	115	7,432
Brownsville, TX	320	45	4	3	1	4	28	1,859
Manatee, FL	355	51	4	4	2	4	32	2,101
Matagorda Ship	1,875	268	22	20	9	22	166	10,961
Panama City, FL	38	5	0	0	0	0	3	204
Pascagoula, MS	2,275	301	26	24	10	25	205	13,293
Tampa, FL	2,282	323	27	24	11	26	202	13,293
Everglades, FL	2,036	495	41	37	15	39	320	21,592
New Orleans, LA	3,506	1,181	96	89	37	92	744	48,739
Baton Rouge, LA	2,603	1,153	93	86	36	90	711	45,874
South Louisiana, LA	5,886	2,187	177	164	68	170	1,365	88,846
Plaquemines, LA	1,322	349	28	26	11	27	221	14,598
Albany, NY	28	8	1	1	0	1	5	326
New York/New Jersey	9,361	1,885	157	144	65	156	1,202	79,931
Portland, ME	2,813	601	49	45	19	47	383	25,538
Hopewell, VA	14	4	0	0	0	0	25	153
Marcus Hook, PA	2,472	904	74	68	28	71	2,255	38,119

Table 3-30 Tanker Ship Deep Sea Port Emissions in 2002 (continued)

Port Name	Installed Power (MW)	Metric Tonnes						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Morehead City, NC	286	51	4	4	2	4	41	2,169
Paulsboro, NJ	2,952	595	48	45	20	48	2,021	23,560
Fall River, MA	13	3	0	0	0	0	5	120
New Castle, DE	524	147	12	11	5	12	357	6,177
Providence, RI	554	116	10	9	4	9	173	4,907
Brunswick, GA	21	5	0	0	0	0	13	200
Canaveral, FL	351	71	6	5	2	6	55	3,032
Charleston, SC	1,213	260	21	20	8	20	366	11,054
New Haven, CT	951	184	15	14	6	14	131	7,846
Palm Beach, FL	124	22	2	2	1	2	19	923
Bridgeport, CT	206	40	3	3	1	3	29	1,705
Camden, NJ	349	103	8	8	3	8	218	4,257
Philadelphia, PA	2,352	845	70	64	24	67	1,891	36,299
Wilmington, DE	159	38	3	3	1	3	83	1,606
Wilmington, NC	1,167	253	21	19	8	20	375	10,753
Jacksonville, FL	1,633	346	28	26	11	27	419	14,554
Miami, FL	161	33	3	3	1	3	26	1,502
Searsport, ME	498	103	9	8	3	8	114	4,482
Boston, MA	3,775	719	64	59	22	56	757	34,227
New Bedford/Fairhaven, MA	96	22	2	2	1	2	22	924
Baltimore, MD	979	424	33	31	14	33	256	15,951
Newport News, VA	118	21	2	1	1	2	13	840
Savannah, GA	2,083	395	31	29	13	31	258	16,547
Catalina, CA	9	1	0	0	0	0	0	31
Carquinez, CA	1,977	270	20	19	9	21	151	9,920
El Segundo, CA	1,685	192	14	13	6	15	108	7,095
Hueneme, CA	95	13	1	1	0	14	8	547
Long Beach, CA	3,380	419	31	28	13	33	245	16,028
Los Angeles, CA	2,998	383	28	26	12	30	223	14,610
Richmond, CA	2,871	323	24	22	10	25	181	11,904
Sacramento, CA	34	8	1	1	0	1	4	282
San Diego, CA	60	6	0	0	0	0	3	224
San Francisco, CA	1,839	184	14	13	6	14	104	6,823
Stockton, CA	370	79	6	6	3	6	44	2,903
Total Tanker	146,245	29,758	2,796	2,562	994.23952	2,695	27,802	1,259,107
Total Tanker (short tons)		***32,802***	***3,082***	***2,824***	***1,096***	***2,971***	***30,646***	***1,387,928***

Table 3-31 Ocean Going Tug Deep Sea Port Emissions in 2002

Port Name	Installed Power (MW)	Metric Tonnes						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Portland, OR	18	6	1	0	0	0	3	234
Seattle, WA	4	2	0	0	0	0	1	78
Kahului, HI	16	2	0	0	0	0	1	77
Galveston, TX	19	2	0	0	0	0	1	80
Houston, TX	16	1	0	0	0	0	1	70
Corpus Christi, TX	47	5	0	0	0	1	4	226
Lake Charles, LA	7	1	0	0	0	0	1	37
Mobile, AL	46	6	1	0	0	2	4	269
Brownsville, TX	3	0	0	0	0	0	0	16
Manatee, FL	7	1	0	0	0	0	1	49
Pascagoula, MS	7	1	0	0	0	0	1	42
Everglades, FL	28	3	0	0	0	0	2	126
New Orleans, LA	21	4	0	0	0	0	3	198
South Louisiana, LA	7	2	0	0	0	0	1	77
Plaquemines, LA	4	1	0	0	0	0	1	43
New York/New Jersey	3	0	0	0	0	0	0	18
Canaveral, FL	28	3	0	0	0	0	2	135
Palm Beach, FL	28	3	0	0	0	0	2	133
Jacksonville, FL	17	2	0	0	0	0	2	97
Miami, FL	31	3	0	0	0	0	2	152
Boston, MA	4	1	0	0	0	0	0	24
Total Ocean Going Tug	361	48	5	4	2	6	34	2,182
Total Ocean Going Tug (short tons)		***53***	***5***	***4***	***2***	***6***	***37***	***2,405***

Table 3-32 Total Emissions by Great Lake Port in 2002

Port Name	Installed Power (MW)	Metric Tonnes						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Alpena, MI	89	1.5	0.3	0.2	0.0	0.1	2.5	156
Buffalo, NY	84	2.9	0.3	0.3	0.1	0.2	2.3	150
Burns Waterway, IN	819	45.5	3.9	3.6	1.5	3.7	30.0	1,982
Calcite, MI	126	3.4	0.3	0.3	0.1	0.3	2.5	158
Cleveland, OH	560	32.6	2.8	2.5	1.0	2.6	21.8	1,448
Dolomite, MI	67	1.9	0.2	0.1	0.1	0.2	1.1	73
Erie, PA	55	2.2	0.2	0.2	0.1	0.2	1.7	112
Escanaba, MI	118	3.1	0.3	0.3	0.1	0.3	2.3	146
Fairport, OH	114	3.0	0.3	0.3	0.1	0.3	2.5	156
Gary, IN	84	3.2	0.3	0.3	0.1	0.3	2.2	141
Lorain, OH	64	1.5	0.2	0.2	0.1	0.1	1.3	84
Marblehead, OH	26	0.5	0.1	0.1	0.0	0.0	0.5	34
Milwaukee, WI	495	26.1	2.3	2.1	0.8	2.1	17.8	1,177
Muskegon, MI	37	0.9	0.1	0.1	0.0	0.1	0.7	47
Presque Isle, MI	562	16.2	1.4	1.3	0.7	1.4	10.0	637
St Clair, MI	156	4.2	0.4	0.4	0.2	0.4	3.0	193
Stoneport, MI	22	0.7	0.1	0.1	0.0	0.1	0.4	28
Two Harbors, MN	48	1.2	0.1	0.1	0.0	0.1	0.9	56
Ashtabula, OH	1,179	36.8	3.4	3.1	1.3	3.1	26.4	1,688
Chicago, IL	492	22.1	1.9	1.8	0.7	1.8	15.3	1,003
Conneaut, OH	1,863	52.6	5.0	4.7	1.9	4.4	39.5	2,501
Detroit, MI	1,359	51.4	4.7	4.4	1.7	4.2	37.5	2,432
Duluth-Superior, MN&WI	3,441	131.8	12.0	11.1	4.5	10.7	94.5	6,130
Indiana, IN	140	5.9	0.5	0.5	0.2	0.5	4.1	272
Inland Harbor, MI	56	1.5	0.1	0.1	0.1	0.1	1.1	69
Manistee, MI	164	17.8	1.5	1.4	0.5	1.4	12.2	827
Sandusky, OH	742	21.0	2.0	1.8	0.8	1.8	15.2	962
Toledo, OH	1,517	57.9	5.1	4.7	2.0	4.7	39.3	2,550
Total Emissions	14,476	549	50	46	19	45	389	25,210
Total Emissions (short tons)		***606***	***55***	***50***	***21***	***50***	***429***	***27,790***

Table 3-33 Auxiliary Engine Emissions by Great Lake Port in 2002

Port Name	Installed Power (MW)	Metric Tonnes						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Alpena, MI	20	1.2	0.1	0.1	0.0	0.1	0.8	57
Buffalo, NY	19	1.5	0.1	0.1	0.0	0.1	1.0	71
Burns Waterway, IN	181	29.6	2.5	2.2	0.8	2.2	19.7	1,366
Calcite, MI	28	1.4	0.1	0.1	0.0	0.1	0.9	63
Cleveland, OH	122	22.5	1.9	1.7	0.6	1.7	15.0	1,039
Dolomite, MI	15	0.6	0.1	0.0	0.0	0.0	0.4	30
Erie, PA	12	1.5	0.1	0.1	0.0	0.1	1.0	68
Escanaba, MI	26	1.2	0.1	0.1	0.0	0.1	0.8	56
Fairport, OH	25	1.3	0.1	0.1	0.0	0.1	0.9	60
Gary, IN	18	1.5	0.1	0.1	0.0	0.1	1.0	70
Lorain, OH	14	0.7	0.1	0.1	0.0	0.1	0.5	32
Marblehead, OH	6	0.3	0.0	0.0	0.0	0.0	0.2	12
Milwaukee, WI	109	17.5	1.4	1.3	0.5	1.3	11.7	806
Muskegon, MI	8	0.4	0.0	0.0	0.0	0.0	0.3	18
Presque Isle, MI	125	5.6	0.5	0.4	0.2	0.4	3.7	257
St Clair, MI	35	1.6	0.1	0.1	0.0	0.1	1.1	76
Stoneport, MI	5	0.2	0.0	0.0	0.0	0.0	0.2	11
Two Harbors, MN	11	0.5	0.0	0.0	0.0	0.0	0.3	21
Ashtabula, OH	262	16.3	1.3	1.2	0.4	1.2	10.9	752
Chicago, IL	108	13.7	1.1	1.0	0.4	1.0	9.1	633
Conneaut, OH	414	20.9	1.7	1.6	0.6	1.6	13.9	964
Detroit, MI	303	29.6	2.5	2.2	0.8	2.2	19.8	1,367
Duluth-Superior, MN&WI	760	74.0	6.1	5.6	2.0	5.6	49.4	3,418
Indiana, IN	31	3.7	0.3	0.3	0.1	0.3	2.5	170
Inland Harbor, MI	12	0.6	0.0	0.0	0.0	0.0	0.4	27
Manistee, MI	35	15.1	1.3	1.2	0.4	1.2	10.1	699
Sandusky, OH	165	8.1	0.7	0.6	0.2	0.6	5.4	376
Toledo, OH	336	30.9	2.6	2.3	0.9	2.3	20.6	1,426
Total Auxiliary Emissions	3,202	302	25	23	8	23	202	13,944
Total Auxiliary Emissions (short tons)		***333***	***28***	***25***	***9***	***25***	***222***	***15,370***

Table 3-34 Cruise Emissions by Great Lake Port in 2002

Port Name	Installed Power (MW)	Metric Tonnes						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Alpena, MI	89	0.3	0.1	0.1	0.0	0.0	1.2	75
Buffalo, NY	84	0.9	0.1	0.1	0.0	0.1	0.9	55
Burns Waterway, IN	819	11.7	1.0	0.9	0.4	0.9	7.5	453
Calcite, MI	126	1.4	0.1	0.1	0.0	0.1	1.1	66
Cleveland, OH	560	7.7	0.7	0.6	0.3	0.6	5.2	314
Dolomite, MI	67	0.8	0.1	0.1	0.0	0.1	0.5	30
Erie, PA	55	0.6	0.1	0.1	0.0	0.0	0.5	33
Escanaba, MI	118	1.5	0.1	0.1	0.1	0.1	1.2	71
Fairport, OH	114	1.2	0.1	0.1	0.0	0.1	1.1	66
Gary, IN	84	1.1	0.1	0.1	0.0	0.1	0.8	48
Lorain, OH	64	0.6	0.1	0.1	0.0	0.0	0.6	37
Marblehead, OH	26	0.1	0.0	0.0	0.0	0.0	0.3	16
Milwaukee, WI	495	6.4	0.6	0.5	0.2	0.5	4.5	275
Muskegon, MI	37	0.4	0.0	0.0	0.0	0.0	0.3	21
Presque Isle, MI	562	7.3	0.6	0.5	0.2	0.6	4.4	265
St Clair, MI	156	1.7	0.2	0.2	0.1	0.1	1.4	82
Stoneport, MI	22	0.3	0.0	0.0	0.0	0.0	0.2	12
Two Harbors, MN	48	0.6	0.1	0.0	0.0	0.0	0.4	26
Ashtabula, OH	1,179	15.1	1.4	1.3	0.5	1.2	11.3	684
Chicago, IL	492	6.4	0.6	0.5	0.2	0.5	4.6	281
Conneaut, OH	1,863	23.1	2.3	2.1	0.8	1.8	18.4	1,113
Detroit, MI	1,359	16.5	1.6	1.5	0.6	1.3	13.1	793
Duluth-Superior, MN&WI	3,441	43.3	4.2	3.9	1.5	3.4	33.3	2,019
Indiana, IN	140	1.7	0.2	0.2	0.1	0.1	1.3	78
Inland Harbor, MI	56	0.7	0.1	0.1	0.0	0.1	0.5	31
Manistee, MI	164	2.0	0.2	0.2	0.1	0.2	1.6	97
Sandusky, OH	742	9.4	0.9	0.8	0.3	0.7	7.1	428
Toledo, OH	1,517	20.2	1.8	1.7	0.7	1.6	14.0	846
Total Cruise Emissions	14,476	183	17	16	6	14	137	8,313
Total Cruise Emissions (short tons)		***202***	***19***	***18***	***7***	***16***	***151***	***9,164***

Table 3-35 Reduced Speed Zone Emissions by Great Lake Port in 2002

Port Name	Installed Power (MW)	Metric Tonnes						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Alpena, MI	89	0.1	0.0	0.0	0.0	0.0	0.3	19
Buffalo, NY	84	0.2	0.0	0.0	0.0	0.0	0.2	14
Burns Waterway, IN	819	2.8	0.2	0.2	0.1	0.2	1.8	112
Calcite, MI	126	0.3	0.0	0.0	0.0	0.0	0.3	16
Cleveland, OH	560	1.9	0.2	0.1	0.1	0.1	1.3	78
Dolomite, MI	67	0.2	0.0	0.0	0.0	0.0	0.1	7
Erie, PA	55	0.1	0.0	0.0	0.0	0.0	0.1	8
Escanaba, MI	118	0.4	0.0	0.0	0.0	0.0	0.3	18
Fairport, OH	114	0.3	0.0	0.0	0.0	0.0	0.3	16
Gary, IN	84	0.3	0.0	0.0	0.0	0.0	0.2	12
Lorain, OH	64	0.1	0.0	0.0	0.0	0.0	0.1	9
Marblehead, OH	26	0.0	0.0	0.0	0.0	0.0	0.1	4
Milwaukee, WI	495	1.6	0.1	0.1	0.1	0.1	1.1	67
Muskegon, MI	37	0.1	0.0	0.0	0.0	0.0	0.1	5
Presque Isle, MI	562	1.7	0.1	0.1	0.1	0.1	1.0	65
St Clair, MI	156	0.4	0.0	0.0	0.0	0.0	0.3	20
Stoneport, MI	22	0.1	0.0	0.0	0.0	0.0	0.0	3
Two Harbors, MN	48	0.1	0.0	0.0	0.0	0.0	0.1	6
Ashtabula, OH	1,179	3.7	0.3	0.3	0.1	0.3	2.8	170
Chicago, IL	492	1.5	0.1	0.1	0.1	0.1	1.1	69
Conneaut, OH	1,863	5.8	0.6	0.5	0.2	0.5	4.5	277
Detroit, MI	1,359	4.1	0.4	0.4	0.1	0.3	3.1	193
Duluth-Superior, MN&WI	3,441	10.8	1.0	0.9	0.4	0.8	8.1	502
Indiana, IN	140	0.4	0.0	0.0	0.0	0.0	0.3	19
Inland Harbor, MI	56	0.2	0.0	0.0	0.0	0.0	0.1	7
Manistee, MI	164	0.5	0.0	0.0	0.0	0.0	0.4	24
Sandusky, OH	742	2.3	0.2	0.2	0.1	0.2	1.7	106
Toledo, OH	1,517	4.9	0.4	0.4	0.2	0.4	3.4	208
Total RSZ Emissions	14,476	45	4	4	2	4	33	2,052
Total RSZ Emissions (short tons)		***50***	***5***	***4***	***2***	***4***	***37***	***2,262***

Table 3-36 Maneuvering Emissions by Great Lake Port in 2002

Port Name	Installed Power (MW)	Metric Tonnes						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Alpena, MI	89	0.2	0.0	0.0	0.0	0.0	0.3	17
Buffalo, NY	84	0.6	0.1	0.1	0.0	0.1	0.4	28
Burns Waterway, IN	819	4.4	0.4	0.4	0.3	0.5	3.0	190
Calcite, MI	126	0.9	0.1	0.1	0.1	0.1	0.6	41
Cleveland, OH	560	2.0	0.2	0.2	0.1	0.2	1.4	89
Dolomite, MI	67	0.5	0.0	0.0	0.0	0.1	0.3	19
Erie, PA	55	0.2	0.0	0.0	0.0	0.0	0.2	11
Escanaba, MI	118	0.3	0.0	0.0	0.0	0.0	0.2	15
Fairport, OH	114	0.8	0.1	0.1	0.0	0.1	0.6	38
Gary, IN	84	0.7	0.1	0.1	0.0	0.1	0.5	32
Lorain, OH	64	0.4	0.0	0.0	0.0	0.0	0.3	18
Marblehead, OH	26	0.1	0.0	0.0	0.0	0.0	0.1	6
Milwaukee, WI	495	2.3	0.2	0.2	0.1	0.3	1.6	105
Muskegon, MI	37	0.2	0.0	0.0	0.0	0.0	0.2	11
Presque Isle, MI	562	4.2	0.4	0.4	0.3	0.5	2.6	167
St Clair, MI	156	1.1	0.1	0.1	0.1	0.1	0.7	47
Stoneport, MI	22	0.2	0.0	0.0	0.0	0.0	0.1	7
Two Harbors, MN	48	0.2	0.0	0.0	0.0	0.0	0.2	10
Ashtabula, OH	1,179	6.0	0.6	0.6	0.3	0.7	4.4	277
Chicago, IL	492	2.0	0.2	0.2	0.1	0.2	1.4	87
Conneaut, OH	1,863	9.7	1.0	0.9	0.6	1.1	7.3	466
Detroit, MI	1,359	5.7	0.6	0.6	0.3	0.6	4.5	284
Duluth-Superior, MN&WI	3,441	15.2	1.6	1.5	0.9	1.7	11.3	718
Indiana, IN	140	0.5	0.1	0.0	0.0	0.1	0.4	24
Inland Harbor, MI	56	0.3	0.0	0.0	0.0	0.0	0.2	13
Manistee, MI	164	0.6	0.1	0.1	0.0	0.1	0.4	27
Sandusky, OH	742	3.8	0.4	0.4	0.2	0.4	2.7	174
Toledo, OH	1,517	6.6	0.7	0.6	0.4	0.8	4.6	291
Total Maneuver Emissions	14,476	70	7	7	4	8	50	3,213
Total Maneuver Emissions (short tons)		***77***	***8***	***7***	***5***	***9***	***56***	***3,542***

Table 3-37 Hotelling Emissions by Great Lake Port in 2002

Port Name	Installed Power (MW)	Metric Tonnes						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Alpena, MI	89	1.0	0.1	0.1	0.0	0.1	0.7	46
Buffalo, NY	84	1.2	0.1	0.1	0.0	0.1	0.8	53
Burns Waterway, IN	819	26.6	2.2	2.0	0.7	2.0	17.7	1,227
Calcite, MI	126	0.8	0.1	0.1	0.0	0.1	0.5	36
Cleveland, OH	560	20.9	1.7	1.6	0.6	1.6	14.0	967
Dolomite, MI	67	0.4	0.0	0.0	0.0	0.0	0.2	16
Erie, PA	55	1.3	0.1	0.1	0.0	0.1	0.9	60
Escanaba, MI	118	0.9	0.1	0.1	0.0	0.1	0.6	42
Fairport, OH	114	0.8	0.1	0.1	0.0	0.1	0.5	36
Gary, IN	84	1.1	0.1	0.1	0.0	0.1	0.7	49
Lorain, OH	64	0.4	0.0	0.0	0.0	0.0	0.3	20
Marblehead, OH	26	0.2	0.0	0.0	0.0	0.0	0.1	8
Milwaukee, WI	495	15.8	1.3	1.2	0.4	1.2	10.5	730
Muskegon, MI	37	0.2	0.0	0.0	0.0	0.0	0.2	11
Presque Isle, MI	562	3.0	0.3	0.2	0.1	0.2	2.0	140
St Clair, MI	156	1.0	0.1	0.1	0.0	0.1	0.6	44
Stoneport, MI	22	0.1	0.0	0.0	0.0	0.0	0.1	6
Two Harbors, MN	48	0.3	0.0	0.0	0.0	0.0	0.2	13
Ashtabula, OH	1,179	12.1	1.0	0.9	0.3	0.9	8.0	557
Chicago, IL	492	12.2	1.0	0.9	0.3	0.9	8.2	565
Conneaut, OH	1,863	14.0	1.2	1.1	0.4	1.1	9.3	645
Detroit, MI	1,359	25.1	2.1	1.9	0.7	1.9	16.8	1,162
Duluth-Superior, MN&WI	3,441	62.6	5.2	4.8	1.7	4.8	41.8	2,891
Indiana, IN	140	3.3	0.3	0.2	0.1	0.2	2.2	152
Inland Harbor, MI	56	0.4	0.0	0.0	0.0	0.0	0.3	18
Manistee, MI	164	14.7	1.2	1.1	0.4	1.1	9.8	679
Sandusky, OH	742	5.5	0.5	0.4	0.2	0.4	3.7	254
Toledo, OH	1,517	26.1	2.2	2.0	0.7	2.0	17.4	1,205
Total Hotel Emissions	14,476	252	21	19	7	19	168	11,631
Total Hotel Emissions (short tons)		***278***	***23***	***21***	***8***	***21***	***185***	***12,821***

Table 3-38 Self-Unloading Bulk Carrier Emissions by Great Lake Port in 2002

Port Name	Installed Power (MW)	Metric Tonnes						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Alpena, MI	89	1.5	0.3	0.2	0.0	0.1	2.5	156
Buffalo, NY	71	2.0	0.2	0.2	0.1	0.2	1.8	112
Burns Waterway, IN	236	7.6	0.7	0.7	0.3	0.7	5.7	362
Calcite, MI	126	3.4	0.3	0.3	0.1	0.3	2.5	158
Cleveland, OH	75	1.3	0.2	0.2	0.0	0.1	1.7	109
Dolomite, MI	67	1.9	0.2	0.1	0.1	0.2	1.1	73
Erie, PA	27	0.5	0.1	0.1	0.0	0.0	0.6	37
Escanaba, MI	118	3.1	0.3	0.3	0.1	0.3	2.3	146
Fairport, OH	114	3.0	0.3	0.3	0.1	0.3	2.5	156
Gary, IN	71	2.3	0.2	0.2	0.1	0.2	1.6	104
Lorain, OH	64	1.5	0.2	0.2	0.1	0.1	1.3	84
Marblehead, OH	26	0.5	0.1	0.1	0.0	0.0	0.5	34
Milwaukee, WI	169	4.3	0.5	0.4	0.2	0.4	3.8	238
Muskegon, MI	37	0.9	0.1	0.1	0.0	0.1	0.7	47
Presque Isle, MI	562	16.2	1.4	1.3	0.7	1.4	10.0	637
St Clair, MI	156	4.2	0.4	0.4	0.2	0.4	3.0	193
Stoneport, MI	22	0.7	0.1	0.1	0.0	0.1	0.4	28
Two Harbors, MN	48	1.2	0.1	0.1	0.0	0.1	0.9	56
Ashtabula, OH	1,047	29.2	2.8	2.6	1.1	2.5	21.6	1,363
Chicago, IL	208	5.5	0.5	0.5	0.2	0.5	4.4	282
Conneaut, OH	1,843	51.3	4.9	4.6	1.9	4.3	38.7	2,449
Detroit, MI	802	20.3	2.1	2.0	0.7	1.7	17.5	1,106
Duluth-Superior, MN&WI	2,201	61.8	6.0	5.6	2.3	5.2	47.9	3,034
Indiana, IN	52	1.3	0.1	0.1	0.0	0.1	1.1	68
Inland Harbor, MI	56	1.5	0.1	0.1	0.1	0.1	1.1	69
Manistee, MI	9	0.2	0.0	0.0	0.0	0.0	0.2	11
Sandusky, OH	735	20.6	1.9	1.8	0.8	1.7	14.8	935
Toledo, OH	987	28.1	2.5	2.3	1.0	2.4	19.3	1,226
Total SU Bulk Carrier	10,015	276	27	25	10	23	210	13,273
Total SU Bulk Carrier (short tons)		***304***	***29***	***27***	***11***	***26***	***231***	***14,631***

Table 3-39 Bulk Carrier Emissions by Great Lake Port in 2002

Port Name	Installed Power (MW)	Metric Tonnes						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Buffalo, NY	13	0.9	0.1	0.1	0.0	0.1	0.6	38
Burns Waterway, IN	562	36.8	3.0	2.8	1.1	2.9	23.5	1,567
Cleveland, OH	427	27.7	2.3	2.1	0.9	2.2	17.7	1,179
Erie, PA	17	1.1	0.1	0.1	0.0	0.1	0.7	46
Gary, IN	7	0.5	0.0	0.0	0.0	0.0	0.3	22
Milwaukee, WI	292	19.9	1.6	1.5	0.6	1.6	12.7	852
Ashtabula, OH	126	7.4	0.6	0.6	0.2	0.6	4.7	313
Chicago, IL	219	12.8	1.1	1.0	0.4	1.0	8.3	550
Conneaut, OH	20	1.2	0.1	0.1	0.0	0.1	0.8	52
Detroit, MI	458	27.2	2.2	2.1	0.9	2.2	17.3	1,149
Duluth-Superior, MN&WI	1,032	61.1	5.2	4.7	1.9	4.8	40.5	2,692
Indiana, IN	88	4.6	0.4	0.4	0.1	0.4	3.1	203
Sandusky, OH	7	0.4	0.0	0.0	0.0	0.0	0.4	27
Toledo, OH	421	25.1	2.1	2.0	0.8	2.0	16.8	1,116
Total Bulk Carrier	3,689	227	19	17	7	18	147	9,807
Total Bulk Carrier (short tons)		***250***	***21***	***19***	***8***	***20***	***162***	***10,811***

Table 3-40 General Cargo Ship Emissions by Great Lake Port in 2002

Port Name	Installed Power (MW)	Metric Tonnes						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Burns Waterway, IN	21	1.2	0.1	0.1	0.0	0.1	0.8	53
Cleveland, OH	58	3.5	0.3	0.3	0.1	0.3	2.4	160
Erie, PA	11	0.6	0.1	0.1	0.0	0.0	0.4	29
Milwaukee, WI	34	1.9	0.2	0.2	0.1	0.2	1.3	87
Ashtabula, OH	6	0.2	0.0	0.0	0.0	0.0	0.2	12
Chicago, IL	44	1.9	0.2	0.2	0.1	0.2	1.3	84
Detroit, MI	44	2.0	0.2	0.2	0.1	0.2	1.3	88
Duluth-Superior, MN&WI	167	6.7	0.6	0.5	0.2	0.5	4.7	305
Toledo, OH	77	3.5	0.3	0.3	0.1	0.3	2.3	152
Total General Cargo	462	22	2	2	1	2	15	969
Total General Cargo (short tons)		***24***	***2***	***2***	***1***	***2***	***16***	***1,068***

Table 3-41 Tanker Ship Emissions by Great Lake Port in 2002

Port Name	Installed Power (MW)	Metric Tonnes						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Chicago, IL	15	1.8	0.1	0.1	0.1	0.1	1.2	80
Detroit, MI	6	0.7	0.1	0.1	0.0	0.1	0.4	30
Duluth-Superior, MN&WI	12	1.4	0.1	0.1	0.0	0.1	0.9	63
Manistee, MI	155	17.6	1.5	1.4	0.5	1.4	12.1	816
Toledo, OH	5	0.5	0.0	0.0	0.0	0.0	0.3	24
Total Tanker	193	22	2	2	1	2	15	1,012
Total Tanker (short tons)		***24***	***2***	***2***	***1***	***2***	***16***	***1,116***

Table 3-42 Integrated Tug-Barge Emissions by Great Lake Port in 2002

Port Name	Installed Power (MW)	Metric Tonnes						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Gary, IN	6	0.3	0.0	0.0	0.0	0.0	0.2	15
Chicago, IL	6	0.1	0.0	0.0	0.0	0.0	0.1	7
Detroit, MI	49	1.2	0.1	0.1	0.0	0.1	0.9	59
Duluth-Superior, MN&WI	29	0.7	0.1	0.1	0.0	0.1	0.6	35
Toledo, OH	27	0.7	0.1	0.1	0.0	0.1	0.5	32
Total ITB	117	3	0	0	0	0	2	149
Total ITB (short tons)		***3***	***0***	***0***	***0***	***0***	***3***	***164***

For Great Lake ports, auxiliary emissions are responsible for roughly 50% of the NO_X and PM emissions, primarily due to emissions during the hotelling mode. Bulk Carrier ships are responsible for the vast majority of the emissions.

3.3.2.6.3 Summary

This section provides a summary of the total port emissions for 2002. Table 3-43 and Table 3-44 provide a breakout of the total port emissions by auxiliary and propulsion engines, in units of metric tonnes and short tons, respectively. Table 3-45 and Table 3-46 provide the breakout by mode of operation, while Table 3-47 and Table 3-48 provide a summary of port emissions by ship type.

Auxiliary emissions at ports are responsible for 39-48% of the total inventory, depending on the pollutant. Hotelling, cruise, and RSZ modes of operation are all important contributors to emissions. Container and Tanker ships are the largest contributors to port emissions.

Table 3-43 2002 Port Emissions Summary by Engine and Port Type (metric tonnes)

Engine Type	Port Type	Metric Tonnes						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Propulsion	Deep Sea	64,288	5,478	5,034	2,532	6,329	52,676	2,360,435
	Great Lakes	248	25	23	11	22	187	11,267
	Total	64,536	5,503	5,057	2,543	6,351	52,863	2,371,702
Auxiliary	Deep Sea	57,317	5,052	4,597	1,615	4,306	41,232	2,635,436
	Great Lakes	302	25	23	8	23	202	13,944
	Total	57,619	5,077	4,620	1,624	4,328	41,433	2,649,380
All	Deep Sea	121,606	10,530	9,631	4,148	10,635	93,908	4,995,871
	Great Lakes	549	50	46	19	45	389	25,210
	Grand Total	122,155	10,580	9,677	4,167	10,680	94,297	5,021,082

Table 3-44 2002 Port Emissions Summary by Engine and Port Type (short tons)

Engine Type	Port Type	Short Tons						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Propulsion	Deep Sea	70,866	6,039	5,549	2,792	6,977	58,065	2,601,934
	Great Lakes	273	27	25	12	24	207	12,419
	Total	71,139	6,066	5,575	2,803	7,001	58,272	2,614,353
Auxiliary	Deep Sea	63,181	5,569	5,067	1,781	4,746	45,450	2,905,071
	Great Lakes	333	28	25	9	25	222	15,370
	Total	63,514	5,597	5,092	1,790	4,771	45,672	2,920,442
All	Deep Sea	134,047	11,608	10,616	4,572	11,723	103,515	5,507,005
	Great Lakes	606	55	50	21	50	429	27,790
	Grand Total	134,653	11,662	10,667	4,593	11,772	103,944	5,534,795

Table 3-45 2002 Port Emissions Summary by Mode and Port Type (metric tonnes)

Mode	Port Type	Metric Tonnes						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Cruise	Deep Sea	34,193	2,826	2,623	1,141	2,651	21,186	1,314,146
	Great Lakes	183	17	16	6	14	137	8,313
	Total	34,376	2,843	2,639	1,148	2,665	21,323	1,322,459
RSZ	Deep Sea	34,427	2,887	2,657	1,280	3,804	35,148	1,318,897
	Great Lakes	45	4	4	2	4	33	2,052
	Total	34,472	2,891	2,661	1,281	3,808	35,181	1,320,950
Maneuvering	Deep Sea	7,383	758	625	440	724	4,356	266,262
	Great Lakes	70	7	7	4	8	50	3,213
	Total	7,452	765	632	444	732	4,406	269,476
Hotelling	Deep Sea	45,603	4,060	3,726	1,287	3,456	33,218	2,096,566
	Great Lakes	252	21	19	7	19	168	11,631
	Total	45,855	4,081	3,745	1,294	3,475	33,386	2,108,197
All	Deep Sea	121,606	10,530	9,631	4,148	10,635	93,908	4,995,871
	Great Lakes	549	50	46	19	45	389	25,210
	Grand Total	122,155	10,580	9,677	4,167	10,680	94,297	5,021,082

Table 3-46 2002 Port Emissions Summary by Mode and Port Type (short tons)

Mode	Port Type	Short Tons						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Cruise	Deep Sea	37,691	3,115	2,891	1,258	2,922	23,353	1,448,598
	Great Lakes	202	19	18	7	16	151	9,164
	Total	37,893	3,134	2,909	1,265	2,938	23,504	1,457,762
RSZ	Deep Sea	37,949	3,182	2,929	1,410	4,193	38,744	1,453,835
	Great Lakes	50	5	4	2	4	37	2,262
	Total	37,999	3,187	2,934	1,412	4,197	38,781	1,456,098
Maneuvering	Deep Sea	8,138	835	689	485	799	4,802	293,504
	Great Lakes	77	8	7	5	9	56	3,542
	Total	8,215	843	696	490	807	4,857	297,046
Hotelling	Deep Sea	50,268	4,475	4,107	1,419	3,809	36,617	2,311,068
	Great Lakes	278	23	21	8	21	185	12,821
	Total	50,546	4,498	4,128	1,426	3,830	36,802	2,323,889
All	Deep Sea	134,047	11,608	10,616	4,572	11,723	103,515	5,507,005
	Great Lakes	606	55	50	21	50	429	27,790
	Grand Total	134,653	11,662	10,667	4,593	11,772	103,944	5,534,795

Table 3-47 2002 Port Emissions Summary by Ship Type and Port Type (metric tonnes)

Ship Type	Port Type	Metric Tonnes						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Auto Carrier	Deep Sea	5,125	421	384	185	577	3,676	198,637
	Great Lakes	0	0	0	0	0	0	0
	Total	5,125	421	384	185	577	3,676	198,637
Barge Carrier	Deep Sea	148	13	12	5	12	141	6,364
	Great Lakes	0	0	0	0	0	0	0
	Total	148	13	12	5	12	141	6,364
Self-Unloading Bulk Carrier	Deep Sea	0	0	0	0	0	0	0
	Great Lakes	276	27	25	10	23	210	13,273
	Total	276	27	25	10	23	210	13,273
Other Bulk Carrier	Deep Sea	19,373	1,570	1,431	633	1,732	14,945	767,825
	Great Lakes	227	19	17	7	18	147	9,807
	Total	19,600	1,589	1,448	640	1,750	15,092	777,632
Container	Deep Sea	33,990	2,733	2,494	1,282	2,833	22,628	1,288,596
	Great Lakes	0	0	0	0	0	0	0
	Total	33,990	2,733	2,494	1,282	2,833	22,628	1,288,596
General Cargo	Deep Sea	7,402	630	576	251	684	6,208	302,338
	Great Lakes	22	2	2	1	2	15	969
	Total	7,424	631	578	252	686	6,223	303,307
Miscellaneous	Deep Sea	179	16	15	6	35	128	8,209
	Great Lakes	0	0	0	0	0	0	0
	Total	179	16	15	6	35	128	8,209
Passenger	Deep Sea	19,165	1,819	1,668	578	1,470	14,184	893,157
	Great Lakes	0	0	0	0	0	0	0
	Total	19,165	1,819	1,668	578	1,470	14,184	893,157
Refrigerated Cargo	Deep Sea	3,027	247	226	98	313	1,968	130,060
	Great Lakes	0	0	0	0	0	0	0
	Total	3,027	247	226	98	313	1,968	130,060
Roll-On/Roll-Off	Deep Sea	3,391	281	259	113	278	2,193	139,396
	Great Lakes	0	0	0	0	0	0	0
	Total	3,391	281	259	113	278	2,193	139,396
Tanker	Deep Sea	29,758	2,796	2,562	994	2,695	27,802	1,259,107
	Great Lakes	22	2	2	1	2	15	1,012
	Total	29,780	2,798	2,564	995	2,697	27,817	1,260,119
Ocean Going Tug	Deep Sea	48	5	4	2	6	34	2,182
	Great Lakes	0	0	0	0	0	0	0
	Total	48	5	4	2	6	34	2,182
Integrated Tug-Barge	Deep Sea	0	0	0	0	0	0	0
	Great Lakes	3	0	0	0	0	2	149
	Total	3	0	0	0	0	2	149
All	Deep Sea	121,606	10,530	9,631	4,148	10,635	93,908	4,995,871
	Great Lakes	549	50	46	19	45	389	25,210
	Grand Total	122,155	10,580	9,677	4,167	10,680	94,297	5,021,082

Table 3-48 2002 Port Emissions Summary by Ship Type and Port Type (short tons)

Ship Type	Port Type	Short Tons						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Auto Carrier	Deep Sea	5,649	464	424	204	636	4,052	218,960
	Great Lakes	0	0	0	0	0	0	0
	Total	5,649	464	424	204	636	4,052	218,960
Barge Carrier	Deep Sea	163	14	13	6	14	156	7,015
	Great Lakes	0	0	0	0	0	0	0
	Total	163	14	13	6	14	156	7,015
Self-Unloading Bulk Carrier	Deep Sea	0	0	0	0	0	0	0
	Great Lakes	304	29	27	11	26	231	14,631
	Total	304	29	27	11	26	231	14,631
Other Bulk Carrier	Deep Sea	21,355	1,731	1,577	697	1,909	16,474	846,382
	Great Lakes	250	21	19	8	20	162	10,811
	Total	21,605	1,752	1,597	705	1,929	16,636	857,193
Container	Deep Sea	37,468	3,012	2,749	1,413	3,123	24,944	1,420,434
	Great Lakes	0	0	0	0	0	0	0
	Total	37,468	3,012	2,749	1,413	3,123	24,944	1,420,434
General Cargo	Deep Sea	8,159	694	635	277	754	6,843	333,270
	Great Lakes	24	2	2	1	2	16	1,068
	Total	8,183	696	637	278	756	6,860	334,338
Miscellaneous	Deep Sea	197	18	17	7	39	141	9,049
	Great Lakes	0	0	0	0	0	0	0
	Total	197	18	17	7	39	141	9,049
Passenger	Deep Sea	21,126	2,005	1,838	638	1,620	15,635	984,538
	Great Lakes	0	0	0	0	0	0	0
	Total	21,126	2,005	1,838	638	1,620	15,635	984,538
Refrigerated Cargo	Deep Sea	3,337	273	249	108	345	2,170	143,367
	Great Lakes	0	0	0	0	0	0	0
	Total	3,337	273	249	108	345	2,170	143,367
Roll-On/Roll-Off	Deep Sea	3,738	310	286	125	306	2,418	153,658
	Great Lakes	0	0	0	0	0	0	0
	Total	3,738	310	286	125	306	2,418	153,658
Tanker	Deep Sea	32,802	3,082	2,824	1,096	2,971	30,646	1,387,928
	Great Lakes	24	2	2	1	2	16	1,116
	Total	32,826	3,084	2,826	1,097	2,973	30,663	1,389,044
Ocean Going Tug	Deep Sea	53	5	4	2	6	37	2,405
	Great Lakes	0	0	0	0	0	0	0
	Total	53	5	4	2	6	37	2,405
Integrated Tug-Barge	Deep Sea	0	0	0	0	0	0	0
	Great Lakes	3	0	0	0	0	3	164
	Total	3	0	0	0	0	3	164
All	Deep Sea	134,047	11,608	10,616	4,572	11,723	103,515	5,507,005
	Great Lakes	606	55	50	21	50	429	27,790
	Grand Total	134,653	11,662	10,667	4,593	11,772	103,944	5,534,795

3.3.3 Interport Emissions

This section presents our nationwide analysis of the methodology and inputs used to estimate interport emissions from main propulsion and auxiliary engines used by Category 3 ocean-going vessels for the 2002 calendar year. The modeling domain for vessels operating in the ocean extends from the U.S. coastline to a 200 nautical mile boundary. For ships operating in the Great Lakes, it extends out to the international boundary with Canada. The emission results are divided into nine geographic regions of the U.S. (including Alaska and Hawaii), and then totaled to provide a national inventory.

The interport emissions described in this section represent total interport emissions prior to any adjustments made to incorporate near-port inventories. The approach used to replace the near-port portion of the interport emissions is provided in Section 3.3.3.3. The final adjusted interport emissions are provided in Section 3.3.4.

3.3.3.1 Methodology

The interport emissions were estimated using the Waterway Network Ship Traffic, Energy, and Environmental Model (STEEM).[3,4] STEEM was developed by the University of Delaware as a comprehensive approach to quantify and geographically represent interport ship traffic, emissions, and energy consumption from large vessels calling on U.S. ports or transiting the U.S. coastline to other destinations, and shipping activity in Canada and Mexico. The model estimates emissions from main propulsion and auxiliary marine engines used on Category 3 vessels that engage in foreign commerce using historical North American shipping activity, ship attributes (i.e., characteristics), and activity-based emission factor information. These inputs are assembled using a geographic information system (GIS) platform that also contains an empirically derived network of shipping lanes. It includes the emissions for all ship operational modes from cruise in unconstrained shipping lanes to maneuvering in a port. The model, however, excludes hotelling operations while the vessel is docked or anchored, and very low speed maneuvering close to a dock. For that reason, STEEM is referred to as an “interport” model, to easily distinguish it from the near ports analysis.

STEEM uses advanced ArcGIS tools and develops emission inventories in the following way.[39] The model begins by building a spatially-defined waterway network based on empirical shipping location information from two global ship reporting databases. The first is the International Comprehensive Ocean-Atmosphere Data Set (ICOADS), which contains reports on marine surface and atmospheric conditions from the Voluntary Observing Ships (VOS) fleet. There are approximately 4,000 vessels worldwide in the VOS system. The ICOADS project is sponsored by the National Oceanic and Atmospheric Administration and National Science Foundation's National Center for Atmospheric Research (NCAR). The second database is the Automated Mutual-Assistance Vessel Rescue (AMVER) system. The AMVER data set is based on a ship search and rescue reporting network sponsored by the U.S. Coast Guard. The AMVER system is also voluntary, but is generally limited to ships over 1,000 gross tons on voyages of 24 hours or longer. About 8,600 vessels reported to AMVER in 2004.

The latitude and longitude coordinates for the ship reports in the above databases are used to statistically create and spatially define the direction and width of each shipping lane in the waterway network. Each statistical lane (route and segment) is given a unique identification number for computational purposes. For the current analysis, STEEM used 20 years of ICOADS data (1983-2002) and about one year of AMVER data (part of 2004 and part of 2005) (Figure 3-2).

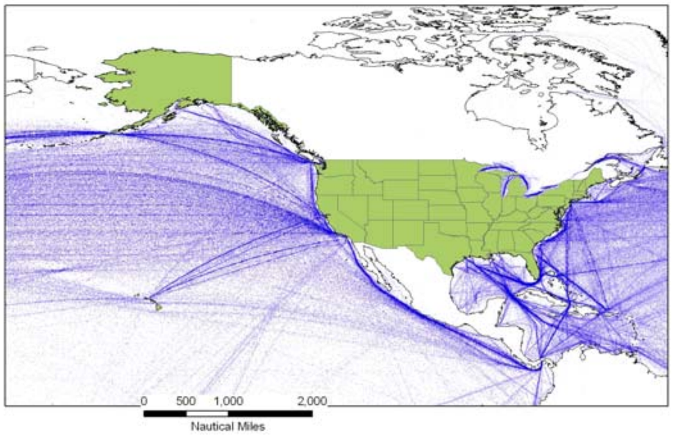

Figure 3-2 AMVER and ICOADS data

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Every major ocean and Great Lake port is also spatially located in the waterway network using ArcGIS software. For the U.S., the latitude and longitude for each port is taken from the USACE report on vessel entrances and clearances.[13] There are 251 U.S. ports in the USACE entrances and clearances report. Each port also has a unique identification number for computational purposes.

As illustrated in Figure 3-3, the waterway network represented by STEEM resembles a highway network on land. It is composed of ports, which are origins and destinations of shipping routes: junctions where shipping routes intersect, and segments that are shipping lanes between two connected junctions. Each segment can have only two junctions or ports, and ship traffic flow can enter and leave a segment only through a junction or at a port. The figure represents only a sample of the many routes contained in the model.

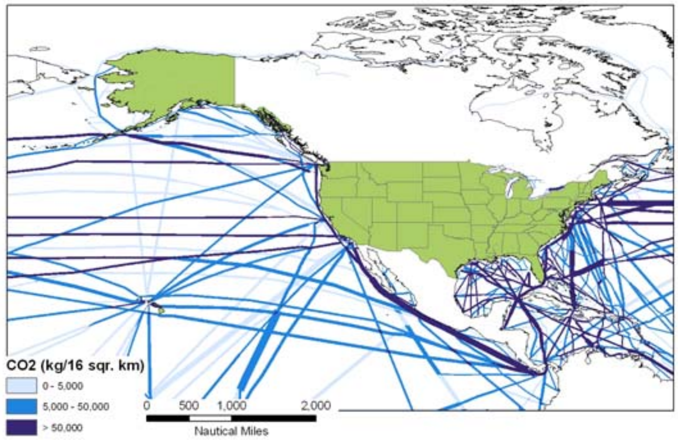

Figure 3-3 Illustration of STEEM Modeling Domain and Spatial Distribution of Shipping Lanes

Every major ocean and Great Lake port is also spatially located in the waterway network using ArcGIS software. For the U.S., the latitude and longitude for each port is taken from the U.S. Army Corps of Engineers report on vessel entrances and clearances (subsequently referred to as USACE).[13] There are 251 U.S. ports in the entrances and clearances report. Each port also has a unique identification number for computational purposes.

The STEEM interport model also employs a number of databases to identify the movements for each vessel (e.g., trips), individual ship attributes (e.g., vessel size and horsepower), and related emission factor information (e.g., emission rates) that are subsequently used in the inventory calculations.

Once the waterway network and various databases are constructed, STEEM uses ArcGIS Network Analyst tools along with specific information on each individual ship movement to solve the most probable path on the network between each pair of ports (i.e., a trip) for a certain ship size. This is assumed to represent the least-energy path, which in most cases is the shortest distance unless prevented by weather or sea conditions, water depth, channel width, navigational regulations, or other constraints that are beyond the model's capability to forecast.

After identifying the shipping route and resulting distance associated with each unique trip, the emissions are simply calculated for each operational mode using the following generalized equation along with information from the ship attributes and emission factor databases:

Emissions per trip = distance (nautical miles) / speed (nautical miles/hour) x horsepower (kW) x fractional load factor x emission factor (g/kW-hour)

In STEEM, emissions are calculated separately for distances representing cruise and maneuvering operational modes. Maneuvering occurs at slower speeds and load factors than during cruise conditions. In STEEM, maneuvering is assumed to occur for the first and last 20 kilometers of each trip when a ship is entering or leaving a port. A ship is assumed to move at maneuvering speed for an entire trip if the distance is less than 20 kilometers.

Finally, the emissions along each shipping route (i.e., segment) for all trips are proportioned among the respective cells that are represented by the gridded modeling domain. For this work, emissions estimates were produced at a cell resolution of 4 kilometers by 4 kilometers, which is appropriate for most atmospheric air quality models. The results for each cell are then summed, as appropriate, to produce emission inventories for the various geographic regions of interest in this analysis.

3.3.3.1.1 Emission Inputs

The STEEM waterway network model relies on a number of inputs to identify the movements for each vessel, individual ship attributes, and related emission factor information. Each of these databases is described separately below.

3.3.3.1.1.1 Shipping Movements

The shipping activity and routes database provides information on vessel movements or trips. It is developed using port entrances and clearances information from the USACE report for the U.S. and the Lloyd's Maritime Intelligence Unit (LMIU) for Canada and Mexico.[40] These sources contain information for each vessel carrying foreign cargo at each major port or waterway that, most importantly for this analysis, includes:

- Vessel name
- Last port of call (entrance record) or next port of call (clearance record)

The database then establishes unique identification numbers for each ship, each port pair, and each resulting trip.

3.3.3.1.1.2 Ship Attributes

The ship attributes data set contains the important characteristics of each ship that are necessary for the STEEM interport model to calculate the emissions associated with each trip. The information in this data set is matched to each previously assigned ship identification number. The following information comes from the USACE entrances and clearances report for each ship identification number:

- Ship type
- Gross registered tonnage (GRT)
- Net registered tonnage (NRT)

The ship attributes data set contains the following information from Lloyd's Register-Fairplay for each ship identification number.[14]

- Main propulsion engine installed power (horsepower)
- Service speed (cruise speed)
- Ship size (length, wide, and draft)

Sometimes data was lacking from the above references for ship speed. In these instances, the missing information was developed for each of nine vessel types and the appropriate value was applied to each individual ship of that type. Specifically, the missing ship speeds for each ship category were obtained from the average speeds used in a Lloyd's Register study of the Baltic Sea and from an Entec UK Limited study for the European Commission.[41,21] The resulting vessel cruise speeds for ships with missing data are shown in Table 3-49.

Table 3-49 Average Vessel Cruise Speed by Ship Type [a]

Ship Type	Average Cruise Speed (knots)
Bulk Carrier	14.1
Container Ship	19.9
General Cargo	12.3
Passenger Ship	22.4
Refrigerated Cargo	16.4
Roll On-Roll Off	16.9
Tanker	13.2
Fishing	11.7
Miscellaneous	12.7

Note:
[a] Used only when ship specific data were missing from the commercial database references.

The average speed during maneuvering is approximately 60 percent of a ship's cruise speed based on using the propeller law described in Section 3.3.2 above and the engine load factor for maneuvering that is presented later in this section.

As with vessel cruise speed, main engine installed power was sometimes lacking in the Lloyd's Register-Fairplay data set. Here again, the missing information was developed for nine different vessel types and the appropriate value was applied to each individual ship of that type when the data were lacking. In this case, the missing main engine horsepower was estimated by regressing the relationships between GRT and NRT, and between installed power and GRT for each category. This operation is performed internally in the model and the result applied to each individual ship, as appropriate.

The ship attributes database also contains information on the installed power of engines used for auxiliary purposes. However, this information is usually lacking in the Lloyds data set, so an alternative technique was employed to estimate the required values. In short, the STEEM model uses a ratio of main engine horsepower to auxiliary engine horsepower that was determined for eight different vessel types using information primarily from ICF International.[42]

(The ICF report attributed these power values to a study for the Port of Los Angeles by Starcrest Consulting.[12]) The auxiliary engine power for each individual vessel of a given ship type is then estimated by multiplying the appropriate main power to auxiliary power ratio and the main engine horsepower rating for that individual ship. The main and auxiliary power values and the resulting auxiliary engine to main engine ratios are shown in Table 3-50.

Table 3-50 Auxiliary Engine Power Ratios

Vessel Type	Average Main Engine Power (kW)	Average Auxiliary Engine Power (kW)	Auxiliary to Main Engine Power Ratio
Bulk Carrier	7,954	1,169	0.147
Container Ship	30,885	5,746	0.186
General Cargo	9,331	1,777	0.190
Passenger Ship	39,563	39,563 [a]	1.000
Refrigerated Cargo	9,567	3,900 [b]	0.136
Roll On-Roll Off	10,696 [c]	2,156 [c]	0.202
Tanker	9,409	1,985	0.211
Miscellaneous	6,252	1,680	0.269

Notes:
[a] The ICF reference reported a value of 11,000 for auxiliary engines used on passenger vessels.[42]
[b] The STEEM used auxiliary engine power as reported in the ARB methodology document.[36]
[c] The STEEM purportedly used values for Roll On-Roll Off main and auxiliary engines that represent a trip weighted average of the Auto Carrier and Cruise Ship power values from the ICF reference.

Finally, the ship attributes database provides information on the load factors for main engines during cruise and maneuvering operation, in addition to load factors for auxiliary marine engines. Main engine load factors for cruise operation were taken from a study of international shipping for all ship types, except passenger vessels.[43] For this analysis, the STEEM model used a propulsion engine load factor for passenger ship engines at cruise speed of 55 percent of the total installed power. This is based on engine manufacturer data contained in two global shipping studies.[43,44] During maneuvering, it was assumed that all main engines, including those for passenger ships, operate at 20 percent of the installed power. This is consistent with a study done by Entec UK for the European Commission.[21] The main engine load factors at cruise speed by ship type are shown in Table 3-51.

Auxiliary engine load factors, except for passenger ships, were obtained from the ICF International study referenced above. These values are also shown in Table 3-51. For cruise mode, neither port nor interport portions of the inventory were adjusted for low load operation, as the low load adjustments are only applied to propulsion engines with load factors below 20%.

Table 3-51 Main and Auxiliary Engine Load Factors at Cruise Speed by Ship Type

Ship Type	Average Main Engine Load Factor (%)	Average Auxiliary Engine Load Factor (%)
Bulk Carrier	75	17
Container Ship	80	13
General Cargo	80	17
Passenger Ship	55	25
Refrigerated Cargo	80	20
Roll On-Roll Off	80	15
Tanker	75	13
Miscellaneous	70	17

3.3.3.1.1.3 Emission Factor Information

The emission factor data set contains emission rates for the various pollutants in terms of grams of pollutant per kilowatt-hour (g/kW-hr). The main engine emission factors are shown in Table 3-52 . The speed specific factors for NO_X, HC, and SO_2 were taken from several recent analyses of ship emissions in the U.S., Canada, and Europe. [21,36,42,43, 45] The PM factor was based on discussions with the California Air Resources Board (ARB) staff. The fuel specific CO emission factor was taken from a report by ENVIRON International.[19] The STEEM study used the composite emission factors shown in the table because the voyage data used in the model do not explicitly identify main engine speed ratings, i.e., slow or medium, or the auxiliary engine fuel type, i.e., marine distillate or residual marine. The composite factor for each pollutant is determined by weighting individual emission factors by vessel engine population data from a 2005 survey of ocean-going vessels that was performed by ARB.[20] Fuel consumption was calculated from CO_2 emissions using the same ratio (1:3.183) as used in the near-port analysis.

Table 3-52 Main Engine Emission Factors by Ship and Fuel Type

Engine Type	Main Engine Emission Factors (g/kW-hr)						
	Fuel Type	NO_X	PM_{10}	$PM_{2.5}$ [a]	HC	CO	SO_2
Slow Speed	Residual Marine	18.1	1.5	1.4	0.6	1.4	10.5
Medium Speed	Residual Marine	14	1.5	1.4	0.5	1.1	11.5
Composite EF	Residual Marine	17.9	1.5	1.4	0.6	1.4	10.6

Note:
[a] Estimated from PM_{10} using a multiplicative adjustment factor of 0.92.

The emission factors for auxiliary engines are shown in Table 3-53. The fuel specific main emission factors for NO_X and HC were taken from several recent analyses of ship emissions in the U.S., Canada, and Europe, as referenced above for the main engine load factors. The PM factor for marine distillate was taken from a report by ENVIRON International, which was also referenced above. The PM factor for residual marine was based on discussions with the California Air Resources Board (ARB) staff. The CO factors are from the Starcrest Consulting study of the Port of Los Angeles.[12] For SO_2, the fuel specific emission factors were obtained from Entec and Corbett and Koehler.[21,43]

The composite emission factors displayed in the table are discussed below.

Table 3-53 Auxiliary Engine Emission Factors by Ship and Fuel Type

Engine Type	Auxiliary Engine Emission Factors (g/kW-hr)						
	Fuel Type	NO_X	PM_{10}	$PM_{2.5}$ [a]	HC	CO	SO_2
Medium Speed	Marine Distillate	13.9	0.3	0.3	0.4	1.1	4.3
Medium Speed	Residual Marine	14.7	1.5	1.4	0.4	1.1	12.3
Composite EF	Residual Marine	14.5	1.2	1.1	0.4	1.1	**

Note:
[a] Estimated from PM_{10} using a multiplicative adjustment factor of 0.92.
[b] See Table 3-54 for composite SO_2 emission factors by vessel type.

As for main engines, the STEEM study used the composite emission factors for auxiliary engines. For all pollutants other than SO_2, underlying data used in the model do not explicitly identify auxiliary engine voyages by fuel type, i.e., marine distillate or residual marine. Again, the composite factor for those pollutants was determined by weighting individual emission factors by vessel engine population data from a 2005 survey of ocean-going vessels that was performed by ARB.[20]

For SO_2, composite emission factors for auxiliary engines were calculated for each vessel type. These composite factors were determined by taking the fuel specific emission factors from Table 3-53 and weighting them with an estimate of the amount of marine distillate and residual marine that is used by these engines. The relative amount of each fuel type consumed was taken from the 2005 ARB survey. The relative amounts of each fuel type for each vessel type and the resulting SO_2 emission factors are shown in Table 3-54.

Table 3-54 Auxiliary Engine SO_2 Composite Emission Factors by Vessel Type

Vessel Type	Residual Marine (%)	Marine Distillate (%)	Composite Emission Factor (g/kW-hr)
Bulk Carrier	71	29	9.98
Container Ship	71	29	9.98
General Cargo	71	29	9.98
Passenger Ship	92	8	11.66
Refrigerated Cargo	71	29	9.98
Roll On-Roll Off	71	29	9.98
Tanker	71	29	9.98
Miscellaneous	0	100	4.3

3.3.3.1.1.4 EPA Adjustments to STEEM PM and SO_2 Emission Inventories

The interport emission results contained in this study for PM_{10} and SO_2 were taken from the STEEM inventories and then adjusted to reflect EPA's recent review of available engine test data and fuel sulfur levels as described Section 3.3.2.3 for the near port analysis. In the near ports work, a PM emission factor of 1.4 g/kW-hr was used for most main engines, e.g., slow speed diesel and medium speed diesel engines, all of which are assumed to use residual marine. A slightly higher value was used for steam turbine and gas turbine engines, and a slightly lower value was used for most auxiliary engines. However, these engines represent only a small fraction of the total emissions inventory. As shown in Section 3.3.3.1.1.3, the STEEM study used an emission factor of 1.5 g/kW-hr for all main engines and a slightly lower value for auxiliary engines. Here again, the auxiliary engines comprise only a small fraction of the total emissions from these ships. Therefore, for simplicity, EPA adjusted the interport PM inventories by multiplying the STEEM results by the ratio of the two primary emission factors, i.e., 1.4/1.5 or 0.933, to approximate the difference in fuel effects.

The STEEM SO_2 emission inventories were similarly adjusted using SO_2 emission factors from the interport analysis (Section 3.3.3.1.1.3) and the near ports analysis (Section 3.3.2.3). This information is displayed in Table 3-55. The composite values in the table are calculated by mathematically weighting the slow speed and medium speed emission factors from each study by their individual population fraction from the 2005 ARB shipping survey, i.e., 95 percent and 5 percent, respectively.[20] Therefore, the interport SO_2 inventories that appear in this report are the result of multiplying the STEEM inventories by the ratio of the two composite g/kW-hr emission factors shown in table, i.e., 10.33 /10.6 or 0.975.

Table 3-55 SO_2 Emission Factors Used to Adjust STEEM Emission Inventories

Engine Type	Fuel Type	STEEM (g/ kW -hr)	Near Ports (g/ kW -hr)	Composite (g/ kW -hr)
Slow Speed	Residual Marine	10.50	10.29	n/a
Medium Speed	Residual Marine	11.50	11.09	n/a
Composite	Residual Marine	10.6 [a]	10.33 [a]	0.975

Note:
[a] Weighted by ship populations from 2005 ARB survey: 95 percent slow speed and 5 percent medium speed.

3.3.3.2 Interport Domestic Traffic

As previously noted, STEEM includes the emissions associated with ships that are engaged in foreign commerce. As a result, U.S-flagged vessels carrying domestic cargo (Jones Act ships) are not included. The STEEM interport analysis also roughly estimated the emissions associated with these ships that are engaged solely in domestic commerce.[1,4] Specifically, the interport analysis estimated that the large ocean-going vessels carrying only domestic cargo excluded from STEEM represent approximately 2-3 percent of the total U.S. emissions.

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In Section 3.3.2.5, in the estimation of port inventories, the estimate of excluded installed power was roughly 6.5 percent. It is not inconsistent that the STEEM estimate of excluded emissions is lower than the excluded power estimated from calls to U.S. ports, since the STEEM model includes ships that are transiting without stopping at U.S. ports. Since most of the Jones Act ships tend to travel closer along the coast line, most of the Jones Act ship traffic is expected to fall within the proposed ECA. Therefore, the results presented in this chapter are expected to underpredict the benefits of the proposed ECA.

3.3.3.3 Combining the Near Port and Interport Inventories

The national and regional inventories in this study are a combination of the results from the near ports analysis described in Section 3.3.2 and the STEEM interport modeling described in this section. The two inventories are quite different in form. As previously presented in Figure 3-1, the STEEM modeling domain spans the Atlantic and Pacific Oceans in the northern hemisphere. The model characterizes emissions from vessels while traveling between ports. That includes when a vessel is maneuvering a distance of 20 kilometers to enter or exist a port, cruising near a port as it traverses the area, or moving in a shipping lane across the open sea. For the U.S., STEEM includes the emissions associated with 251 ports. The results are spatially reported in a gridded format that is resolved to a cell dimension of 4 kilometers by 4 kilometers.

The near port results, however, are much more geographically limited and are not reported in a gridded format. The analysis includes the emissions associated with ship movements when entering or exiting each of 117 major U.S. ports. For deep sea ports that includes when a vessel is hotelling and maneuvering in the port, operating in the RSZ that varies in length for each port, and cruising 25 nautical miles between the end of the RSZ and an unconstrained shipping lane. For Great Lakes ports that includes hotelling and maneuvering, three nautical miles of RSZ operation, and cruising 7 nautical miles between the end of the RSZ and open water. The results are reported for each port and mode of operation.

To precisely replace only the portion of the STEEM interport inventory that is represented in the near port inventory results, it is necessary to spatially allocate the emissions in a format that is compatible with the STEEM 4 kilometers by 4 kilometers gridded output. Once that has been accomplished, the two inventories can be blended together. Both of these processes are described below. This work was conducted by ENVIRON International as a subcontractor under the EPA contract with ICF.[2]

3.3.3.3.1 Spatial Location of the Near Port Inventories

The hotelling, maneuvering, RSZ, and cruise emissions from the near port inventories were spatially located by their respective latitude and longitude coordinates using ArcGIS software. For this study, shapefiles were created that depicted the emission locations as described above. Additional shapefiles were also obtained to locate other geographic features such as the coastline and rivers of the U.S. These shapefiles and the STEEM output can be layered upon each other, viewed in ArcMap, and analyzed together. The following sections provide a more detailed description of how the shapefiles representing the ports, RSZ lanes, and cruise lanes were developed.

3.3.3.3.1.1 Ports

Each port, and thus the designated location for hotelling and maneuvering emissions, is modeled as a single latitude/longitude coordinate point using the port center as defined by the Army Corp of Engineers in the Principal Ports of the United States dataset.[11] One additional port, “Other Puget Sound,” which was specially created in the near ports analysis, was added to the list of ports. Some port locations were inspected by consulting Google Earth satellite images to ensure that the point that defined the port’s location was physically reasonable for the purposes of this analysis. This resulted in slightly modifying the locations of five ports: Gray’s Harbor, Washington; Freeport and Houston, Texas; Jacksonville, Florida; and Moreshead City, North Carolina. In all five cases the change was very small. The hotelling and maneuvering emissions represented by the latitude/longitude coordinate for each port were subsequently assigned to a single cell in the gridded inventory where that point was located. It should be noted that modeling a port as a point will over specify the location of the emissions associated with that port if it occupies an area greater than one grid cell, or 4 kilometers by 4 kilometers. The coordinates of all of the 117 ports used in this work are shown in the Appendix, Table 3-102.

3.3.3.3.1.2 Reduced Speed Zone Operation

The RSZ routes associated with each of the 117 ports were modeled as lines. Line shapefiles were constructed using the RSZ distance information described in Section 3.3.2 and the Army Corp of Engineers National Waterway Network (NWN) geographic database of navigable waterways in and around the U.S.[16] The coordinates of RSZ endpoints for all of the 117 ports used in this work are shown in the Appendix, Table 3-103.

The RSZ emissions were distributed evenly along the length of the line. The latitude/longitude coordinates for each point along the line were subsequently used to assign the emissions to a grid cell based on the proportion of the line segment that occurred in the respective cell. Figure 3-4 illustrates how the length of the RSZ line can vary in any grid cell.

In several instances the NWN links and STEEM data indicated there were two RSZs. These ports are: Honolulu, Hawaii; Los Angeles, Long Beach and El Segundo, California; Brunswick, Georgia; and Baton Rouge, New Orleans, Port of South Louisiana, and Plaquemines, Louisiana. The lengths of the two lines were similar in every case, so the RSZ emissions from the near ports analysis were divided equally between both branches. Figure 3-5 shows an example of a port with multiple RSZs.

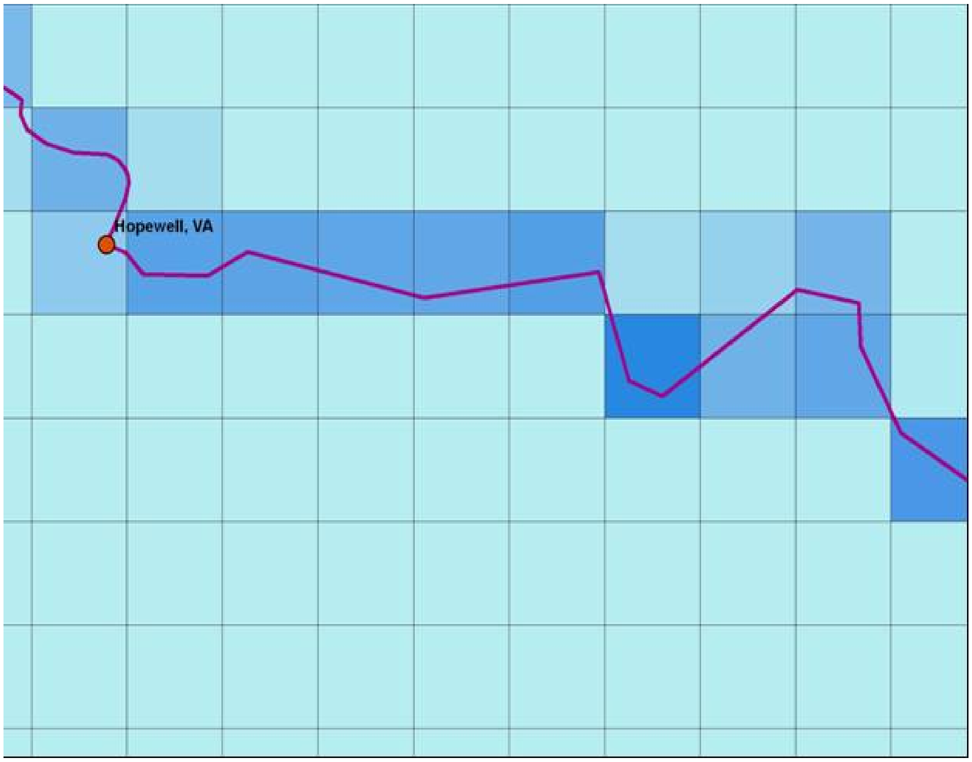


Figure 3-4 Example of Gridded RSZ Lane (Hopewell, Virginia)

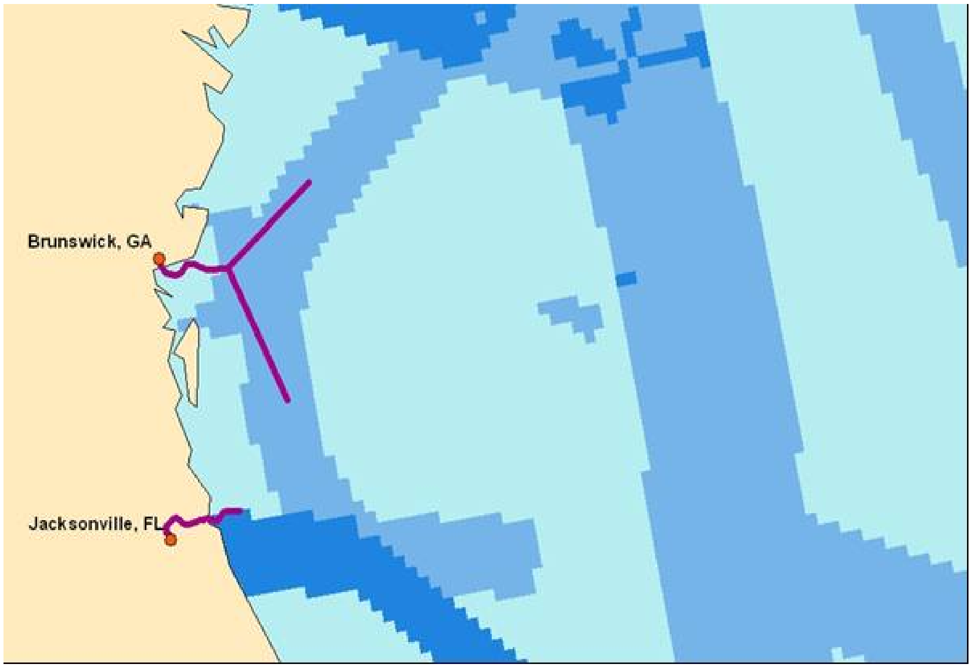


Figure 3-5 Example of Multiple RSZ Lanes (Brunswick, Georgia)

3.3.3.3.1.3 Cruise Operations

The cruise mode links that extend 25 nautical miles for deep sea ports or 7 nautical miles for Great Lake ports from the end of the RSZ end point were also modeled with line shapefiles. These links were spatially described for each port following the direction of the shipping lane evident in the STEEM data. Again, as with RSZ emissions, the latitude/longitude coordinates for each point along the line were subsequently used to assign the emissions to a grid cell based on the proportion of the line segment that occurred in the respective cell.

The STEEM data sometimes indicated there were two or three cruise mode links associated with a port. In these cases, the underlying STEEM ship movement data was evaluated to determine whether any particular route should be assigned larger emissions than the others. That information was judged to be inadequate to justify such differential treatment, so the near port cruise emissions for ports with multiple cruise lanes were assigned equally to each link. Figure 3-6 provides an example of multiple cruise lanes.

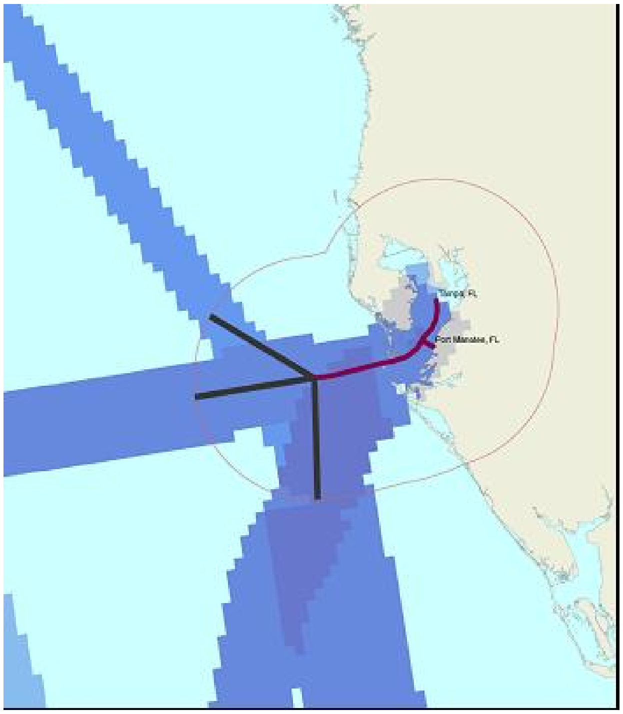


Figure 3-6 Example of Multiple Cruise Lanes (Tampa and Port Manatee, Florida)

3.3.3.3.2 Combining the Near Port and STEEM Emission Inventories

After spatially defining the geographic location of the near port emissions, but before actually inserting them into the gridded STEEM inventory, it was necessary to determine if all of the STEEM emissions within an affected cell should be replaced, or if some of the emissions should be retained. In this latter case, ships would be traversing the area near a port, but not actually entering or exiting the port.

This evaluation was performed for each port by first overlaying the RSZ and cruise shapefiles on the STEEM gridded inventory, and then using ArcGIS tools to create a series of circular buffers with a radius of 25 nautical miles around each of the points that represented an RSZ line. A single elongated buffer was then made from the intersection or outer boundaries of all the individual circular buffers. As illustrated in Figure 3-6, the resulting RSZ buffer encloses the port, RSZ links and cruise mode links. The STEEM emissions underneath the buffer were then evaluated. In cases where the STEEM data showed that ships were routed directly to an isolated port, the STEEM emissions were completely replaced by near port emissions (Figure 3-7). Conversely, when the examination revealed that the underlying STEEM emissions included some ship passages that were simply traversing near the port, the emissions associated with those vessel movements were retained, i.e., not completely replaced with the near port emission results (Figure 3-8). The methodology for determining the emissions from transient ship operation is described below.

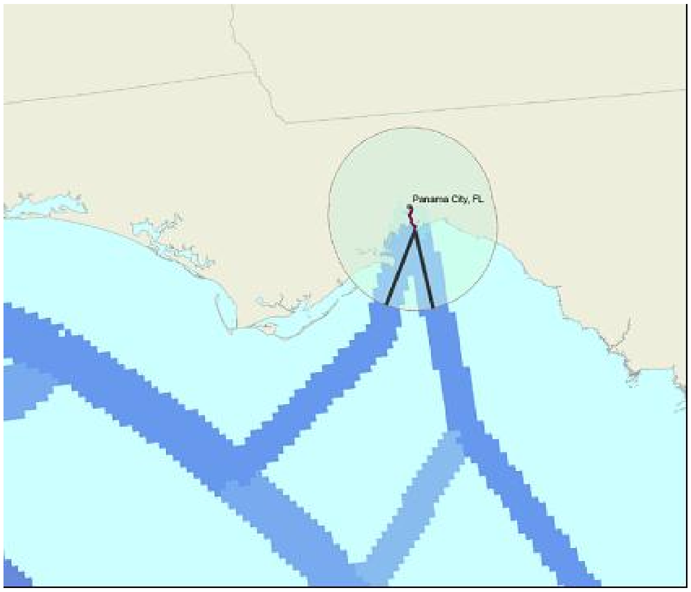


Figure 3-7 Example of Complete Replacement of STEEM Emissions (Panama City, Florida)

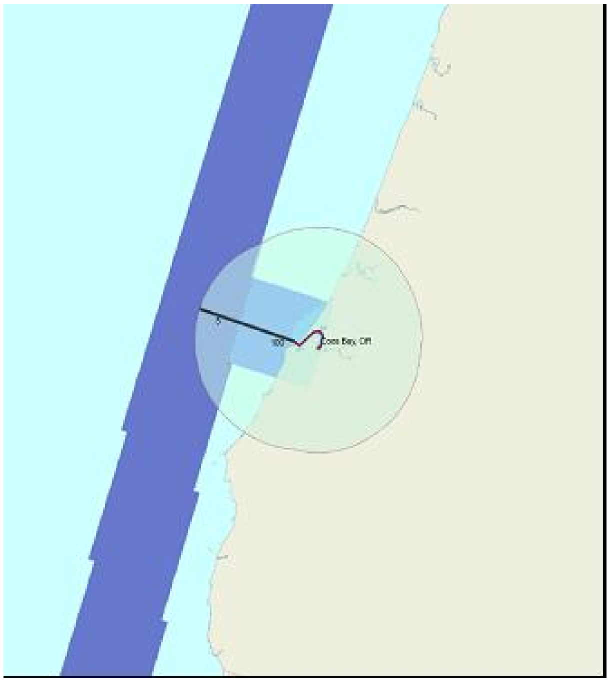


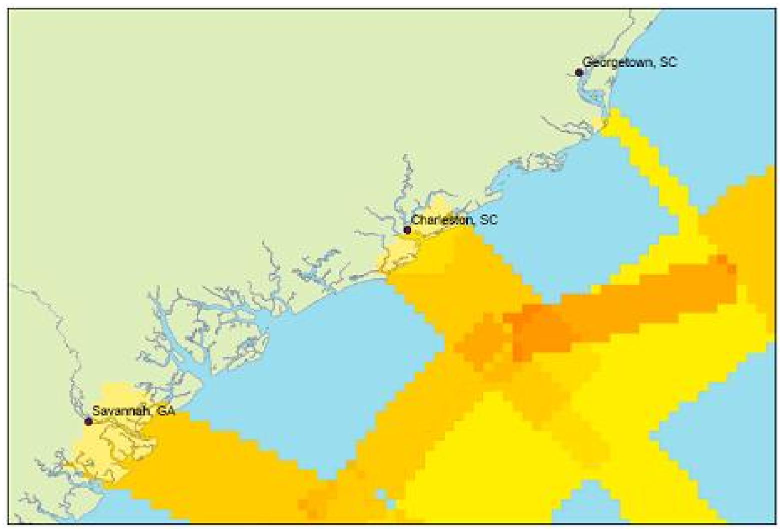
Figure 3-8 Example of Partial Replacement of STEEM Emissions (Coos Bay, Oregon)

The percentage of STEEM emissions that are attributable to a port, and should be replaced, were approximated by dividing the STEEM emissions in the isolated portion of the route that lead only to the port, with the STEEM emissions in the major shipping lane. As an example, the STEEM emissions in the portion of the buffer in Figure 3-8 that only went to the port were approximately 347 kg/cell/year. The emissions within the buffer for just the major shipping lane were 6996 kg/cell/year. Therefore, the emissions in the grid cells that comprised the portion of the buffer overlaying the major shipping lane were reduced by the fraction 347/6996, or 5 percent before the near port emissions were added to the gridded inventory.

The actual merging of the two inventories was performed by creating a number of databases that identified the fraction of the near port inventory for each pollutant species and operating mode that should be added to the grid cells for each port. A similar database was also created that identified how much of the original STEEM emissions should be reduced to account for ship movements associated directly with a port, while preserving those that represented transient vessel traffic. These databases were subsequently used to calculate the new emission results for each affected cell in the original STEEM gridded inventory, resulting in the combined inventory results for this study.

Figure 3-9 provides side-by-side comparisons of the original STEEM emissions inventory and the new merged inventory. The results indicate that the spatial allocation of the near port emissions conducted in this study provides a more precise assessment of vessel travel near a port than the STEEM methodology. As previously described, the near port ship emissions may be over specified, but this approach generally provides a more reasonable placement of emissions near the coastline than the wide shipping lanes in the STEEM model, which in some cases show shipping emissions over land.

Original



New

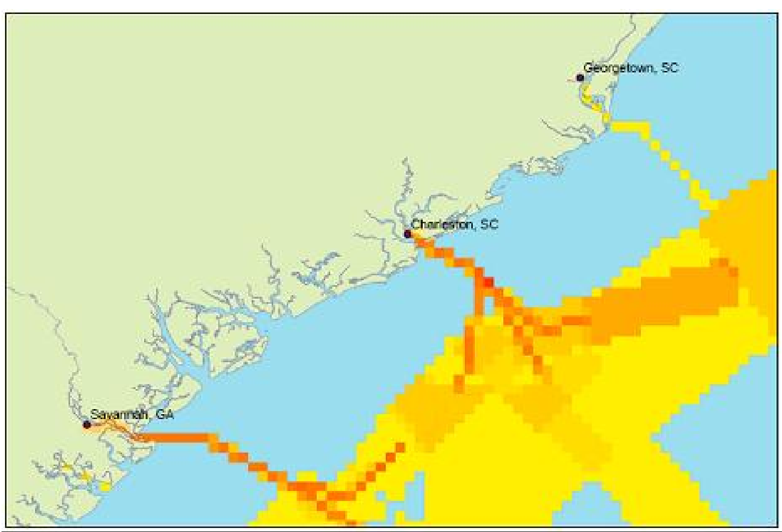


Figure 3-9 Spatial Comparison of the Original STEEM and New Combined Gridded Inventories—Southeast United States

3.3.4 2002 Baseline Emission Inventories

The modeling domain of the new combined emission inventory described above is the same as the original STEEM domain, i.e., the Atlantic and Pacific Oceans, the Gulf of Mexico, the Great Lakes, Alaska and Hawaii. Inventories for the nine geographic regions of the U.S. specified in Section 3.2 were created using ArcGIS software to intersect the regional shapefiles with the 4 kilometers by 4 kilometers gridded domain. Any grid cell split by a regional boundary was considered to be within a region if over 50 percent of its area was within the region. The emissions in each of the cells defined within a region were then summed. The final emission inventories for 2002 are shown in Table 3-56 for each of the nine geographic regions and the nation. The geographic scope of these regions was previously displayed in Figure 3-1. The fuel consumption by fuel type associated with each region is also provided in Table 3-57.

Table 3-56 2002 Regional and National Emissions from Category 3 Vessel Main and Auxiliary Engines

Region	Metric Tonnes						
	NO_X	PM_{10}	$PM_{2.5}$ [a]	HC	CO	SO_2	CO_2
Alaska East (AE)	18,051	1,425	1,311	597	1,410	10,618	657,647
Alaska West (AW)	60,019	4,689	4,313	1,989	4,685	34,786	2,143,720
East Coast (EC)	219,560	17,501	16,101	7,277	17,231	145,024	8,131,553
Gulf Coast (GC)	172,897	14,043	12,920	5,757	14,169	104,852	6,342,139
Hawaii East (HE)	22,600	1,775	1,633	749	1,765	13,182	818,571
Hawaii West (HW)	31,799	2,498	2,297	1,053	2,484	18,546	1,151,725
North Pacific (NP)	26,037	2,154	1,982	938	2,090	15,295	990,342
South Pacific (SP)	104,155	8,094	7,447	3,464	8,437	60,443	3,796,572
Great Lakes (GL)	15,019	1,179	1,085	498	1,174	8,766	541,336
Total Metric Tonnes	670,137	53,358	49,089	22,322	53,445	411,512	24,573,605
Total Short Tons [b]	738,700	58,817	54,112	24,606	58,913	453,614	27,087,763

Notes:
[a] Estimated from PM_{10} using a multiplicative adjustment factor of 0.92.
[b] Converted from metric tonnes using a multiplicative conversion factor of 1.102 short tons per metric tonne.

Table 3-57 2002 Regional and National Fuel Consumption

Region	Metric Tonnes Fuel		
	Distillate	Residual	Total
Alaska East (AE)	1,887	204,725	206,612
Alaska West (AW)	0	673,490	673,490
East Coast (EC)	91,529	2,463,153	2,554,682
Gulf Coast (GC)	63,876	1,928,628	1,992,504
Hawaii East (HE)	4,375	252,794	257,170
Hawaii West (HW)	0	361,836	361,836
North Pacific (NP)	15,905	295,230	311,135
South Pacific (SP)	35,052	1,157,714	1,192,765
Great Lakes (GL)	1,270	168,801	170,071
Total Metric Tonnes	213,894	7,506,371	7,720,265
Total Short Tons [b]	235,778	8,274,358	8,510,136

As previously noted, the inventories in the above table reflect the emissions associated with Category 3 ocean-going vessels that are engaged in foreign commerce. The STEEM interport analysis also roughly estimated the emissions associated with these ships that are engaged solely in domestic commerce.[1,4] These vessels are sometimes referred to as Jones Act ships, as explained in Section 3.3.2.5. Specifically, the interport analysis estimated that the emissions from large ocean-going vessels carrying only domestic cargo represent approximately 2-3 percent of the total values presented in Table 3-56. This is less than the 6.5 percent estimate based on calls to U.S. ports, since the interport traffic includes transiting traffic in U.S. waters.

The relative contributions of the near port and interport emission inventories to the total U.S. emissions are presented in Table 3-58 and Table 3-59. As expected, based on the geographic scope of the two types of inventories, the interport and near port inventories are about 80 percent and 20 percent of the total, respectively. The deep sea ports are about 97 to nearly 100 percent and the Great Lake ports are about 3 to almost zero percent of the total inventories, depending on the port region. This result is also expected given the small number of Great Lake ports and more limited geographic area of the modeling domain.

Table 3-58 2002 Contribution of Near Ports and Interport Emissions to the Total C3 Inventory

Region and Port Type	Metric Tonnes								
	NO_X			PM_{10}			$PM_{2.5}$ [a]		
	Total	% Region	% Type	Total	% Region	% Type	Total	% Region	% Type
Interport	549,852	82.1	100	42,945	80.5	100	39,510	80.5	100
Deep Sea	535,325	--	97.4	41,811	--	97.4	38,465	--	97.4
Great Lakes	14,528	--	2.6	1,135	--	2.6	1,044	--	2.6
Near Port	120,285	17.9	100	10,413	19.5	100	9,580	19.5	100
Deep Sea	119,793	--	99.6	10,368	--	99.6	9,539	--	99.6
Great Lakes	491	--	0.4	44	--	0.4	41	--	0.4
All Regions	670,137	100	--	53,358	100	--	49,089	100	--
Deep Sea	655,118	--	97.8	52,179	--	97.8	48,004	--	97.8
Great Lakes	15,019	--	2.2	1,179	--	2.2	1,085	--	2.2
All Region Short Tons [b]	738,700	--	--	58,817	--	--	54,112	--	--

Notes:
[a] Estimated from PM_{10} using a multiplicative adjustment factor of 0.92.
[b] Converted from metric tonnes using a multiplicative adjustment factor of 1.102 short tons per metric tonne.

Table 3-59 2002 Contribution of Near Ports and Interport Emissions to the Total C3 Inventory (Cont'd)

Region and Port Type	Metric Tonnes								
	HC			CO			SO_2		
	Total	% Region	% Type	Total	% Region	% Type	Total	% Region	% Type
Interport	18,219	81.6	100	42,912	80.3	100	318,450	77.4	*100*
Deep Sea	17,738	--	97.4	41,778	--	97.4	310,030	--	*97.4*
Great Lakes	481	--	2.6	1,134	--	2.6	8,420	--	*2.6*
Near Port	4,103	18.4	100	10,533	19.7	100	93,062	22.6	*100*
Deep Sea	4,086	--	99.6	10,493	--	99.6	92,716	--	*99.6*
Great Lakes	17	--	0.4	40	--	0.4	346	--	*0.4*
All Regions	22,322	100	--	53,445	100	--	411,512	100	--
Deep Sea	21,824	--	97.8	52,271	--	97.8	402,746	--	*97.9*
Great Lakes	498	--	2.2	1,174	--	2.2	8,766	--	*2.1*
All Region Short Tons [a]	24,606	--	--	58,913	--	--	453,614	--	--

Note:
[a] Converted from metric tonnes using a multiplicative adjustment factor of 1.102 short tons per metric tonne.

3.4 Development of 2020 and 2030 Scenarios

3.4.1 Outline of Methodology

The emissions from Category 3 ocean-going vessels (main propulsion and auxiliary engines) are projected to 2020 and 2030 by applying certain adjustment factors to the 2002 emission inventories to account for the change in ship traffic over these time periods, i.e., growth, and the effect of the current controls and the NO_X and fuel controls described in the proposed rule.

The following sections describe the derivation of the growth adjustment factors for each of the modeling regions described in Section 3.2, the emission adjustment factors, and the resulting 2020 and 2030 emission inventories.

The final section describes the baseline and control emission inventories that were developed for calendar years 2020 and 2030. The 2030 inventories were used for air quality modeling, although the 2020 control inventories reported here have been updated relative to those used for the air quality modeling. A comparison of the 2020 control case inventories reported here with those used for the air quality modeling is provided in Section 3.7.

3.4.2 Growth Factors by Geographic Region

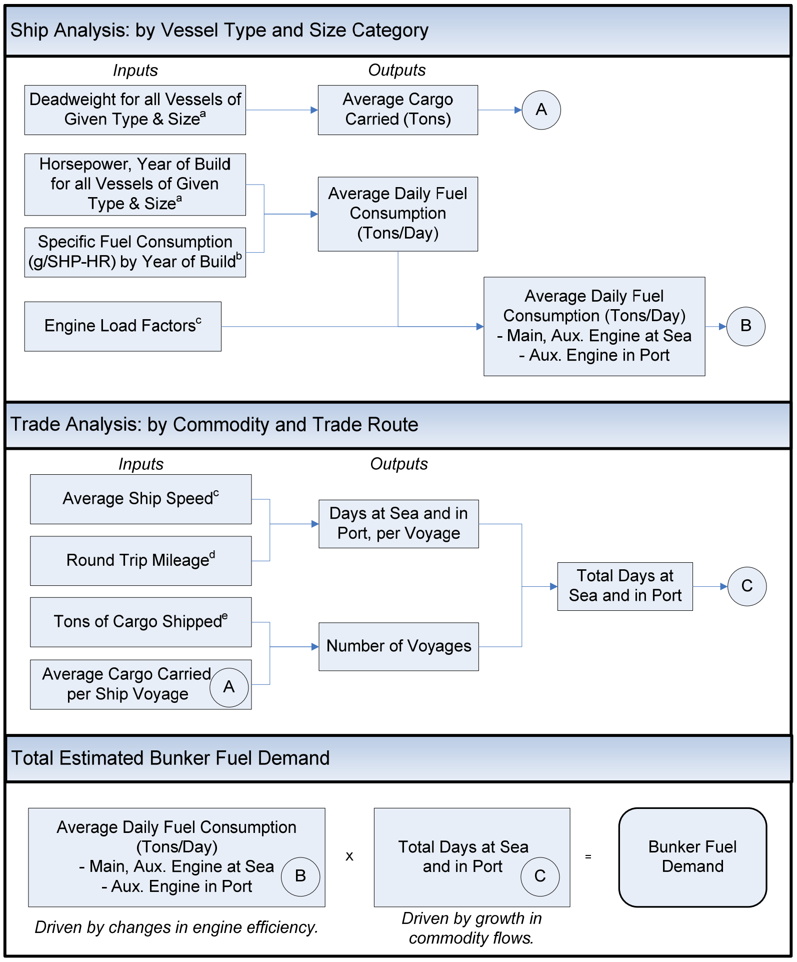
This section describes the growth factors that are used to project the emissions to 2020 and 2030 for each of the nine geographic regions evaluated in this analysis. These factors are based on the expected demand for marine bunker fuels that is associated with shipping goods, i.e., commodities, into and out of the U.S. The use of bunker fuel as a surrogate for estimating future emissions is appropriate because the quantity of fuel consumed by C3 engines is highly correlated with the amount of combustion products, i.e., pollutants, that are emitted from those vessels. The term bunker fuel in this report also includes marine distillate oil and marine gas oil that are used in some auxiliary power engines.

The remainder of this section first summarizes the development of growth rates by RTI International (RTI) for five geographic regions of the U.S., as performed under contract to EPA (Section 3.4.2.1).[5,6] This is followed by the derivation of the growth factors that are used in this study for the nine geographic regions of interest (Section 3.4.2.9).

3.4.2.1 Summary of Regional Growth Rate Development

RTI developed fuel consumption growth rates for five geographic regions of the U.S. These regions are the East Coast, Gulf Coast, North Pacific, South Pacific, and Great Lakes. The amount of bunker fuel required in any region and year is based on the demand for transporting various types of cargo by Category 3 vessels. This transportation demand is in turn driven by the demand for commodities that are produced in one location and consumed in another, as predicted by an econometric model. The flow of commodities is matched with typical vessels for trade routes (characterized according to cargo capacity, engine horsepower, age, specific fuel consumption, and engine load factors). Typical voyage parameters are then assigned to the trade routes that include average ship speed, round trip mileage, tons of cargo shipped, and days in port. Fuel consumption for each trade route and commodity type thus depends on commodity projections, ship characteristics, and voyage characteristics. Figure 3-10 from RTI illustrates the approach to developing baseline projections of marine fuel consumption.

As a means of comparison, the IMO Secretary General's Informal Cross Government/Industry Scientific Group of Experts presented a growth rate that ranged from 3.3% to 3.7%.[46] RTI's overall U.S. growth rate was projected at 3.4%, which is consistent with that range.



a – Clarksons Ship Register Database
b – Engine Manufacturers' Data, Technical Papers
c – Corbett and Wang (2005) "Emission Inventory Review: SECA Inventory Progress Discussion"
d - Combined trade routes and heavy leg analysis
e – Global Insight Inc. (GII) Trade Flow Projections

Figure 3-10 Illustration of Method for Estimating Bunker Fuel Demand

3.4.2.2 Trade Analysis

The trade flows between geographic regions of the world, as illustrated by the middle portion of Figure 3-10, were defined for the following eight general types of commodities:

- liquid bulk – crude oil
- liquid bulk – refined petroleum products
- liquid bulk – residual petroleum products

- liquid bulk – chemicals (organic and inorganic)
- liquid bulk –gas (including LNG and LPG)
- dry bulk (e.g., grain, coal, steel, ores and scrap)
- general cargo (e.g., lumber/forest products)
- containerized cargo

The analysis specifically evaluated trade flows between 21 regions of the world. Table 3-60 shows the countries associated with each region.

Table 3-60 Aggregate Regions and Associated Countries

Aggregate Regions	Base Countries / Regions
U.S. Atlantic Coast	U.S. Atlantic Coast
U.S. Great Lakes	U.S. Great Lakes
U.S. Gulf Coast	U.S. Gulf Coast
E. Canada[a]	Canada[a]
W. Canada[a]	Canada[a]
U.S. Pacific North	U.S. Pacific North
U.S. Pacific South	U.S. Pacific South
Greater Caribbean	Colombia, Mexico, Venezuela, Caribbean Basin, Central America
South America	Argentina, Brazil, Chile, Peru, Other East Coast of S. America, Other West Coast of S. America
Africa – West	Western Africa
Africa-North/East-Mediterranean	Mediterranean Northern Africa, Egypt, Israel,
Africa-East/South	Kenya, Other Eastern Africa, South Africa, Other Southern Africa
Europe-North	Austria, Belgium, Denmark, Finland, France, Germany, Ireland, Netherlands, Norway, Sweden, Switzerland, United Kingdom
Europe-South	Greece, Italy, Portugal, Spain, Turkey, Other Europe
Europe-East	Bulgaria, Czech Republic, Hungary, Poland, Romania, Slovak Republic
Caspian Region	Southeast CIS
Russia/FSU	The Baltic States, Russia Federation, Other Western CIS
Middle East Gulf	Jordan, Saudi Arabia, UAE, Other Persian Gulf
Australia/NZ	Australia, New Zealand
Japan	Japan
Pacific-High Growth	Hong Kong S.A.R., Indonesia, Malaysia, Philippines, Singapore, South Korea, Taiwan, Thailand
China	China
Rest of Asia	Viet Nam, India, Pakistan, Other Indian Subcontinent

Note:
[a] Canada is treated as a single destination in the GI model. Shares of Canadian imports from and exports to regions of the world in 2004 are used to divide Canada trade into shipments to/from Eastern Canada ports and shipments to/from Western Canada ports.[47]

The overall forecast of demand for shipping services and bunker fuel was determined for each of the areas using information on commodity flows from Global Insight's (GI) World Trade Service. Specifically, GI provided a specialized forecast that reports the flow of each commodity type for the period 1995–2024, based on a proprietary econometric model. The general structure of the GI model for calculating trade flows assumes a country's imports from another country are driven by the importing country's demand forces (given that the exporting country possesses enough supply capacity), and affected by exporting the country's export price and importing country's import cost for the commodity. The model then estimates demand forces, country-specific exporting capacities, export prices, and import costs.

The GI model included detailed annual region-to-region trade flows for eight composite commodities from 1995 to 2024, in addition to the total trade represented by the commodities. Table 3-61 illustrates the projections for 2012 and 2020, along with baseline data for 2005. In 2005, dry bulk accounted for 41 percent of the total trade volume, crude oil accounted for 28 percent, and containers accounted for 12 percent. Dry bulk and crude oil shipments are expected to grow more slowly over the forecast period than container shipments. By 2020, dry bulk represents 39 percent of the total, crude oil is 26 percent, and containers rise to 17 percent.

Table 3-61 Illustration of World Trade Estimates for Composite Commodities, 2005, 2012, and 2020

Commodity Type	Cargo (millions of tons)		
	2005	2012	2020
Dry Bulk	2,473	3,051	3,453
Crude Oil	1,703	2,011	2,243
Container	714	1,048	1,517
Refined Petroleum	416	471	510
General Cargo	281	363	452
Residual Petroleum and Other Liquids	190	213	223
Chemicals	122	175	228
Natural Gas	79	91	105
Total International Cargo Demand	5,979	7,426	8,737

3.4.2.3 Ship Analysis by Vessel Type and Size

Different types of vessels are required to transport the different commodities to the various regions of the world. As shown at the top of Figure 3-10, profiles of these ships were developed to identify the various vessel types and size categories that are assigned to transport commodities of each type along each route. These profiles include attributes such as ship size, engine horsepower, engine load factors, age, and engine fuel efficiency. This information was subsequently used to estimate average daily fuel consumption for each typical ship type and size category.

The eight GI commodity categories were mapped to the type of vessel that would be used to transport that type of cargo using information from Clarksons Shipping Database.[48] These assignments are shown in Table 3-62.

Table 3-62 Assignment of Commodities to Vessel Types

Commodity	Ship Category	Vessel Type
Liquid bulk – crude oil	Crude Oil Tankers	Tanker
Liquid bulk – refined petroleum products	Product Tankers	Product Carrier
Liquid bulk – residual petroleum products	Product Tankers	Product Carrier
Liquid bulk – chemicals (organic and inorganic)	Chemical Tankers	Chemical & Oil Carrier
Liquid bulk – natural gas (including LNG and LPG)	Gas Carriers	LNG Carrier, LPG Carrier, Chemical & LPG Carrier, Ethylene/LPG, Ethylene/LPG/Chemical, LNG/Ethylene/LPG, LNG/Regasification, LPG/Chemical, LPG/Oil, Oil & Liquid Gas Carrier
Dry bulk (e.g. grain, coal, steel, ores and scrap)	Dry Bulk Carriers	Bulk Carrier
General cargo (including neobulk, lumber/forest products)	General Cargo	General Cargo Liner, Reefer, General Cargo Tramp, Reefer Fish Carrier, Ro-Ro, Reefer/Container, Ro-Ro Freight/Passenger, Reefer/Fleet Replen., Ro-Ro/Container, Reefer/General Cargo, Ro-Ro/Lo-Lo, Reefer/Pallets Carrier, Reefer/Pass./Ro-Ro, Reefer/Ro-Ro Cargo
Containerizable cargo	Container Ships	Fully Cellular Container

Each of the vessel types were classified by their cargo carrying capacity or deadweight tons (DWT). The size categories were identified based on both industry definitions and natural size breaks within the data. Table 3-63 summarizes the size categories that were used in the analysis and provides other information on the general attributes of the vessels from Clarksons Shipping Database. The vessel size descriptions are also used to define shipping routes based on physical limitations that are represented by canals or straits through which ships can pass. Very large crude oil tankers are the largest by DWT rating, and the biggest container ships (Suezmax) are also very large.

Table 3-63 Fleet Characteristics

Ship Type	Size by DWT	Minimum Size (DWT)	Maximum Size (DWT)	Number of Ships	Total DWT (millions)	Total Horse Power (millions)
Container	Suezmax	83,000	140,000	101	9.83	8.56
	PostPanamax	56,500	83,000	465	30.96	29.30
	Panamax	42,100	56,500	375	18.04	15.04
	Intermediate	14,000	42,100	1,507	39.80	32.38
	Feeder	0	14,000	1,100	8.84	7.91
General Cargo	All	All		3,214	26.65	27.07
Dry Bulk	Capesize	79,000	0	715	114.22	13.81
	Panamax	54,000	79,000	1,287	90.17	16.71
	Handymax	40,000	54,000	991	46.50	10.69
	Handy	0	40,000	2,155	58.09	19.58
Crude Oil Tanker	VLCC	180,000	0	470	136.75	15.29
	Suezmax	120,000	180,000	268	40.63	5.82
	AFRAmax	75,000	120,000	511	51.83	8.58
	Panamax	43,000	75,000	164	10.32	2.17
	Handymax	27,000	43,000	100	3.45	1.13
	Coastal	0	27,000	377	3.85	1.98
Chemical Tanker	All	All		2,391	38.80	15.54
Petroleum Product Tanker	AFRAmax	68,000	0	226	19.94	3.60
	Panamax	40,000	68,000	352	16.92	4.19
	Handy	27,000	40,000	236	7.90	2.56
	Coastal	0	27,000	349	3.15	1.54
Natural Gas Carrier	VLGC	60,000	0	157	11.57	5.63
	LGC	35,000	60,000	140	6.88	2.55
	Midsize	0	35,000	863	4.79	3.74
Other	All	All		7,675	88.51	53.60
Total	--	--	--	26,189	888.40	308.96

The average fuel consumption for each vessel type and size category was estimated in a multi-step process using individual vessel data on engine characteristics. Clarksons' Shipping Database Register provides each ship's total installed horsepower (HP), type of propulsion (diesel or steam), and year of build. These characteristics are then matched to information on typical specific fuel consumption (SFC), which is expressed in terms of grams of bunker fuel burned per horsepower-hour (g/HP-hr).

The specific SFC values are based on historical data from Wartsila Sulzer, a popular manufacturer of diesel engines for marine vessels. RTI added an additional 10 percent to the reported "test bed" or "catalogue" numbers to account for the guaranteed tolerance level and an in-service SFC differential. Overall, the 10 percent estimate is consistent with other analyses that show some variation between the "test bed" SFC values reported in the manufacturer product catalogues and those observed in actual service. This difference is explained by the fact that old, used engines consume more fuel than brand new engines and in-service fuels may be different than the test bed fuels.[49]

Figure 3-11 shows SFC values that were used in the model regarding the evolution of specific fuel oil consumption rates for diesel engines over time. Engine efficiency in terms of SFC has improved over time, most noticeably in the early 1980s in response to rising fuel prices. However, there is a tradeoff between improving fuel efficiency and reducing emissions. Conversations with engine manufacturers indicate that it is reasonable to assume SFC will remain constant for the projection period of this study, particularly as they focus on meeting NO_X emission standard as required by MARPOL Annex VI, or other potential pollution control requirements.

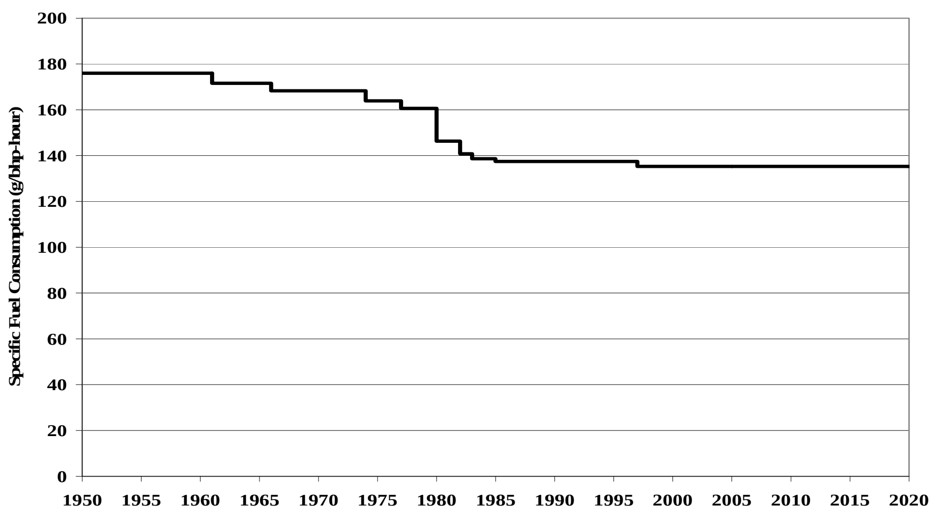


Figure 3-11 Diesel Engine Specific Fuel Consumption

RTI assumed a fixed SFC of 220 g/HP-hr for steam engines operating on bunker fuel.

Using the above information, the average daily fuel consumption (AFC), expressed in metric tons of fuel at full engine load, for each vessel type and size category is found using the following equation:

Equation 3-27

$$\text{Fleet AFC}_{v,s} = \frac{1}{N}\sum\left[SFC_{v,s} \times HP_{v,s} \times 10^{-6}\,tonnes/g\right]$$

Where:
Fleet AFC = Average daily fuel consumption in metric tonnes at full engine load
v = Vessel type
s = Vessel size category
N = Number of vessels in the fleet
SFC = Specific fuel consumption in grams of bunker fuel burned per horsepower-hour in use(g/HP-hr)
HP = Total installed engine power, in horsepower (HP)
10^6 tonnes/g = Conversion from grams to metric tonnes

As previously noted, AFC values calculated in the above equation are based on total horsepower; therefore, they must be scaled down to reflect typical operation using less than 100 percent of the horsepower rating, i.e., actual engine load. Table 3-64 shows the engine load factors that were used to estimate the typical average daily fuel consumption (tons/day) for the main propulsion engine and the auxiliary engines when operated at sea and in port.[50]

Table 3-64 Main and Auxiliary Engine Load Factors

Vessel Type	Main Engine Load Factor (%)	Auxiliary Engine as Percent of Main Engine	Auxiliary Engine as Percent of Main Engine at Sea
Container Vessels	80	22.0	11.0
General Cargo Carriers	80	19.1	9.5
Dry Bulk Carriers	75	22.2	11.1
Crude Oil Tankers	75	21.1	10.6
Chemical Tankers	75	21.1	10.6
Petroleum Product Tankers	75	21.1	10.6
Natural Gas Carrier	75	21.1	10.6
Other	70	20.0	10.0

The RTI analysis also assumed that the shipping fleet changes over time as older vessels are scrapped and replaced with newer ships. Specifically, vessels over 25 years of age are retired and replaced by new ships of the most up-to-date configuration. This assumption leads to the following change in fleet characteristics over the projection period:

- New ships have engines rated at the current SFC, so even though there are no further improvements in specific fuel consumption, the fuel efficiency of the fleet as a whole will improve over time through retirement and replacement.

- New ships will weigh as much as the average ship built in 2005, so the total cargo capacity of the fleet will increase over time as smaller ships retire and are replaced.

- Container ships will increase in size over time on the trade routes between Asia to either North America or Europe.

3.4.2.4 Trade Analysis by Commodity Type and Trade Route

Determining the total number of days at sea and in port, as shown in the middle portion of Figure 3-10, requires information on the relative amount of each commodity that is carried by the different ship type size categories on each of the trade routes. For example, to serve the large crude oil trade from the Middle East Gulf region to the Gulf Coast of the U.S., 98 percent of the deadweight tonnage is carried on very large oil tankers, while the remaining 2 percent is carried on smaller Suezmax vessels. After the vessel type size distribution was found, voyage parameters were estimated. Specifically, these are days at sea and in port for each voyage (based on ports called, distance between ports, and ship speed**)**, and the number of voyages (based on cargo volume projected by GI and the DTW from Clarksons Shipping Database). The length of each voyage and number of voyages were used to estimate the total number of days at sea and at port, which is a parameter used later to calculate total fuel consumption for each vessel type and size category over each route and for each commodity type. (More information on determining the round trip distance for each voyage that is associated with cargo demand for the U.S. is provided in Section 3.4.2.5.)

The days at sea were calculated by dividing the round trip distance by the average vessel speed:

Equation 3-28

$$\text{Days at Sea Per Voyage}_{v,s,route} = \frac{\text{round trip distance route}}{\text{speed}_{v,s} \times 24\text{ hrs}}$$

Where:
v = Vessel type
s = Vessel size category
route = Unique trip itinerary
round trip route distance = Trip length in nautical miles
speed = Vessel speed in knots or nautical miles per hour
24 hrs = Number of hours in one day

Table 3-65 presents the speeds by vessel type that were used in the analysis.[50] These values are the same for all size categories, and are assumed to remain constant over the forecast period.

Table 3-65 Vessel Speed by Type

Vessel Type	Speed (knots)
Crude Oil Tankers	13.2
Petroleum Product Tankers	13.2
Chemical Tankers	13.2
Natural Gas Carriers	13.2
Dry Bulk Carriers	14.1
General Cargo Vessels	12.3
Container Vessels	19.9
Other	12.7

The number of voyages along each route for each trade was estimated for each vessel type *v* and size category *s* serving a given route by dividing the tons of cargo moved by the amount of cargo (DTW) per voyage:

Equation 3-29

$$\text{Number of Voyages}_{v,s,trade} = \frac{\text{total metric tonnes of cargo moved}}{\text{fleet average DWT}_{v,s} \times \text{utilization rate}}$$

Where:
v = Vessel type
s = Vessel size category
trade = Commodity type
Fleet average DWT = Median dead weight tonnage carrying capacity in metric tons
Utilization rate = Fraction of total ship DWT capacity used

The cargo per voyage is based on the fleet average ship size from the vessel profile analysis. For most cargo, a utilization rate of 0.9 is assumed to be constant throughout the forecast period. Lowering this factor would increase the estimated number of voyages required to move the forecasted cargo volumes, which would lead to an increase in estimated fuel demand.

In addition to calculating the average days at sea per voyage, the average days in port per voyage was also estimated by assuming that most types of cargo vessels spend four days in port per voyage. RTI notes, however, that this can vary somewhat by commodity and port.

3.4.2.5 Worldwide Estimates of Fuel Demand

This section describes how the information from the vessel and trade analyses were used to calculate the total annual fuel demand associated with international cargo trade. Specifically, for each year *y* of the analysis, the total bunker fuel demand is the sum of the fuel consumed on each route of each trade (commodity). The fuel consumed on each route of each trade is in turn the sum of the fuel consumed for each route and trade for that year by propulsion main engines and auxiliary engines when operated at sea and in port. These steps are illustrated by the following equations:

Equation 3-30

$$FC_y = \sum_{trade} \sum_{route} FC_{trade,route,year}$$
$$= \sum_{trade} \sum_{route} \left[AFC_{trade,route,y\,at\,sea} \text{ x } \text{Days at Sea}_{trade,route,y} + AFC_{trade,route,y\,at\,port} \text{ x Days at Port}_{trade,route,y} \right]$$

Where:
FC = Fuel consumed in metric tonnes
y = calendar year
trade = Commodity type
route = Unique trip itinerary
AFC = Average daily fuel consumption in metric tonnes
yatsea = Calendar year main and auxiliary engines are operated at sea
yatport = Calendar year main and auxiliary engines are operated in port

Equations 3-31

$$AFC_{trade,route,y\,at\,sea} = \sum_{v,s,t,r} (\text{Percent of trade along route})_{v,s} \left[\text{Fleet AFC}_{v,s} \text{ x } (\text{MELF} + \text{AE at sea LF}) \right]$$
$$AFC_{trade,route,y\,at\,port} = \sum_{v,s,t,r} (\text{Percent of trade along route})_{v,s} \left[\text{Fleet AFC}_{v,s} \text{ x AE import LF} \right]$$
$$\text{Days at Sea}_{trade,route,y} = \sum_{v,s,t,r} (\text{Percent of trade along route})_{v,s} \left[\text{Days at sea per voyage}_{v,s} \text{ x Number of voyages}_{v,s} \right]$$
$$\text{Days at Port}_{trade,route,y} = \sum_{v,s,t,r} (\text{Percent of trade along route})_{v,s} \left[\text{Days at port per voyage x Number of voyages} \right]$$

Where:
AFC = Average daily fuel consumption in metric tonnes
trade = Commodity type
route = Unique trip itinerary
yatsea = Calendar year main and auxiliary engines are operated at sea
yatport = Calendar year main and auxiliary engines are operated in port
y = calendar year
v = Vessel type
s = Vessel size category
t = Trade
r = Route
Fleet AFC = Average daily fuel consumption in metric tonnes at full engine load
MELF = main engine load factor, unitless
AE at sea LF = auxiliary engine at-sea load factor, unitless
AE in port LF = auxiliary engine in-port load factor, unitless

The inputs for these last four equations are all derived from the vessel analysis in Section 3.4.2.3 and the trade analysis in Section 3.4.2.2.

3.4.2.6 Worldwide Bunker Fuel Consumption

Based on the methodology outlined above, estimates of global fuel consumption over time were computed, and growth rates determined from these projections. Figure 3-12 shows estimated world-wide bunker fuel consumption by vessel type.

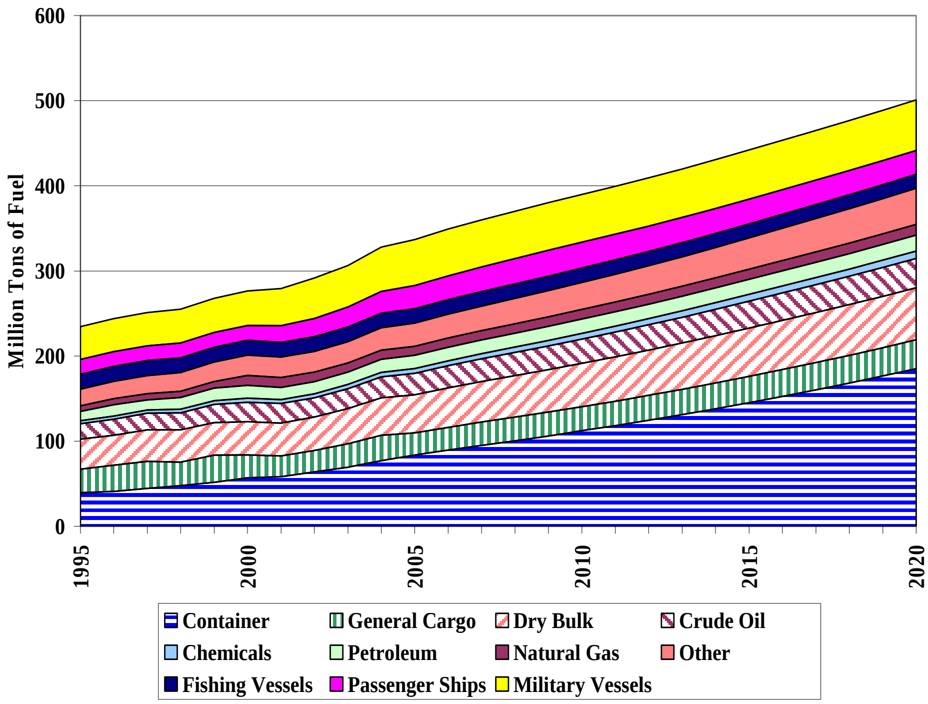


Figure 3-12 Worldwide Bunker Fuel Consumption

Figure 3-13 shows the annual growth rates by vessel-type/cargo that are used in the projections shown in Figure 3-12. Total annual growth is generally between 2.5 percent and 3.5 percent over the time period between 2006 and 2020 and generally declines over time, resulting in an average annual growth of around 2.6 percent.

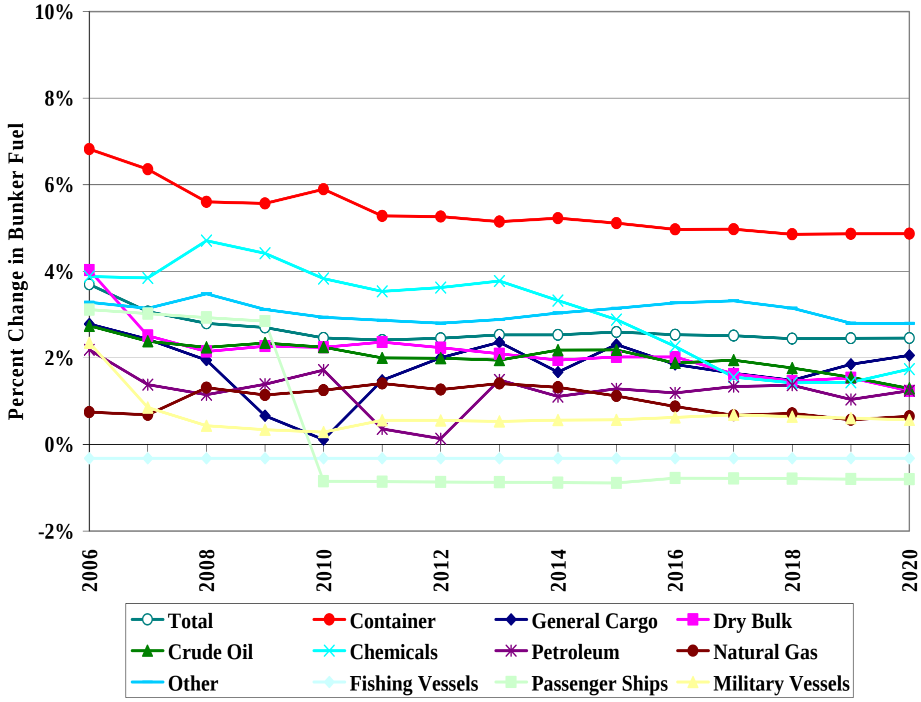


Figure 3-13 Annual Growth Rate in World-Wide Bunker Fuel Use by Commodity Type

3.4.2.7 Fuel Demand Used to Import and Export Cargo for the United States

The methodology described above provides an estimate of fuel consumption for international cargo worldwide. RTI also estimated the subset of fuel demand for cargo imported to and exported from five regions of the U.S. The five regions are:

- North Pacific
- South Pacific
- Gulf
- East Coast
- Great Lakes

For this analysis, the same equations were used, but were limited to routes that carried cargo between specific cities in Asia, Europe and Middle East to the various ports in the specific regions of the U.S.

The trip distances for non-container vessel types were developed from information from Worldscale Association and Maritime Chain.[51] The data from Worldscale is considered to be the industry standard for measuring port-to-port distances, particularly for tanker traffic. The reported distances account for common routes through channels, canals, or straits. This distance information was supplemented by data from Maritime Chain, a web service that provides port-to-port distances along with some information about which channels, canals, or straits must be passed on the voyage.

Voyage distances for container vessels are based on information from Containerization International Yearbook (CIY) and calculations by RTI. That reference provides voyage information for all major container services. Based on the frequency of the service, number of vessels assigned to that service, and the number of days in operation per year, RTI estimated the average length of voyages for the particular bilateral trade routes in the Global Insights trade forecasts.

The distance information developed above was combined with the vessel speeds previously shown in Table 3-65 to find the length of a voyage in days. Table 3-66 presents the day lengths for non-containerized vessel types and Table 3-67 shows the same information for container vessels.

Table 3-66 Day Length for Voyages for Non-Container Cargo Ship (approximate average)

	Days per Voyage				
Global Insights Trade Regions	US South Pacific	US North Pacific	US East Coast	US Great Lakes	*US Gulf*
Africa East-South	68	75	57	62	*54*
Africa North-Mediterranean	49	56	37	43	*47*
Africa West	56	63	36	46	*43*
Australia-New Zealand	48	47	65	81	*63*
Canada East	37	46	7	18	*19*
Canada West	11	5	40	58	*39*
Caspian Region	95	89	41	46	*48*
China	41	36	73	87	*69*
Europe Eastern	61	68	38	45	*46*
Europe Western-North	53	60	24	32	*34*
Europe Western-South	54	61	30	37	*37*
Greater Caribbean	26	33	16	29	*17*
Japan	35	31	65	81	*62*
Middle East Gulf	77	72	56	65	*83*
Pacific High Growth	52	48	67	76	*88*
Rest of Asia	68	64	66	64	*73*
Russia-FSU	64	71	38	46	*48*
Rest of South America	*51*	*30*	*41*	*46*	*44*

Table 3-67 Day Length for Voyages for Container-Ship Trade Routes

Origin – Destination Regions	***Days per Voyage***
Asia – North America (Pacific)	*37*
Europe – North America (Atlantic)	*37*
Mediterranean – North America	*41*
Australia/New Zealand – North America	*61*
South America – North America	*48*
Africa South – North America (Atlantic)	*54*
Africa West – North America (Atlantic)	*43*
Asia – North America (Atlantic)	*68*
Europe – North America (Pacific)	*64*
Africa South – North America (Pacific)	*68*
Africa West – North America (Pacific)	*38*
Caspian Region – North America (Atlantic)	*42*
Caspian Region – North America (Pacific)	*38*
Middle East/Gulf Region – North America (Atlantic)	*63*
Middle East/Gulf Region – North America (Pacific)	*80*

3.4.2.8 Bunker Fuel Consumption for the United States

Figure 3-14 and Figure 3-15 present the estimates of fuel use for delivering trade goods to and from the U.S. The results in Figure 3-14 show estimated historical bunker fuel use in year 2001 of around 47 million tons (note: while this fuel is used to carry trade goods to and from the U.S., it is not necessarily all purchased in the U.S. and is not all burned in U.S. waters). This amount grows to over 90 million tons by 2020 with the most growth occurring on trade routes from the East Coast and the "South Pacific" region of the West Coast.

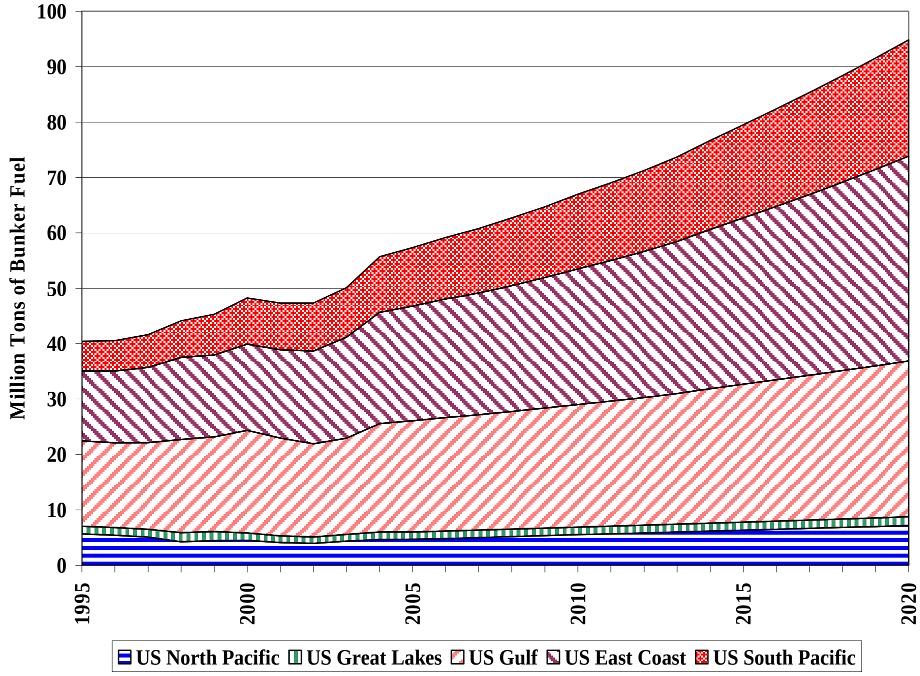


Figure 3-14 Bunker Fuel Used to Import and Export Cargo by Region of the United States

Figure 3-15 shows the estimated annual growth rates for the fuel consumption that are used in the projections shown in Figure 3-14. Overall, the average annual growth rate in marine bunkers associated with future U.S. trade flows is 3.4 percent between 2005 and 2020.

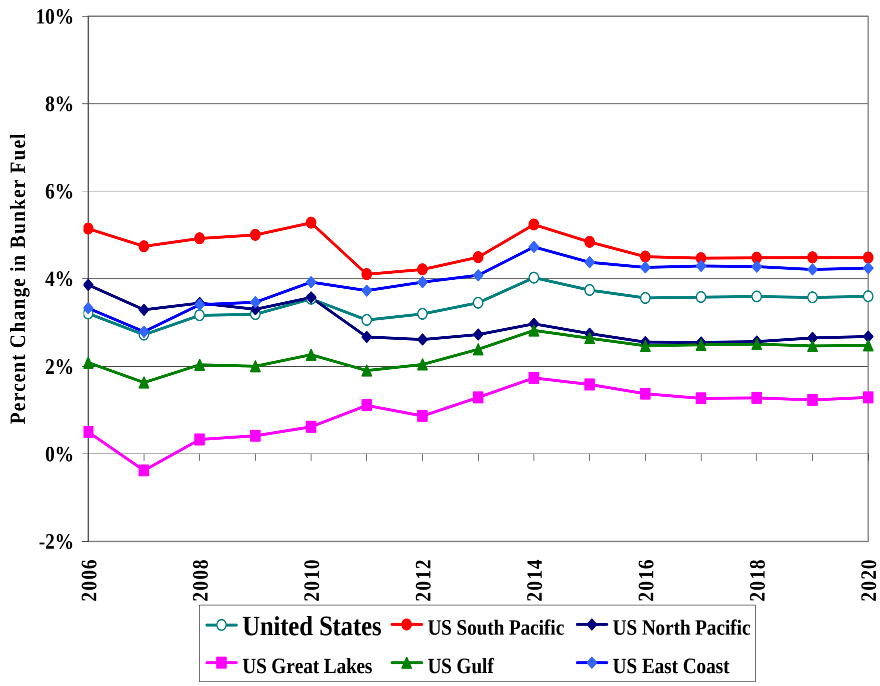


Figure 3-15 Annual Growth Rates for Bunker Fuel Used to Import and Export Cargo by Region of the United States

3.4.2.9 2020 and 2030 Growth Factors for Nine Geographic Regions

The results of the RTI analysis described above are used to develop the growth factors that are necessary to project the 2002 base year emissions inventory to 2020 and 2030. The next two sections describe how the five RTI regions were associated with the nine regions analyzed in this report, and how the specific growth rates for each of the nine regions were developed.

3.4.2.9.1 Mapping the RTI Regional Results to the Nine Region Analysis

As described in Section 3.3.4, the nine geographic regions analyzed in this study were designed to be consistent with the five RTI regional modeling domains. More specifically, four of the nine geographic areas in this study, i.e., Alaska East, Alaska West, Hawaii East, and Hawaii West are actually subsets of two broader regional areas that were analyzed by RTI, i.e., the North Pacific for both Alaska regions and South Pacific for Hawaii. Therefore, the growth rate information from the related larger region was assumed to be representative for that state.

The nine geographic regions represented in the emission inventory study are presented in Figure 3-1. The association of the RTI regions to the emission inventory regions is shown in Table 3-68.

Table 3-68 Association of the RTI Regions to the Nine Emission Inventory Regions

Consumption Region	Corresponding Emission Inventory Region
North Pacific	North Pacific (NP)
North Pacific	Alaska East (AE)
North Pacific	Alaska West (AW)
South Pacific	South Pacific (SP)
South Pacific	Hawaii East (HE)
South Pacific	Hawaii West (HW)
Gulf	Gulf Coast (GC)
East Coast	East Coast (EC)
Great Lakes	Great Lakes (GL)

3.4.2.9.2 Growth Factors for the Emission Inventory Analysis

Emission inventories for 2020 and 2030 are estimated in Section 3.4.5 by multiplying the 2002 baseline inventory for each region by a corresponding growth factor that was developed from the RTI regional results. Specifically, the average annual growth rate from 2002-2020 was calculated for each of the five regions. Each regional growth rate was then compounded over the inventory projection time period for 2020 and 2030, i.e., 18 and 28 years, respectively. The resulting multiplicative growth factors for each emission inventory region and the associated RTI average annual growth rate are presented in Table 3-69 for each projection year.

Table 3-69 Regional Emission Inventory Growth Factors for 2020 and 2030

Emission Inventory Region	2002-2020 Average Annualized Growth Rate (%)	Multiplicative Growth Factor Relative to 2002	
		2020	2030
Alaska East (AE)	3.3	1.79	2.48
Alaska West (AW)	3.3	1.79	2.48
East Coast (EC)	4.5	2.21	3.43
Gulf Coast (GC)	2.9	1.67	2.23
Hawaii East (HE)	5.0	2.41	3.92
Hawaii West (HW)	5.0	2.41	3.92
North Pacific (NP)	3.3	1.79	2.48
South Pacific (SP)	5.0	2.41	3.92
Great Lakes (GL)	1.7	1.35	1.60

3.4.3 Emission Controls in Baseline and Control Scenarios

This section describes the control programs present in the baseline and control scenarios, as well as the resulting emission factors.

The baseline scenario includes the International Marine Organization's (IMO) Tier 1 NO_X standard for marine diesel engines that became effective in 2000. The control scenario applies global controls as well as additional ECA controls within the ECA boundaries

The global NO_X controls include a retrofit program for Tier 0 (pre-control) engines, which was modeled as 11 percent control from Tier 0 for 80 percent of 1990 thru 1999 model year (MY) engines greater than 90 liters per cylinder (L/cyl) starting in 2011. The retrofit program was also modeled with a five year phase-in. The current Tier 1 controls, which also are modeled as achieving an 11 percent reduction from Tier 0, apply to the 2000 thru 2010 MY engines. In 2011 thru 2015, Tier 2 controls are applied. Tier 2 controls are modeled as a 2.5 g/kW-hr reduction from Tier 1. Fuel sulfur content for the global control area is assumed to be controlled to 5,000 ppm. No controls are assumed for HC or CO.

Within the ECA areas, additional Tier 3 NO_X controls are applied for 2016 MY engines and beyond. Tier 3 controls are modeled as achieving an 80 percent reduction from Tier 1 levels. In addition to the NO_X control program, fuel sulfur content is also assumed to be controlled to 1,000 ppm within the ECA in 2020 and 2030. Fuel sulfur content affects SO_2 and PM emissions. Note that gas and steam turbine engines are not subject to any of the NO_X standards; however, these engines are not a large part of the inventory.

Within the control scenario, global controls are applied for the Alaska West and Hawaii West regions. Global controls are also applied beyond 200 nm from shore for the 48 contiguous states, Alaska East, and Hawaii East. The ECA controls are applied within 200 nm from shore for the 48 contiguous states as well as the Alaska East and Hawaii East regions.

3.4.3.1 2020 and 2030 Emission Factors

The baseline scenario described in the previous section includes Tier 1 NO_X control. The control scenario includes additional NO_X controls and fuel sulfur controls, the latter affecting PM and SO_2 emissions. The switch to lower sulfur distillate fuel use is also assumed to lower CO_2 emissions slightly. HC and CO are assumed to remain unchanged.

The NO_X emission factors (EFs) by engine/ship type and tier are provided in Table 3-70. Tier 0 refers to pre-control. There are separate entries for Tier 0/1 base and Tier 0/1 control, since the Tier 0/1 control engines would be using distillate fuel, and there are small NO_X emission reductions assumed when switching from residual to distillate fuel.[21] The NO_X control EFs by tier were derived using the assumptions described in Section 3.4.3.

Table 3-70 Modeled NO_X Emission Factors by Tier

Engine/ Ship Type	NO_X EF (g/kW-hr)						
	Baseline		Control Areas				
	Tier 0	Tier 1	Tier 0	T0 retrofit [a]	Tier 1	Tier 2	Tier 3
Main							
SSD	18.1	16.1	17	15.1	15.1	12.6	3
MSD	14	12.5	13.2	11.7	11.7	9.2	2.3
ST	2.1	n/a	2	n/a	n/a	n/a	n/a
GT	6.1	n/a	5.7	n/a	n/a	n/a	n/a
Aux							
Pass	14.6	13.0	14.6	n/a*	13	10.5	2.6
Other	14.5	12.9	14.5	n/a*	12.9	10.4	2.6

Note:
[a] The retrofit program applies to engines over 90 L/cyl; auxiliary engines are smaller than this cutpoint and would therefore not be subject to the program.

The NO_X EFs by tier were then used with the age distributions in Table 3-71 and Table 3-72 below to generate calendar year NO_X EFs by engine/ship type for the base and control areas included in the scenarios. These calendar year NO_X EFs are provided in Table 3-73. Since the age distributions are different for vessels in the Great Lakes, NO_X EFs were determined separately for the Great Lakes.

Table 3-71 Vessel Age Distribution for Deep Sea Ports by Engine Type

Age Group (years old)	*Propulsion Engine Type[a] (Fraction of Total)*				All Auxiliary Engines
	MSD	SSD	GT	ST	
0	0.00570	0.02667	0.00000	0.00447	0.01958
1	0.07693	0.07741	0.07189	0.12194	0.07670
2	0.10202	0.07512	0.14045	0.16464	0.08426
3	0.08456	0.07195	0.05608	0.05321	0.07489
4	0.08590	0.05504	0.67963	0.00000	0.07831
5	0.06427	0.05563	0.04165	0.00000	0.05685
6	0.06024	0.04042	0.00000	0.00000	0.04455
7	0.07867	0.07266	0.00626	0.00000	0.07150
8	0.06730	0.05763	0.00000	0.00000	0.05764
9	0.04181	0.04871	0.00000	0.00000	0.04475
10	0.04106	0.04777	0.00000	0.00000	0.04364
11	0.03100	0.03828	0.00000	0.00000	0.03538
12	0.04527	0.03888	0.00000	0.04873	0.04160
13	0.03583	0.02787	0.00000	0.00000	0.02909
14	0.03519	0.02824	0.00000	0.00000	0.02935
15	0.02921	0.01466	0.00000	0.00000	0.01869
16	0.00089	0.01660	0.00000	0.00000	0.01189
17	0.01326	0.01582	0.00000	0.00000	0.01462
18	0.00847	0.02414	0.00000	0.00000	0.01966
19	0.00805	0.01982	0.00000	0.00000	0.01550
20	0.00566	0.02258	0.00000	0.00000	0.01756
21	0.00495	0.02945	0.00000	0.00000	0.02260
22	0.00503	0.01883	0.00000	0.00875	0.01467
23	0.00676	0.01080	0.00000	0.00883	0.00943
24	0.00539	0.01091	0.00000	0.00883	0.00900
25	0.01175	0.01099	0.00000	0.18029	0.01224
26	0.00803	0.01045	0.00000	0.11065	0.01130
27	0.00522	0.00835	0.00000	0.01395	0.00738
28	0.00294	0.00788	0.00000	0.08657	0.00659
29	0.00285	0.00370	0.00034	0.02907	0.00349
30	0.00254	0.00106	0.00370	0.05126	0.00193
31	0.00084	0.00113	0.00000	0.00605	0.00096
32	0.00023	0.00367	0.00000	0.07105	0.00322
33	0.00117	0.00582	0.00000	0.00000	0.00419
34	0.00132	0.00092	0.00000	0.00000	0.00098
35+	0.01967	0.00013	0.00000	0.03172	0.00598

Note:
[a] MSD is medium speed diesel, SSD is slow speed diesel, GT is gas turbine, ST is steam turbine.

Table 3-72 Vessel Age Distribution for Great Lake Ports by Engine Type

Age Group (years old)	Propulsion Engine Type[a] (Fraction of Total)			
	MSD	SSD	ST	All Auxiliary Engines
0	0.01610	0.03913	0.00000	0.02399
1	0.02097	0.03489	0.00000	0.02243
2	0.01370	0.04644	0.00000	0.02544
3	0.02695	0.03040	0.00000	0.02511
4	0.01571	0.04547	0.00000	0.02497
5	0.04584	0.01498	0.00000	0.02442
6	0.01494	0.02180	0.00000	0.01528
7	0.01327	0.01857	0.00000	0.01391
8	0.00099	0.04842	0.00000	0.02107
9	0.00027	0.03376	0.00000	0.01454
10	0.01085	0.01177	0.00000	0.01076
11	0.00553	0.01183	0.00000	0.00782
12	0.00739	0.00546	0.00000	0.00626
13	0.02289	0.02557	0.00000	0.02242
14	0.00000	0.00286	0.00000	0.00121
15	0.00275	0.00510	0.00000	0.00361
16	0.00069	0.00073	0.00000	0.00078
17	0.00000	0.00104	0.00000	0.00041
18	0.00342	0.01967	0.00000	0.01059
19	0.00219	0.01220	0.00000	0.00645
20	0.00867	0.06140	0.00000	0.03034
21	0.00000	0.05638	0.00000	0.02503
22	0.03375	0.02108	0.00000	0.02279
23	0.04270	0.02051	0.00000	0.02606
24	0.08161	0.01010	0.00000	0.03744
25	0.02935	0.05217	0.00000	0.03480
26	0.18511	0.00522	0.00000	0.07701
27	0.01870	0.00389	0.00000	0.01083
28	0.13815	0.01438	0.00000	0.06181
29	0.05487	0.01160	0.00000	0.02697
30	0.00000	0.00114	0.00000	0.00047
31	0.03986	0.00000	0.00000	0.01611
32	0.03654	0.00282	0.00000	0.01631
33	0.03358	0.00000	0.00000	0.01358
34	0.00295	0.00123	0.00000	0.00165
35+	0.06974	0.30796	1.00000	0.31734

Notes:
[a] MSD is medium speed diesel, SSD is slow speed diesel, GT is gas turbine, ST is steam turbine.
[b] Fleet average weighted by installed power (ship port calls x main propulsion engine power).

Table 3-73 Modeled NO_X Emission Factors by Calendar Year and Control Type

Engine/ Ship Type	CY NO_X EF (g/kW-hr)												
		2020 Base		2020 ECA Control		2020 Global Control		2030 Base		2030 ECA Control		2030 Global Control	
	2002	DSP[a]	GL[b]	DSP	GL	DSP	GL	DSP	GL	DSP	GL	DSP	GL
Main													
SSD	18.1	16.36	17.12	10.80	13.07	13.74	14.95	16.13	16.73	5.68	10.44	13.00	14.20
MSD	14	12.58	13.64	7.72	11.79	10.17	12.44	12.50	12.74	3.58	9.95	9.49	11.44
ST	2.1	2.1	2.1	2.0	2.0	2.0	2.0	2.1	2.1	2.0	2.0	2.0	2.0
GT	6.1	6.1	n/a[c]	5.7	n/a	5.7	n/a	6.1	n/a	5.7	n/a	5.7	n/a
Aux													
Pass	14.6	13.21	14.13	8.59	11.99	n/a	n/a	13.05	13.61	4.39	10.30	n/a	n/a
Other	14.5	13.06	13.97	8.59	11.99	n/a	n/a	12.90	13.46	4.39	10.30	n/a	n/a

Notes:
[a] DSP = Deep sea ports and areas other than the Great Lakes
[b] GL = Great Lakes
[c] n/a = not applicable. There are no GT engines assumed to be operating in the Great Lakes. Auxiliary engines are assumed to be operating in ports and therefore not subject to global controls.

For PM and SO_2, there are no proposed standards; however, the control of fuel sulfur affects these pollutants. Therefore, the PM and SO_2 EFs are strictly a function of fuel sulfur level. For the baseline portions of the inventory, there are two residual fuel sulfur levels modeled: 25,000 ppm for the West Coast and 27,000 ppm for the rest of the U.S. The baseline distillate fuel sulfur level assumed for all areas is 15,000 ppm. As discussed in Section 3.3.2.3.5, for the baseline, main engines use residual fuel and auxiliary engines use a mix of residual and distillate fuel. For the control areas, there are two levels of distillate fuel sulfur assumed to be used by all engines: 5,000 ppm for the global control areas and 1,000 ppm for the ECA control areas.

Table 3-74 provides the PM_{10} EFs by engine/ship type and fuel sulfur level. For modeling purposes, $PM_{2.5}$ is assumed to be 92 percent of PM_{10}. The PM EFs are adjusted to reflect the appropriate fuel sulfur levels using the equation described in Section 3.3.2.3.6.

Table 3-75 provides the modeled SO_2 EFs. SO_2 emission reductions are directly proportional to reductions in fuel sulfur content.

CO_2 is directly proportional to fuel consumed. Table 3-76 provides the modeled CO_2 and brake specific fuel consumption (BSFC) EFs. Due to the higher energy content of distillate fuel on a mass basis, the switch to distillate fuel for the control areas results in a small reduction to BSFC and, correspondingly, CO_2 emissions.[21]

Table 3-74 Modeled PM_{10} Emission Factors*

Engine/ Ship Type	PM_{10} EF (g/kW-hr)			
	Baseline		Control Areas	
	Other than West Coast 27,000 ppm S	West Coast[a] 25,000 ppm S	ECA 5,000 ppm S	Global Control 1,000 ppm S
Main				
SSD	1.40	1.40	0.31	0.19
MSD	1.40	1.40	0.31	0.19
ST	1.50	1.40	0.35	0.17
GT	1.50	1.40	0.35	0.17
Aux				
Pass	1.40	1.30	0.31	0.19
Other	1.20	1.10	0.31	0.19

Note:
[a] For the base cases, the West Coast fuel is assumed to be used in the following regions: Alaska East (AE), Alaska West (AW), Hawaii East (HE), Hawaii West (HW), North Pacific (NP), and South Pacific (SP).

Table 3-75 Modeled SO_2 Emission Factors*

Engine/ Ship Type	SO_2 EF (g/kW-hr)			
	Baseline		Control Areas	
	Other than West Coast 27,000 ppm S	West Coast[a] 25,000 ppm S	ECA 5,000 ppm S	Global Control 1,000 ppm S
Main				
SSD	10.29	9.53	1.81	0.36
MSD	11.09	10.26	1.96	0.39
ST	16.10	14.91	2.83	0.57
GT	16.10	14.91	2.83	0.57
Aux				
Pass	10.70	9.93	1.96	0.39
Other	9.66	9.07	1.96	0.39

Note:
[a] For the base cases, the West Coast fuel is assumed to be used in the following regions: Alaska East (AE), Alaska West (AW), Hawaii East (HE), Hawaii West (HW), North Pacific (NP), and South Pacific (SP).

Table 3-76 Modeled Fuel Consumption and CO_2 Emission Factors

Engine/ Ship Type	EF (g/kW-hr)			
	Baseline		Control Areas	
	BSFC	CO_2	BSFC	CO_2
Main				
SSD	195	620.62	185	588.86
MSD	210	668.36	200	637.05
ST	305	970.71	290	923.07
GT	305	970.71	290	923.07
Aux				
Pass	210	668.36	200	636.60
Other	210	668.36	200	636.60

3.4.4 Calculation of Near Port and Interport Inventories

Based on the emission factors described in Section 3.4.3.1, appropriate growth factors and emission adjustment factors were applied to the 2002 baseline inventory to obtain the NO_X, PM (PM_{10} and $PM_{2.5}$), SO_2, and CO_2 inventory of each 2020 and 2030 scenario. Adjustment factors are ratios of the 2020 or 2030 calendar year EFs to the 2002 calendar year EFs. Adjustment factors are derived separately by engine type for propulsion and auxiliary engines. The adjustment factors for propulsion engines are applied to the propulsion portion of the port inventory and the interport portion of the inventory. The adjustment factors for auxiliary engines are applied to the auxiliary portion of the port inventory. This section describes the development and application of the adjustment factors to the port and interport inventories, and the methodology for combining the port and interport portions.

3.4.4.1 Port Methodology

3.4.4.1.1 Non-California Ports

For the non-California ports, 2002 emissions for each port are summed by engine/ship type. Propulsion and auxiliary emissions are summed separately, since the EF adjustment factors differ. The appropriate regional growth factor, as provided in Table 3-69, is then applied, along with EF adjustment factors by engine/ship type. The EF adjustment factors are a ratio of the control EF to the 2002 EF. Table 3-77 thru Table 3-81 provide the EF adjustment factors for each pollutant and control area. The ports will be subject to ECA controls in the control scenarios. These tables are also used as input for the California ports and interport control inventory development, discussed in subsequent sections. Since the control scenario assumes a portion of the inventory is subject to global controls, the adjustment factors for the 2020 and 2030 global controls are also provided. The baseline adjustment factors are also provided.

Table 3-77 NO_X EF Adjustment Factors by Engine/Ship Type and Control Type[a]

Engine/ Ship Type	2020 Base		2020 ECA Control		2020 Global Control		2030 Base		2030 ECA Control		2030 Global Control	
	DSP[b]	GL[c]	DSP	GL	DSP	GL	DSP	GL	DSP	GL	DSP	GL
Main												
SSD	0.9037	0.9459	0.5967	0.7219	0.7592	0.8261	0.8913	0.9243	0.3138	0.5771	0.7183	0.7847
MSD	0.8987	0.9744	0.5515	0.8423	0.7265	0.8883	0.8926	0.9101	0.2559	0.7109	0.6776	0.8170
ST	1.0000	1.0000	0.9524	0.9524	0.9524	0.9524	1.0000	1.0000	0.9524	0.9524	0.9524	0.9524
GT	1.0000	n/a	0.9344	n/a	0.9344	n/a	1.0000	n/a	0.9344	n/a	0.9344	n/a
Aux												
Pass	0.9025	0.9657	0.5869	0.8196	n/a	n/a	0.8917	0.9301	0.3003	0.7042	n/a	n/a
Other	0.9025	0.9657	0.5940	0.8295	n/a	n/a	0.8917	0.9301	0.3039	0.7127	n/a	n/a

Notes:
[a] NO_X adjustment factors are a ratio of future base or control EFs to 2002 EFs
[b] DSP = deep sea ports and areas other than the Great Lakes
[c] GL = Great Lakes

Table 3-78 PM_{10} EF Adjustment Factors by Engine/Ship Type and Control Type[a]

Engine/ Ship Type	Base		ECA Control		Global Control	
	Other[b]	WC[c]	Other	WC	Other	WC
Main						
SSD	1.0000	1.0000	0.1352	0.1352	0.2183	0.2183
MSD	1.0000	1.0000	0.1328	0.1328	0.2227	0.2227
ST	1.0000	1.0000	0.1108	0.1187	0.2324	0.2490
GT	1.0000	1.0000	0.1108	0.1187	0.2324	0.2490
Aux						
Pass	1.0000	1.0000	0.1328	0.1430	0.2227	0.2398
Other	1.0000	1.0000	0.1550	0.1691	0.2598	0.2834

Notes:
[a] PM_{10} adjustment factors are a ratio of the control EFs to the baseline EFs. PM is not adjusted for the future baselines because fuel sulfur levels are only assumed to change within the ECA and global control areas.
[b] Other = Other than West Coast
[c] WC = Ports/areas within the West Coast. This includes the regions of Alaska, Hawaii, North Pacific, and South Pacific.

Table 3-79 $PM_{2.5}$ EF Adjustment Factors by Engine/Ship Type and Control Type[a]

Engine/ Ship Type	Base		ECA Control		Global Control	
	Other[b]	WC[c]	Other	WC	Other	WC
Main						
SSD	1.0000	1.0000	0.1339	0.1339	0.2163	0.2163
MSD	1.0000	1.0000	0.1316	0.1316	0.2207	0.2207
ST	1.0000	1.0000	0.1092	0.1176	0.2291	0.2467
GT	1.0000	1.0000	0.1092	0.1176	0.2291	0.2467
Aux						
Pass	1.0000	1.0000	0.1316	0.1426	0.2207	0.2390
Other	1.0000	1.0000	0.1555	0.1711	0.2608	0.2868

Notes:
[a] $PM_{2.5}$ adjustment factors are a ratio of the control EFs to the baseline EFs. PM is not adjusted for the future baselines because fuel sulfur levels are only assumed to change within the ECA and global control areas. The $PM_{2.5}$ adjustment factors are slightly different from those for PM_{10} due to rounding.
[b] Other = Other than West Coast
[c] WC = Ports/areas within the West Coast. This includes the regions of Alaska, Hawaii, North Pacific, and South Pacific.

Table 3-80 SO_2 EF Adjustment Factors by Engine/Ship Type and Control Type[a]

Engine/ Ship Type	Base		ECA Control		Global Control	
	Other[b]	WC[c]	Other	WC	Other	WC
Main						
SSD	1.0000	1.0000	0.0351	0.0380	0.1757	0.1898
MSD	1.0000	1.0000	0.0353	0.0381	0.1764	0.1907
ST	1.0000	1.0000	0.0352	0.0380	0.1761	0.1901
GT	1.0000	1.0000	0.0352	0.0380	0.1761	0.1901
Aux						
Pass	1.0000	1.0000	0.0365	0.0394	0.1827	0.1969
Other	1.0000	1.0000	0.0405	0.0431	0.2024	0.2156

Notes:
[a] SO_2 adjustment factors are a ratio of the control EFs to the baseline EFs. SO_2 is not adjusted for the future baselines because fuel sulfur levels are only assumed to change within the ECA and global control areas.
[b] Other = Other than West Coast
[c] WC = Ports/areas within the West Coast. This includes the regions of Alaska, Hawaii, North Pacific, and South Pacific.

Table 3-81 CO_2 EF Adjustment Factors by Engine/Ship Type and Control Type[a]

Engine/ Ship Type	Base		ECA Control		Global Control	
	Other[b]	WC[c]	Other	WC	Other	WC
Main						
SSD	1.0000	1.0000	0.9488	0.9488	0.9488	0.9488
MSD	1.0000	1.0000	0.9531	0.9531	0.9531	0.9531
ST	1.0000	1.0000	0.9509	0.9509	0.9509	0.9509
GT	1.0000	1.0000	0.9509	0.9509	0.9509	0.9509
Aux						
Pass	1.0000	1.0000	0.9525	0.9593	0.9525	0.9593
Other	1.0000	1.0000	0.9525	0.9683	0.9525	0.9683

Notes:
[a] CO_2 adjustment factors are a ratio of the control EFs to the baseline EFs. CO_2 is not adjusted for the future baselines because fuel consumption (BSFC) is only assumed to change within the ECA and global control areas.
[b] Other = Other than West Coast
[c] WC = Ports/areas within the West Coast. This includes the regions of Alaska, Hawaii, North Pacific, and South Pacific.

3.4.4.1.2 California Ports

For the California ports, 2002 emissions for each port are summed by ship type. Propulsion and auxiliary emissions are summed separately, since the EF adjustment factors differ. The EF adjustment factors by engine/ship type, provided in the previous section, are consolidated by ship type, using the CARB assumption that engines on all ships except passenger ships are 95 percent slow speed diesel (SSD) engines and 5 percent medium speed diesel engines (MSD) based upon a 2005 ARB survey.[53] All passenger ships were assumed to be medium speed diesel engines with electric drive propulsion (MSD-ED). Steam turbines (ST) and gas-turbines (GT) are not included in the CARB inventory. The EF adjustment factors by ship type are then applied, along with ship-specific growth factors supplied by CARB. The ship-specific growth factors relative to 2002 are provided in Table 3-82 below.

Deleted: [52].

Table 3-82 Growth Factors by Ship Type for California Ports Relative to 2002

Ship Type	Calendar Year		
	2002	2020	2030
Auto	1.0000	1.5010	1.8478
Bulk	1.0000	0.2918	0.1428
Container	1.0000	2.5861	4.2828
General	1.0000	0.7331	0.5985
Passenger	1.0000	7.5764	26.4448
Reefer	1.0000	1.0339	1.0532
RoRo	1.0000	1.5010	1.8478
Tanker	1.0000	2.0979	3.0806

3.4.4.2 Interport Methodology

The interport portion of the inventory is not segregated by engine or ship type. As a result, regional EF adjustment factors were developed based on the assumed mix of main (propulsion) engine types in each region. The mix of main engine types by region was developed using the ship call and power data and is presented in Table 3-83 and Figure 3-16. Main engines are considered a good surrogate for interport emissions, since the majority of emissions while underway are due to the main engines. The EF adjustment factors by main engine type in Section 3.4.4.1.1 were used together with the mix of main engine types by region to develop the EF regional adjustment factors for each control area. The resulting EF regional adjustment factors for each pollutant and control area are provided in Table 3-84 thru Table 3-88 below. These EF regional adjustment factors, together with the regional growth factors in Table 3-69, were applied to calculate the future inventories for each control area.

Table 3-83 Installed Power by Main Engine Type for Deep Sea Ports [a]

Region	2020 Installed Power (%)					2030 Installed Power (%)				
	MSD	SSD	GT	ST	Total	MSD	SSD	GT	ST	Total
Alaska East (AE)	19.1%	18.4%	0.3%	62.2%	0.8%	19.1%	18.4%	0.3%	62.2%	0.6%
Alaska West (AW)	19.1%	18.4%	0.3%	62.2%	0.8%	19.1%	18.4%	0.3%	62.2%	0.6%
East Coast (EC)	25.6%	72.5%	0.9%	1.0%	45.4%	25.6%	72.5%	0.9%	1.0%	42.3%
Gulf Coast (GC)	13.7%	85.5%	0.0%	0.8%	16.8%	13.7%	85.5%	0.0%	0.8%	13.4%
Hawaii East(HE)	66.2%	18.5%	7.4%	8.0%	2.0%	66.2%	18.5%	7.4%	8.0%	2.0%
Hawaii West (HW)	66.2%	18.5%	7.4%	8.0%	2.0%	66.2%	18.5%	7.4%	8.0%	2.0%
North Pacific (NP)	5.1%	83.5%	1.6%	9.7%	5.0%	5.1%	83.5%	1.6%	9.7%	4.1%
South Pacific (SP)	29.2%	70.8%	0.0%	0.0%	30.0%	45.5%	54.5%	0.0%	0.0%	37.6%

Note:
[a] Installed power is main propulsion engine power (kW) multiplied by ship port calls by engine type. MSD is medium speed diesel, SSD is slow speed diesel, GT is gas turbine, ST is steam turbine.

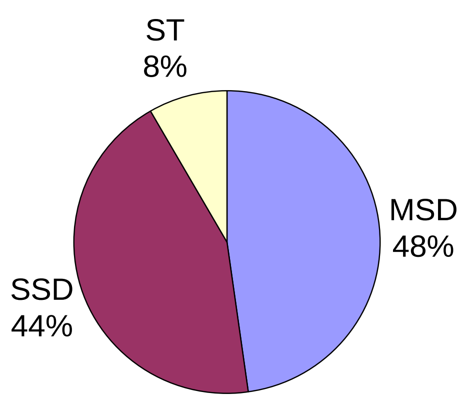


Figure 3-16 Installed Power by Main Engine Type for Great Lake Ports [D]

[D] Installed power is main propulsion engine power (kW) multiplied by ship port calls by engine type. MSD is medium speed diesel, SSD is slow speed diesel, GT is gas turbine, ST is steam turbine.

Table 3-84 NO_X EF Adjustment Factors by Region and Control Type[a]

U.S. Region	2002	2020			2030		
		Base	ECA Control	Global Control	Base	ECA Control	Global Control
Alaska East (AE)	1.0000	0.9629	0.8104	n/a	0.9595	0.7019	n/a
Alaska West (AW)	1.0000	0.9629	n/a	0.8737	0.9595	n/a	0.8568
East Coast (EC)	1.0000	0.9042	0.5917	n/a	0.8937	0.3110	n/a
Gulf Coast (GC)	1.0000	0.9038	0.5935	n/a	0.8924	0.3113	n/a
Hawaii East (HE)	1.0000	0.9152	0.6201	n/a	0.9088	0.3723	n/a
Hawaii West (HW)	1.0000	0.9152	n/a	0.7659	0.9088	n/a	0.7260
North Pacific (NP)	1.0000	0.9143	0.6343	n/a	0.9036	0.3828	n/a
South Pacific (SP)	1.0000	0.9022	0.5837	n/a	0.8919	0.2877	n/a
Great Lakes (GL)	1.0000	0.9641	0.7989	n/a	0.9238	0.6726	n/a
Out of Region[b]	1.0000	0.8942	n/a	0.7557	0.8940	n/a	0.7103

Notes:
[a] NO_X adjustment factors are a ratio of future base or control EFs to 2002 EFs. These regional adjustment factors are used to adjust the interport portion of the 2002 inventory.
[b] Out of Region refers to areas outside 200nm, but within the air quality modeling domain. The out of region adjustment factors are derived by weighting the regional adjustment factors by the main propulsion power in each region. ECA control is only assumed within 200nm.

Table 3-85 PM_{10} EF Adjustment Factors by Region and Control Type[a]

U.S. Region	2002	2020			2030		
		Base	ECA Control	Global Control	Base	ECA Control	Global Control
Alaska East (AE)	1.0000	1.0000	0.1244	n/a	1.0000	0.1244	n/a
Alaska West (AW)	1.0000	1.0000	n/a	0.2280	1.0000	n/a	0.2280
East Coast (EC)	1.0000	1.0000	0.1341	n/a	1.0000	0.1341	n/a
Gulf Coast (GC)	1.0000	1.0000	0.1347	n/a	1.0000	0.1347	n/a
Hawaii East (HE)	1.0000	1.0000	0.1311	n/a	1.0000	0.1311	n/a
Hawaii West (HW)	1.0000	1.0000	n/a	0.2246	1.0000	n/a	0.2246
North Pacific (NP)	1.0000	1.0000	0.1332	n/a	1.0000	0.1332	n/a
South Pacific (SP)	1.0000	1.0000	0.1345	n/a	1.0000	0.1341	n/a
Great Lakes (GL)	1.0000	1.0000	0.1320	n/a	1.0000	0.1320	n/a
Out of Region[b]	1.0000	1.0000	n/a	0.2198	1.0000	n/a	0.2200

Notes:
[a] PM_{10} adjustment factors are a ratio of future base or control EFs to 2002 EFs. These regional adjustment factors are used to adjust the interport portion of the 2002 inventory.
[b] Out of Region refers to areas outside 200nm, but within the air quality modeling domain. The out of region adjustment factors are derived by weighting the regional adjustment factors by the main propulsion power in each region. ECA control is only assumed within 200nm.

Table 3-86 $PM_{2.5}$ EF Adjustment Factors by Region and Control Type[a]

U.S. Region	2002	2020			2030		
		Base	ECA Control	Global Control	Base	ECA Control	Global Control
Alaska East (AE)	1.0000	1.0000	0.1233	n/a	1.0000	0.1233	n/a
Alaska West (AW)	1.0000	1.0000	n/a	0.2252	1.0000	n/a	0.2252
East Coast (EC)	1.0000	1.0000	0.1329	n/a	1.0000	0.1329	n/a
Gulf Coast (GC)	1.0000	1.0000	0.1334	n/a	1.0000	0.1334	n/a
Hawaii East (HE)	1.0000	1.0000	0.1299	n/a	1.0000	0.1299	n/a
Hawaii West (HW)	1.0000	1.0000	n/a	0.2225	1.0000	n/a	0.2225
North Pacific (NP)	1.0000	1.0000	0.1320	n/a	1.0000	0.1320	n/a
South Pacific (SP)	1.0000	1.0000	0.1332	n/a	1.0000	0.1329	n/a
Great Lakes (GL)	1.0000	1.0000	0.1307	n/a	1.0000	0.1307	n/a
Out of Region[b]	1.0000	1.0000	n/a	0.2177	1.0000	n/a	0.2180

Notes:
[a] $PM_{2.5}$ adjustment factors are a ratio of future base or control EFs to 2002 EFs. These regional adjustment factors are used to adjust the interport portion of the 2002 inventory.
[b] Out of Region refers to areas outside 200nm, but within the air quality modeling domain. The out of region adjustment factors are derived by weighting the regional adjustment factors by the main propulsion power in each region. ECA control is only assumed within 200nm.

Table 3-87 SO_2 EF Adjustment Factors by Region and Control Type[a]

U.S. Region	2002	2020			2030		
		Base	ECA Control	Global Control	Base	ECA Control	Global Control
Alaska East (AE)	1.0000	1.0000	0.0380	n/a	1.0000	0.0380	n/a
Alaska West (AW)	1.0000	1.0000	n/a	0.1814	1.0000	n/a	0.1814
East Coast (EC)	1.0000	1.0000	0.0352	n/a	1.0000	0.0352	n/a
Gulf Coast (GC)	1.0000	1.0000	0.0352	n/a	1.0000	0.0352	n/a
Hawaii East (HE)	1.0000	1.0000	0.0381	n/a	1.0000	0.0381	n/a
Hawaii West (HW)	1.0000	1.0000	n/a	0.1893	1.0000	n/a	0.1893
North Pacific (NP)	1.0000	1.0000	0.0380	n/a	1.0000	0.0380	n/a
South Pacific (SP)	1.0000	1.0000	0.0380	n/a	1.0000	0.0380	n/a
Great Lakes (GL)	1.0000	1.0000	0.0352	n/a	1.0000	0.0352	n/a
Out of Region[b]	1.0000	1.0000	n/a	0.1811	1.0000	n/a	0.1821

Notes:
[a] SO_2 adjustment factors are a ratio of future base or control EFs to 2002 EFs. These regional adjustment factors are used to adjust the interport portion of the 2002 inventory.
[b] Out of Region refers to areas outside the 200nm, but within the air quality modeling domain. The out of region adjustment factors are derived by weighting the regional adjustment factors by the main propulsion power in each region. ECA control is only assumed within 200nm.

Table 3-88 CO_2 EF Adjustment Factors by Region and Control Type[a]

U.S. Region	2002	2020			2030		
		Base	ECA Control	Global Control	Base	ECA Control	Global Control
Alaska East (AE)	1.0000	1.0000	0.9509	n/a	1.0000	0.9509	n/a
Alaska West (AW)	1.0000	1.0000	n/a	0.9509	1.0000	n/a	0.9509
East Coast (EC)	1.0000	1.0000	0.9499	n/a	1.0000	0.9499	n/a
Gulf Coast (GC)	1.0000	1.0000	0.9494	n/a	1.0000	0.9494	n/a
Hawaii East (HE)	1.0000	1.0000	0.9519	n/a	1.0000	0.9519	n/a
Hawaii West (HW)	1.0000	1.0000	n/a	0.9519	1.0000	n/a	0.9519
North Pacific (NP)	1.0000	1.0000	0.9493	n/a	1.0000	0.9493	n/a
South Pacific (SP)	1.0000	1.0000	0.9501	n/a	1.0000	0.9507	n/a
Great Lakes (GL)	1.0000	1.0000	0.9510	n/a	1.0000	0.9510	n/a
Out of Region[b]	1.0000	1.0000	n/a	0.9499	1.0000	n/a	0.9502

Notes:
[a] CO_2 adjustment factors are a ratio of future base or control EFs to 2002 EFs. These regional adjustment factors are used to adjust the interport portion of the 2002 inventory.
[b] Out of Region refers to areas outside 200nm, but within the air quality modeling domain. The out of region adjustment factors are derived by weighting the regional adjustment factors by the main propulsion power in each region. ECA control is only assumed within 200nm.

3.4.4.3 Estimating and Combining the Near Port and Interport Inventories

To produce future year control scenarios, the interport inventories were scaled by a growth factor to 2020 and 2030, as previously described. An ECA boundary line was drawn so that each point on it was at a 200 nm distance from the nearest point on land. Adjustment factors, as described in Section 3.4.3.1, were then applied to interport emissions within the ECA boundary.

To create control scenarios in the near port inventories, growth and control factors were applied to the 2002 near port inventories (described in Sections 3.4.2 and 3.4.3.1). The near port inventories were then converted into a gridded format (Section 3.3.3.3). Using this grid, STEEM values were removed from near port cells and near port emissions were used as replacement values. In cases where the emissions near ports were only partially attributable to port traffic, the STEEM inventory was reduced rather than removed.

Interport and near port emissions were then aggregated to form regional totals.

3.4.5 2020 and 2030 Baseline Inventories

The resulting 2020 and 2030 estimated emission inventories by region and the nation are shown in Table 3-89 and Table 3-90. These baseline inventories account for growth as well as implementation of the Tier 1 NO_X standard. Estimated fuel consumption for the baseline inventories by region and fuel type is given in Table 3-91.

Table 3-89 2020 Baseline Emissions Inventory

U.S. Region	Metric Tonnes per Year						
	NO_X	PM_{10}	$PM_{2.5}$[a]	HC	CO	SO_2	CO_2
Alaska East (AE)	29,242	2,561	2,356	1,073	2,534	19,084	1,182,047
Alaska West (AW)	93,685	8,118	7,469	3,444	8,112	60,227	3,711,596
East Coast (EC)	439,604	39,003	35,882	16,216	38,382	323,038	18,121,202
Gulf Coast (GC)	259,295	23,403	21,531	9,590	23,628	174,751	10,567,512
Hawaii East (HE)	48,026	4,185	3,850	1,765	4,161	31,075	1,930,172
Hawaii West (HW)	67,573	5,888	5,417	2,483	5,855	43,722	2,715,741
North Pacific (NP)	42,644	3,916	3,603	1,706	3,799	27,807	1,800,743
South Pacific (SP)	234,968	20,148	18,536	8,585	20,686	149,751	9,490,502
Great Lakes (GL)	19,842	1,613	1,484	681.914	1,607	11,993	740,624
Total U.S. Metric Tonnes	1,234,879	108,835	100,128	45,544	108,762	841,447	50,260,140
Total U.S. Short Tons[b]	*1,361,221*	*119,970*	*110,372*	*50,204*	*119,890*	*927,537*	*55,402,321*

Notes:
[a] Estimated from PM_{10} using a multiplicative conversion factor of 0.92.
[b] Converted from metric tonnes using a multiplicative conversion factor of 1.102 short tons per metric tonne.

Table 3-90 2030 Baseline Emissions Inventory

U.S. Region	Metric Tonnes per Year						
	NO_X	PM_{10}	$PM_{2.5}$[a]	HC	CO	SO_2	CO_2
Alaska East (AE)	42,930	3,544	3,260	1,485	3,505	26,404	1,635,479
Alaska West (AW)	137,951	11,232	10,333	4,765	11,223	83,329	5,135,278
East Coast (EC)	679,271	60,615	55,766	25,207	59,678	502,305	28,163,780
Gulf Coast (GC)	341,903	31,142	28,651	12,761	31,427	232,547	14,062,207
Hawaii East (HE)	78,806	6,818	6,273	2,875	6,780	50,630	3,144,932
Hawaii West (HW)	110,880	9,593	8,825	4,045	9,539	71,237	4,424,900
North Pacific (NP)	58,937	5,433	4,999	2,372	5,278	38,556	2,497,078
South Pacific (SP)	394,335	34,948	32,152	14,635	35,208	259,982	16,470,350
Great Lakes (GL)	22,471	1,910	1,757	807	1,902	14,196	876,636
Total U.S. Metric Tonnes	1,867,484	165,235	152,016	68,951	164,539	1,279,185	76,410,639
Total U.S. Short Tons[b]	*2,058,549*	*182,140*	*167,569*	*76,006*	*181,373*	*1,410,061*	*84,228,311*

Notes:
[a] Estimated from PM_{10} using a multiplicative conversion factor of 0.92.
[b] Converted from metric tonnes using a multiplicative conversion factor of 1.102 short tons per metric tonne.

Table 3-91 Fuel Consumption by Category 3 Vessels in Baseline Scenarios

U.S. Region	Metric Tonnes Fuel					
	2020 Baseline			2030 Baseline		
	Distillate	Residual	Total	Distillate	Residual	Total
Alaska East (AE)	3,386	367,977	371,363	4,685	509,132	513,817
Alaska West (AW)	0	1,166,068	1,166,068	0	1,613,345	1,613,345
East Coast (EC)	202,139	5,490,981	5,693,120	313,916	8,534,271	8,848,187
Gulf Coast (GC)	96,428	3,223,557	3,319,985	128,338	4,289,571	4,417,910
Hawaii East (HE)	10,529	595,871	606,400	17,151	970,889	988,040
Hawaii West (HW)	0	853,202	853,202	0	1,390,166	1,390,166
North Pacific (NP)	28,532	537,206	565,738	39,476	745,028	784,505
South Pacific (SP)	83,576	2,898,045	2,981,622	157,878	5,016,595	5,174,474
Great Lakes (GL)	1,269	231,412	232,681	2,037	273,375	275,412
Total U.S. Metric Tonnes	425,860	15,364,319	15,790,179	663,482	23,342,374	24,005,856
Total U.S. Short Tons	*469,431*	*16,936,262*	*17,405,693*	*731,364*	*25,730,563*	*26,461,926*

3.4.6 2020 and 2030 Control Inventories

For the control scenario, the inventories for each of the nine geographic regions, the U.S. total, and the 48-state total are presented in Table 3-92 and Table 3-93. The regional and total inventories include all emissions within 200nm of shore. For the purposes of this analysis, ECA controls are assumed to apply to all regions, except Alaska West and Hawaii West. For the Alaska West and Hawaii West regions, global controls apply. Estimated fuel consumption for the control inventories by region and fuel type is given in Table 3-94.

Table 3-92 Category 3 Vessel Inventories for 2020 Control Case[a]

U.S. Region	Metric Tonnes per Year						
	NO_X	PM_{10}	$PM_{2.5}$[a]	HC	CO	SO_2	CO_2
Alaska East (AE)	25,978	322	296	1,072	2,534	728	1,124,652
Alaska West (AW)	90,787	1,851	1,703	3,444	8,112	10,927	3,529,505
East Coast (EC)	289,671	5,286	4,863	16,231	38,421	11,514	17,233,800
Gulf Coast (GC)	170,861	3,201	2,945	9,581	23,615	6,255	10,034,946
Hawaii East (HE)	32,952	551	507	1,764	4,162	1,187	1,838,832
Hawaii West (HW)	57,406	1,323	1,217	2,483	5,855	8,277	2,585,222
North Pacific (NP)	29,105	539	496	1,709	3,803	1,076	1,715,210
South Pacific (SP)	150,461	2,753	2,533	8,546	20,585	5,786	9,009,986
Great Lakes (GL)	16,420	207	190	676	1,602	420	704,390
Total U.S. Metric Tonnes	863,642	16,032	14,750	45,507	108,688	46,168	47,776,542
Total U.S. Short Tons[b]	*952,002*	*17,673*	*16,259*	*50,163*	*119,808*	*50,892*	*52,664,623*

Note:
[a] This scenario assumes ECA controls apply within 200 nautical miles of all U.S. regions except Alaska West and Hawaii West, with global controls applied in all other areas. Corrected boundaries are used.

Table 3-93 Category 3 Vessel Inventories for 2030 Control Case[a]

U.S. Region	Metric Tonnes per Year						
	NO_X	PM_{10}	$PM_{2.5}$[a]	HC	CO	SO_2	CO_2
Alaska East (AE)	30,722	445	410	1,485	3,505	1,008	1,556,045
Alaska West (AW)	123,187	2,677	2,463	4,765	11,223	15,847	4,883,341
East Coast (EC)	235,378	8,221	7,563	25,207	59,678	17,896	26,763,558
Gulf Coast (GC)	118,930	4,261	3,920	12,761	31,426	8,325	13,355,741
Hawaii East (HE)	31,992	899	827	2,875	6,780	1,933	2,995,263
Hawaii West (HW)	88,502	2,175	2,001	4,045	9,539	13,596	4,214,197
North Pacific (NP)	22,758	751	691	2,372	5,278	1,494	2,378,683
South Pacific (SP)	128,302	4,769	4,388	14,635	35,202	10,030	15,713,679
Great Lakes (GL)	16,369	253	233	807	1,902	501	833,733
Total U.S. Metric Tonnes	796,140	24,451	22,495	68,951	164,539	70,630	72,694,239
Total U.S. Short Tons[b]	*877,594*	*26,953*	*24,797*	*76,006*	*181,373*	*77,856*	*80,131,682*

Note:
[a] This scenario assumes ECA controls apply within 200 nautical miles of all U.S. regions, except Alaska West and Hawaii West, with global controls elsewhere. Corrected boundaries are used.

Table 3-94 Fuel Consumption by Category 3 Vessels in Control Scenarios

U.S. Region	Metric Tonnes Fuel					
	2020 Control			2030 Control		
	Distillate	Residual	Total	Distillate	Residual	Total
Alaska East (AE)	353,331	0	353,331	488,861	0	488,861
Alaska West (AW)	1,108,861	0	1,108,861	1,534,194	0	1,534,194
East Coast (EC)	5,414,326	0	5,414,326	8,408,281	0	8,408,281
Gulf Coast (GC)	3,152,669	0	3,152,669	4,195,960	0	4,195,960
Hawaii East (HE)	577,704	0	577,704	941,019	0	941,019
Hawaii West (HW)	812,197	0	812,197	1,323,970	0	1,323,970
North Pacific (NP)	538,866	0	538,866	747,309	0	747,309
South Pacific (SP)	2,830,658	0	2,830,658	4,936,751	0	4,936,751
Great Lakes (GL)	221,297	0	221,297	261,933	0	261,933
Total U.S. Metric Tonnes	15,009,910	0	15,009,910	22,838,278	0	22,838,278
Total U.S. Short Tons	*16,545,593*	*0*	*16,545,593*	*25,174,892*	*0*	*25,174,892*

3.5 Estimated Category 3 Inventory Contribution

This section describes the contribution of Category 3 marine engines to national and selected local emission inventories in 2002, 2020, and 2030. The pollutants analyzed are NO_X, directly emitted $PM_{2.5}$, and SO_2. All weight units in the following tables are short tons.

3.5.1 Baseline Contribution of C3 Vessels to National Level Inventory

Category 3 marine engines contribute to the formation of ground level ozone and concentrations of fine particles in the ambient atmosphere. Based on our current emission inventory analysis, we estimate that these engines contributed nearly 6 percent of mobile source NO_X, over 10 percent of mobile source $PM_{2.5}$, and about 40 percent of mobile source SO_2 in 2002. We estimate that their contribution will increase to about 40 percent of mobile source NO_X, 48 percent of mobile source $PM_{2.5}$, and 95 percent of mobile source SO_2 by 2030 without further controls on these engines. Our current estimates for NO_X, $PM_{2.5}$, and SO_2 inventories are set out in the following tables. Inventory projections for 2020 and 2030 include the effect of existing emission mobile source and stationary source control programs previously adopted by EPA.

Table 3-95 50 State Annual NO_X Baseline Emission Levels for Mobile and Other Source Categories

Category	2002			2020			2030		
	short tons	% of mobile source	% of total	short tons	% of mobile source	% of total	short tons	% of mobile source	% of total
Commercial Marine (C3)	738,700	5.8	3.5	1,361,221	24.4	12.0	2,058,549	39.8	18.8
Locomotive	1,118,786	8.8	5.2	669,405	12.0	5.9	437,245	8.4	4.0
Recreational Marine Diesel	40,437	0.3	0.2	43,579	0.8	0.4	43,665	0.8	0.4
Commercial Marine (C1 & C2)	834,025	6.6	3.9	499,798	8.9	4.4	308,614	6.0	2.8
Land-Based Nonroad Diesel	1,555,812	12.2	7.3	683,481	12.2	6.0	435,774	8.4	4.0
Small Nonroad SI	119,833	0.9	0.6	80,901	1.4	0.7	91,913	1.8	0.8
Recreational Marine SI	49,902	0.4	0.2	87,709	1.6	0.8	73,961	1.4	0.7
SI Recreational Vehicles	10,614	0.1	0.0	30,108	0.5	0.3	34,318	0.7	0.3
Large Nonroad SI (>25hp)	336,292	2.6	1.6	48,270	0.9	0.4	47,766	0.9	0.4
Aircraft	103,591	0.8	0.5	132,278	2.4	1.2	143,986	2.8	1.3
Total Off Highway	4,907,990	38.6	23.0	3,636,750	65.1	32.0	3,675,790	71.0	33.6
Highway Diesel	3,529,046	27.7	16.5	681,142	12.2	6.0	355,817	6.9	3.2
Highway non-diesel	4,293,733	33.7	20.1	1,270,269	22.7	11.2	1,144,199	22.1	10.4
Total Highway	7,822,779	61.4	36.7	1,951,411	34.9	17.2	1,500,016	29.0	13.7
Total Mobile Sources	12,730,769	100.0	59.6	5,588,160	100.0	49.2	5,175,806	100.0	47.3
Stationary Point & Area Sources	8,613,718	-	40.4	5,773,927	-	50.8	5,773,927	-	52.7
Total Man-Made Sources	21,344,488	-	100	11,362,088	-	100	10,949,734	-	100

Table 3-96 50 State Annual $PM_{2.5}$ Baseline Emission Levels for Mobile and Other Source Categories

Category	2002			2020			2030		
	short tons	% of diesel mobile	% of total	short tons	% of diesel mobile	% of total	short tons	% of diesel mobile	% of total
Commercial Marine (C3)	54,112	14.7	1.5	110,372	52.9	3.3	167,569	74.8	4.9
Locomotive	29,660	8.1	0.8	15,145	7.3	0.4	8,584	3.8	0.3
Recreational Marine Diesel	1,096	0.3	0.0	973	0.5	0.0	1,053	0.5	0.0
Commercial Marine (C1 & C2)	28,730	7.8	0.8	15,787	7.6	0.5	10,017	4.5	0.3
Land-Based Nonroad Diesel	159,111	43.3	4.5	46,056	22.1	1.4	17,902	8.0	0.5
Small Nonroad SI	25,700		0.7	31,981		0.9	36,795		1.1
Recreational Marine SI	16,262		0.5	2,845		0.1	1,225		0.0
SI Recreational Vehicles	13,710		0.4	11,901		0.4	10,090		0.3
Large Nonroad SI (>25hp)	1,652		0.0	2,421		0.1	2,844		0.1
Aircraft	17,979		0.5	22,176		0.7	24,058		0.7
Total Off Highway	348,013		9.9	259,656		7.7	280,136		8.2
Highway Diesel	94,982	25.8	2.7	20,145	9.7	0.6	18,802	8.4	0.6
Highway non-diesel	51,694		1.5	45,329		1.3	51,621		1.5
Total Highway	146,676		4.2	65,474		1.9	70,423		2.1
Total Mobile Sources	494,690		14.1	325,131		9.6	350,559		10.3
Stationary Point & Area Sources	3,025,244		85.9	3,047,714		90.4	3,047,714		89.7
Total Man-Made Sources	3,519,933		100	3,372,845		100	3,398,274		100

Table 3-97 50 State Annual SO_2 Baseline Emission Levels for Mobile and Other Source Categories

Category	2002			2020			2030		
	short tons	% of mobile source	% of total	short tons	% of mobile source	% of total	short tons	% of mobile source	% of total
Commercial Marine (C3)	453,614	43.2	3.0	927,537	93.3	10.5	1,410,061	94.9	15.1
Locomotive	75,385	7.2	0.5	396	0.0	0.0	464	0.0	0.0
Recreational Marine Diesel	5,145	0.5	0.0	162	0.0	0.0	192	0.0	0.0
Commercial Marine (C1 & C2)	80,353	7.6	0.5	2,961	0.3	0.0	3,002	0.2	0.0
Land-Based Nonroad Diesel	172,304	16.4	1.2	999	0.1	0.0	1,079	0.1	0.0
Small Nonroad SI	6,742	0.6	0.0	8,870	0.9	0.1	10,282	0.7	0.1
Recreational Marine SI	2,755	0.3	0.0	2,995	0.3	0.0	3,184	0.2	0.0
SI Recreational Vehicles	1,530	0.1	0.0	2,862	0.3	0.0	3,019	0.2	0.0
Large Nonroad SI (>25hp)	933	0.1	0.0	905	0.1	0.0	1,020	0.1	0.0
Aircraft	8,701	0.8	0.1	11,171	1.1	0.1	12,197	0.8	0.1
Total Off Highway	807,463	76.9	5.4	958,857	96.5	10.8	1,444,498	97.2	15.4
Highway Diesel	71,147	6.8	0.5	4,218	0.4	0.0	5,478	0.4	0.1
Highway non-diesel	171,866	16.4	1.1	30,922	3.1	0.3	36,011	2.4	0.4
Total Highway	243,013	23.1	1.6	35,140	3.5	0.4	41,489	2.8	0.4
Total Mobile Sources	1,050,475	100.0	7.0	993,998	100.0	11.2	1,485,986	100.0	15.9
Stationary Point & Area Sources	13,897,968	-	93.0	7,864,681	-	88.8	7,864,681	-	84.1
Total Man-Made Sources	14,948,443	-	100	8,858,678	-	100	9,350,667	-	100

3.5.2 Contribution to Mobile Source Inventories for Selected Cities

Commercial marine vessels, powered by Category 3 marine engines, contribute significantly to the emissions inventory for many U.S. ports. This is illustrated in Table 3-98, which presents the mobile source inventory contributions of these vessels for several ports. The ports in this table were selected to present a sampling over a wide geographic area along the U.S. coasts. In 2005, these twenty ports received approximately 60 percent of the vessel calls to the U.S. from ships of 10,000 dead weight tons (DWT) or greater.[54]

Table 3-98 Contribution of Commercial Marine Vessels to Mobile Source Inventories for Selected Ports in 2002[a]

Port Area	% of total NO_X	% of total $PM_{2.5}$	% of total SO_2
Valdez, AK	4	10	43
Seattle, WA	10	20	56
Tacoma, WA	20	38	74
San Francisco, CA	1	1	31
Oakland, CA	8	14	80
LA/Long Beach, CA	5	10	71
Beaumont, TX	6	20	55
Galveston, TX	5	12	47
Houston, TX	3	10	41
New Orleans, LA	14	24	59
South Louisiana, LA	12	24	58
Miami, FL	13	25	66
Port Everglades, FL	9	20	56
Jacksonville, FL	5	11	52
Savannah, GA	24	39	80
Charleston, SC	22	33	87
Wilmington, NC	7	16	73
Baltimore, MD	12	27	69
New York/New Jersey	4	9	39
Boston, MA	4	5	30

Note:
[a] This category includes emissions from Category 3 (C3) propulsion engines and C2/3 auxiliary engines used on ocean-going vessels.

Currently, more than 40 major U.S. deep sea ports are located in areas that are designated as being in nonattainment for either or both the 8-hour ozone NAAQS and $PM_{2.5}$ NAAQS. Many ports are located in areas rated as class I federal areas for visibility impairment and regional haze. It should be noted that emissions from ocean-going vessels are not simply a localized problem related only to cities that have commercial ports. Virtually all U.S. coastal areas are affected by emissions from ships that transit between those ports, using shipping lanes that are close to land. Many of these coastal areas also have high population densities. For example, Santa Barbara, which has no commercial port, estimates that engines on ocean-going marine vessels currently contribute about 37 percent of total NO_X in their area.[55] These emissions are from ships that transit the area, and "are comparable to (even slightly larger than) the amount of NO_X produced onshore by cars and truck." By 2015 these emissions are expected to increase 67 percent, contributing 61 percent of Santa Barbara's total NO_X emissions. This mix of emission sources led Santa Barbara to point out that they will be unable to meet air quality standards for ozone without significant emission reductions from these vessels, even if they completely eliminate all other sources of pollution. Interport emissions from OGV also contribute to other environmental problems, affecting sensitive marine and land ecosystems.

3.6 Projected Emission Reductions

The projected tons reductions for each of the 2020 control cases relative to the 2020 baseline, as well as the tons reductions for the 2030 control case relative to the 2030 baseline, are presented in Table 3-99 thru Table 3-100. Reductions by region, for the total U.S., and for the total 48-states, are provided by pollutant in each table.

Table 3-99 Reductions for 2020 Control Case[a]

U.S. Region	Metric Tonnes per Year						
	NO_X	**PM_{10}**	**$PM_{2.5}$[a]**	**HC**	**CO**	**SO_2**	**CO_2**
Alaska East (AE)	3,264	2,239	2,060	0	0	18,356	57,395
Alaska West (AW)	2,897	6,267	5,766	0	0	49,300	182,091
East Coast (EC)	149,933	33,717	31,020	0	0	311,523	887,402
Gulf Coast (GC)	88,434	20,202	18,586	0	0	168,496	532,567
Hawaii East (HE)	15,074	3,634	3,343	0	0	29,888	91,340
Hawaii West (HW)	10,166	4,565	4,200	0	0	35,445	130,519
North Pacific (NP)	13,539	3,377	3,107	0	0	26,731	85,533
South Pacific (SP)	84,507	17,395	16,003	0	0	143,965	480,516
Great Lakes (GL)	3,422	1,406	1,294	0	0	11,574	36,235
Total U.S. Metric Tonnes	371,237	92,803	85,378	0	0	795,279	2,483,598
Total U.S. Short Tons	*409,219*	*102,297*	*94,114*	*0*	*0*	*876,645*	*2,737,698*

Note:
[a] The emission reductions are relative to the 2020 baseline.

Table 3-100 Reductions for 2030 Control Case[a]

U.S. Region	Metric Tonnes per Year						
	NO_X	PM_{10}	$PM_{2.5}$[a]	HC	CO	SO2	CO2
Alaska East (AE)	12,208	3,099	2,851	0	0	25,397	79,434
Alaska West (AW)	14,764	8,555	7,870	0	0	67,482	251,937
East Coast (EC)	443,893	52,394	48,203	0	0	484,409	1,400,222
Gulf Coast (GC)	222,973	26,881	24,731	0	0	224,221	706,466
Hawaii East (HE)	46,814	5,919	5,446	0	0	48,698	149,669
Hawaii West (HW)	22,377	7,417	6,824	0	0	57,641	210,703
North Pacific (NP)	36,179	4,683	4,308	0	0	37,062	118,395
South Pacific (SP)	266,033	30,179	27,764	0	6	249,952	756,671
Great Lakes (GL)	6,102	1,657	1,524	0	0	13,694	42,904
Total U.S. Metric Tonnes	1,071,344	140,783	129,521	0	0	1,208,555	3,716,400
Total U.S. Short Tons	1,180,955	155,187	142,772	0	0	1,332,204	4,096,630

Note:
[a] The emission reductions are relative to the 2030 baseline.

3.7 Inventories Used for Air Quality Modeling

The emission inventories for 2020 presented in this chapter are slightly different from the emissions inventories used in the air quality modeling presented in Chapter 2. Specifically, the 2020 inventories used in the air quality modeling reflect a slightly different boundary for the proposed ECA that was based on a measurement error. Due to the nature of the measurement error, the corrections to the ECA boundaries are not uniform, but are different by coastal area. The measurement error affects only those portions that are farthest from shore. The 2030 inventories are not affected by this error.

A comparison of the air quality and final inventories by region for the 2020 baseline scenario is provided in Table 3-101. Results are provided only for NO_X, $PM_{2.5}$, and SO_2, since the air quality modeling is focused on ozone and $PM_{2.5}$. In addition, Alaska and Hawaii are not included, since the air quality modeling domain does not include these states. As seen in Table 3-101, the changes due to the boundary error are not expected to have a significant impact on the results of our analysis.

Table 3-101 Comparison of Air Quality versus Final Inventories for 2020 Baseline Case

	Metric Tonnes per Year								
	NO_X			$PM_{2.5}$			SO_2		
U.S. Region	**AQ**	**Final**	**% Diff**	**AQ**	**Final**	**% Diff**	**AQ**	**Final**	**% Diff**
East Coast (EC)	439,713	439,604	0%	35,891	35,882	0%	323,108	323,038	0%
Gulf Coast (GC)	261,024	259,295	1%	21,669	21,531	1%	175,862	174,751	1%
North Pacific (NP)	42,291	42,644	-1%	3,575	3,603	-1%	27,580	27,807	-1%
South Pacific (SP)	216,849	234,968	-8%	17,092	18,536	-8%	138,102	149,751	-8%
Great Lakes (GL)	19,842	19,842	0%	1,484	1,484	0%	11,993	11,993	0%
Total 48-State	**979,719**	**996,353**	**-2%**	**79,711**	**81,036**	**-2%**	**676,645**	**687,340**	**-2%**

The 2020 control inventories are also subject to the boundary error. In addition, the 2020 air quality control case does not include global controls for areas that are beyond 200 nm but within the air quality modeling domain. The impact of this latter difference is expected to be minimal.

The modeling for 2030 was based on inventories that reflected an ECA distance closer to shore than what we are proposing. The air quality modeling, and related estimates of benefits, therefore reflect the impacts associated with approximately 80% of the emission reductions achieved by the proposed coordinated strategy. As a result, the 2030 air quality impacts and health benefits presented in Chapters 2 and 6, respectively, should be considered conservative estimates of the improvements in air quality associated with the proposal. For the final RIA, we plan to model the 2030 coordinated strategy to control ship emissions with a 200 nm boundary and global controls beyond.

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APPENDIX 3A

Port Coordinates and Reduced Speed Zone Information

Table 3-102 Port Coordinates

Port Name	US ACE Code	Port Coordinates	
		Longitude	Latitude
Albany, NY	C0505	-73.7482	42.64271
Alpena, MI	L3617	-83.4223	45.0556
Anacortes, WA	C4730	-122.6	48.49617
Anchorage, AK	C4820	-149.895	61.23778
Ashtabula, OH	L3219	-80.7917	41.91873
Baltimore, MD	C0700	-76.5171	39.20899
Barbers Point, Oahu, HI	C4458	-158.109	21.29723
Baton Rouge, LA	C2252	-91.1993	30.42292
Beaumont, TX	C2395	-94.0881	30.08716
Boston, MA	C0149	-71.0523	42.35094
Bridgeport, CT	C0311	-73.1789	41.172
Brownsville, TX	C2420	-97.3981	25.9522
Brunswick, GA	C0780	-81.4999	31.15856
Buffalo, NY	L3230	-78.8953	42.8783
Burns Waterway Harbor, IN	L3739	-87.1552	41.64325
Calcite, MI	L3620	-83.7756	45.39293
Camden-Gloucester, NJ	C0551	-75.1043	39.94305
Carquinez, CA	CCA01	-122.123	38.03556
Catalina, CA	CCA02	-118.496	33.43943
Charleston, SC	C0773	-79.9216	32.78878
Chester, PA	C0297	-75.3222	39.85423
Chicago, IL	L3749	-87.638	41.88662
Cleveland, OH	L3217	-81.6719	41.47852
Conneaut, OH	L3220	-80.5486	41.96671
Coos Bay, OR	C4660	-124.21	43.36351
Corpus Christi, TX	C2423	-97.3979	27.81277
Detroit, MI	L3321	-83.1096	42.26909
Duluth-Superior, MN and WI	L3924	-92.0964	46.77836
El Segundo, CA	CCA03	-118.425	33.91354
Erie, PA	L3221	-80.0679	42.15154
Escanaba, MI	L3795	-87.025	45.73351
Eureka, CA	CCA04	-124.186	40.79528
Everett, WA	C4725	-122.229	47.98476
Fairport Harbor, OH	L3218	-81.2941	41.76666
Fall River, MA	C0189	-71.1588	41.72166
Freeport, TX	C2408	-95.3304	28.9384
Galveston, TX	C2417	-94.8127	29.31049
Gary, IN	L3736	-87.3251	41.61202
Georgetown, SC	C0772	-79.2896	33.36682
Grays Harbor, WA	C4702	-124.122	46.91167
Gulfport, MS	C2083	-89.0853	30.35216
Hilo, HI	C4400	-155.076	19.72861
Honolulu, HI	C4420	-157.872	21.31111
Hopewell, VA	C0738	-77.2763	37.32231

Port Name	US ACE Code	Port Coordinates	
		Longitude	Latitude
Houston, TX	C2012	-95.2677	29.72538
Indiana Harbor, IN	L3738	-87.4455	41.67586
Jacksonville, FL	C2017	-81.6201	30.34804
Kahului, Maui, HI	C4410	-156.473	20.89861
Kalama, WA	C4626	-122.863	46.02048
Lake Charles, LA	C2254	-93.2221	30.22358
Long Beach, CA	C4110	-118.21	33.73957
Longview, WA	C4622	-122.914	46.14222
Lorain, OH	L3216	-82.1951	41.48248
Los Angeles, CA	C4120	-118.241	33.77728
Manistee, MI	L3720	-86.3443	44.25082
Marblehead, OH	L3212	-82.7091	41.52962
Marcus Hook, PA	C5251	-75.4042	39.81544
Matagorda Ship Channel, TX	C2410	-96.5641	28.5954
Miami, FL	C2164	-80.1832	25.78354
Milwaukee, WI	L3756	-87.8997	42.98824
Mobile, AL	C2005	-88.0411	30.72527
Morehead City, NC	C0764	-76.6947	34.71669
Muskegon, MI	L3725	-86.3501	43.19492
Nawiliwili, Kauai, HI	C4430	-159.353	21.96111
New Bedford, MA	C0187	-70.9162	41.63641
New Castle, DE	C0299	-75.5616	39.65668
New Haven, CT	C1507	-72.9047	41.29883
New Orleans, LA	C2251	-90.0853	29.91414
New York, NY and NJ	C0398	-74.0384	40.67395
Newport News, VA	C0736	-76.4582	36.98522
Nikishka, AK	C4831	-151.314	60.74793
Oakland, CA	C4345	-122.308	37.82152
Olympia, WA	C4718	-122.909	47.06827
Other Puget Sound, WA	C4754	-122.72	48.84099
Palm Beach, FL	C2162	-80.0527	26.76904
Panama City, FL	C2016	-84.1993	30.19009
Pascagoula, MS	C2004	-88.5588	30.34802
Paulsboro, NJ	C5252	-75.2266	39.82689
Penn Manor, PA	C0298	-74.7408	40.13598
Pensacola, FL	C2007	-87.2579	30.40785
Philadelphia, PA	C0552	-75.2022	39.91882
Plaquemines, LA, Port of	C2255	-89.6875	29.48
Port Angeles, WA	C4708	-123.453	48.1305
Port Arthur, TX	C2416	-93.9607	29.83142
Port Canaveral, FL	C2160	-80.6082	28.41409
Port Dolomite, MI	L3627	-84.3128	45.99139
Port Everglades, FL	C2163	-80.1178	26.09339
Port Hueneme, CA	C4150	-119.208	34.14824
Port Inland, MI	L3803	-85.8628	45.95508

Port Name	US ACE Code	Port Coordinates	
		Longitude	Latitude
Port Manatee, FL	C2023	-82.5613	27.63376
Portland, ME	C0128	-70.2513	43.64951
Portland, OR	C4644	-122.665	45.47881
Presque Isle, MI	L3845	-87.3852	46.57737
Providence, RI	C0191	-71.3984	41.81178
Redwood City, CA	CCA05	-122.21	37.51306
Richmond, CA	C4350	-122.374	37.92424
Richmond, VA	C0737	-77.4194	37.45701
Sacramento, CA	CCA06	-121.544	38.56167
San Diego, CA	C4100	-117.178	32.70821
San Francisco, CA	C4335	-122.399	37.80667
Sandusky, OH	L3213	-82.7123	41.47022
Savannah, GA	C0776	-81.0954	32.08471
Searsport, ME	C0112	-68.925	44.45285
Seattle, WA	C4722	-122.359	47.58771
South Louisiana, LA, Port of	C2253	-90.6179	30.03345
St. Clair, MI	L3509	-82.4941	42.82663
Stockton, CA	C4270	-121.316	37.9527
Stoneport, MI	L3619	-83.4703	45.28073
Tacoma, WA	C4720	-122.452	47.28966
Tampa, FL	C2021	-82.5224	27.78534
Texas City, TX	C2404	-94.9181	29.36307
Toledo, OH	L3204	-83.5075	41.66294
Two Harbors, MN	L3926	-91.6626	47.00428
Valdez, AK	C4816	-146.346	61.12473
Vancouver, WA	C4636	-122.681	45.62244
Wilmington, DE	C0554	-75.507	39.71589
Wilmington, NC	C0766	-77.954	34.23928

Table 3-103 Port RSZ Information

Port Name	RSZ Speed (knts)	RSZ distance (naut mi)	Final RSZ End Point(s)	
			Longitude	Latitude
Albany, NY	c	142.5	-73.8929	40.47993
Alpena, MI	e	3	-83.2037	44.99298
Anacortes, WA	a	108.3	-124.771	48.49074
Anchorage, AK	14.5	143.6	-152.309	59.5608
Ashtabula, OH	e	3	-80.8097	42.08549
Baltimore, MD	c	157.1	-75.8067	36.8468
Barbers Point, Oahu, HI	10	5.1	-158.132	21.21756
			-89.4248	28.91161
Baton Rouge, LA	10	219.8	-89.137	28.98883
Beaumont, TX	7	53.5	-93.7552	29.55417
Boston, MA	10	14.3	-70.7832	42.37881
Bridgeport, CT	10	2	-73.1863	41.13906
Brownsville, TX	8.8	18.7	-97.0921	26.06129
			-80.9345	31.29955
Brunswick, GA	13	38.8	-81.1357	30.68935
Buffalo, NY	e	3	-79.0996	42.81683
Burns Waterway Harbor, IN	e	3	-87.1032	41.80625
Calcite, MI	e	3	-83.5383	45.39496
Camden-Gloucester, NJ	c	94	-75.0095	38.79004
Carquinez, CA	12	39	-122.632	37.76094
Catalina, CA	12	11.9	-118.465	33.63641
Charleston, SC	12	17.3	-79.6452	32.62557
Chester, PA	c	78.2	-75.0095	38.79004
Chicago, IL	e	3	-87.4141	41.86971
Cleveland, OH	e	3	-81.765	41.63079
Conneaut, OH	e	3	-80.5639	42.13361
Coos Bay, OR	6.5	13	-124.359	43.35977
Corpus Christi, TX	d	30.1	-96.8753	27.74433
Detroit, MI	e	3	-83.1384	42.10308
Duluth-Superior, MN and WI	e	3	-91.8536	46.78916
			-118.926	33.91252
El Segundo, CA	12	23.3	-118.465	33.63641
Erie, PA	e	3	-80.115	42.3151
Escanaba, MI	e	3	-86.9224	45.58297
Eureka, CA	12	9	-124.347	40.75925
Everett, WA	a	123.3	-124.771	48.49074
Fairport Harbor, OH	e	3	-81.3917	41.91401
Fall River, MA	9	22.7	-71.3334	41.41708
Freeport, TX	c	2.6	-95.2949	28.93323
Galveston, TX	c	9.3	-94.6611	29.3247
Gary, IN	e	3	-87.2824	41.77658
Georgetown, SC	12	17.6	-79.0779	33.1924

Port Name	RSZ Speed (knts)	RSZ distance (naut mi)	Final RSZ End Point(s) Longitude	Latitude
Grays Harbor, WA	a	4.9	-124.24	46.89509
Gulfport, MS	10	17.4	-88.9263	30.11401
Hilo, HI	10	7.1	-154.985	19.76978
			-157.956	21.17658
Honolulu, HI	10	10	-157.785	21.23827
Hopewell, VA	10	91.8	-75.8067	36.8468
Houston, TX	c	49.6	-94.6611	29.3247
Indiana Harbor, IN	e	3	-87.4007	41.8401
Jacksonville, FL	10	18.6	-81.3649	30.39769
Kahului, Maui, HI	10	7.5	-156.44	21.01066
Kalama, WA	b	68.2	-124.137	46.22011
Lake Charles, LA	6	38	-93.3389	29.73094
			-118.465	33.63641
Long Beach, CA	12	18.1	-118.13	33.45211
Longview, WA	b	67.3	-124.137	46.22011
Lorain, OH	e	3	-82.2701	41.64023
			-118.465	33.63641
Los Angeles, CA	12	20.6	-118.13	33.45211
Manistee, MI	e	3	-86.3819	44.41573
Marblehead, OH	e	3	-82.7293	41.69638
Marcus Hook, PA	c	94.7	-75.0095	38.79004
Matagorda Ship Channel, TX	7.3	24	-96.2287	28.33472
Miami, FL	12	3.8	-80.1201	25.75787
Milwaukee, WI	e	3	-87.6718	42.97343
Mobile, AL	11	36.1	-88.0644	30.1457
Morehead City, NC	10	2.2	-76.6679	34.68999
Muskegon, MI	e	3	-86.5377	43.29151
Nawiliwili, Kauai, HI	10	7.3	-159.266	21.87705
New Bedford, MA	9	22.4	-71.1013	41.38499
New Castle, DE	c	60.5	-75.0095	38.79004
New Haven, CT	10	2.1	-72.9121	41.26588
			-89.4248	28.91161
New Orleans, LA	10	104.2	-89.137	28.98883
New York, NY and NJ	c	15.7	-73.8929	40.47993
Newport News, VA	14	24.3	-75.8067	36.8468
Nikishka, AK	14.5	90.7	-152.309	59.5608
Oakland, CA	12	18.4	-122.632	37.76094
Olympia, WA	a	185.9	-124.771	48.49074
Other Puget Sound, WA	a	106	-124.771	48.49074
Palm Beach, FL	3	3.1	-79.9973	26.77129
Panama City, FL	10	10	-84.1797	30.0818
Pascagoula, MS	10	17.5	-88.4804	30.09597
Paulsboro, NJ	c	83.5	-75.0095	38.79004
Penn Manor, PA	c	114.5	-75.0095	38.79004
Pensacola, FL	12	12.7	-87.298	30.27777

Port Name	RSZ Speed (knts)	RSZ distance (naut mi)	Final RSZ End Point(s)	
			Longitude	Latitude
Philadelphia, PA	c	88.1	-75.0095	38.79004
Plaquemines, LA, Port of	10	52.4	-89.4248	28.91161
			-89.137	28.98883
Port Angeles, WA	a	65	-124.771	48.49074
Port Arthur, TX	7	21	-93.7552	29.55417
Port Canaveral, FL	10	4.4	-80.5328	28.41439
Port Dolomite, MI	e	3	-84.2445	45.83181
Port Everglades, FL	7.5	2.1	-80.082	26.08627
Port Hueneme, CA	12	2.8	-119.238	34.10859
Port Inland, MI	e	3	-85.6524	45.87553
Port Manatee, FL	9	27.4	-83.0364	27.59078
Portland, ME	10	11.4	-70.1077	43.54224
Portland, OR	b	105.1	-124.137	46.22011
Presque Isle, MI	e	3	-87.082	46.5804
Providence, RI	9	24.9	-71.3334	41.41708
Redwood City, CA	12	36	-122.632	37.76094
Richmond, CA	12	22.6	-122.632	37.76094
Richmond, VA	10	106.4	-75.8067	36.8468
Sacramento, CA	12	90.5	-122.632	37.76094
San Diego, CA	12	11.7	-117.315	32.62184
San Francisco, CA	12	14.4	-122.632	37.76094
Sandusky, OH	e	3	-82.5251	41.56193
Savannah, GA	13	45.5	-78.0498	33.83598
Searsport, ME	9	22.2	-68.7645	44.1179
Seattle, WA	a	133.3	-124.771	48.49074
South Louisiana, LA, Port of	10	142.8	-89.4248	28.91161
			-89.137	28.98883
St. Clair, MI	e	3	-82.5838	42.55923
Stockton, CA	12	86.9	-122.632	37.76094
Stoneport, MI	e	3	-83.2355	45.25919
Tacoma, WA	a	150.5	-124.771	48.49074
Tampa, FL	9	30	-83.0364	27.59078
Texas City, TX	c	15.1	-94.6611	29.3247
Toledo, OH	e	3	-83.3034	41.7323
Two Harbors, MN	e	3	-91.4414	46.93391
Valdez, AK	10	27.2	-146.881	60.86513
Vancouver, WA	b	95.7	-124.137	46.22011
Wilmington, DE	c	65.3	-75.0095	38.79004
Wilmington, NC	10	27.6	-80.325	31.84669

[a] Cruise speed through Strait of Juan de Fuca, then varies by ship type for remaining journey
[b] Inbound on Columbia River at 6.5 knots, outbound at 12 knots
[c] Speed varies by ship type similar to typical like port
[d] Speed varies by ship DWTs
[e] All Great Lake ports have reduced speed zone distances of 3 nautical miles with speeds halfway between service speed and maneuvering speed.

APPENDIX 3B

Inventory Impacts of Alternative Program

The proposed program represents a comprehensive approach to reduce emissions from Category 3 marine diesel engines. As we developed this proposal, we evaluated an alternative, which considers the possibility of pulling ahead the CAA Tier 3 NO_X standard from 2016 to 2014. NO_X emissions were calculated for the year 2023 under three scenarios: Tier 1 only NO_X standards (the base case), the coordinated strategy as proposed in NPRM which includes the 2016 NO_X standards in effect 2016 (the primary case), and NO_X standards for U.S.-vessels only pulled ahead to 2014 (the alternative case). This appendix describes the methodology that was used to estimate the NO_X inventories for the proposed and alternative program scenarios in 2023.

The inventories described in this chapter are for calendar years 2002, 2020, and 2030. To calculate inventories for 2023, a spreadsheet model was developed and used. For both the proposed and alternative scenarios, it was assumed that the proposed ECA controls apply within 200 nautical miles for all 48 contiguous states. The only difference modeled was the different start dates for Tier 3. Note that only emissions from U.S. vessels are impacted by the proposed alternative.

Under the proposed base scenario, 48-state NO_X emissions in 2023 are 10,494,636 short tons. With the coordinated strategy in effect (the primary case), 48-state NO_X emissions in 2023 are 7,515,389 short tons, a 28.4 % reduction from Tier 1 only standards. Under the alternative scenario, 48-state NO_X emissions in 2023 are 7,444,866 short tons, a difference of 0.9 percent from the primary case (Figure 3B-1).

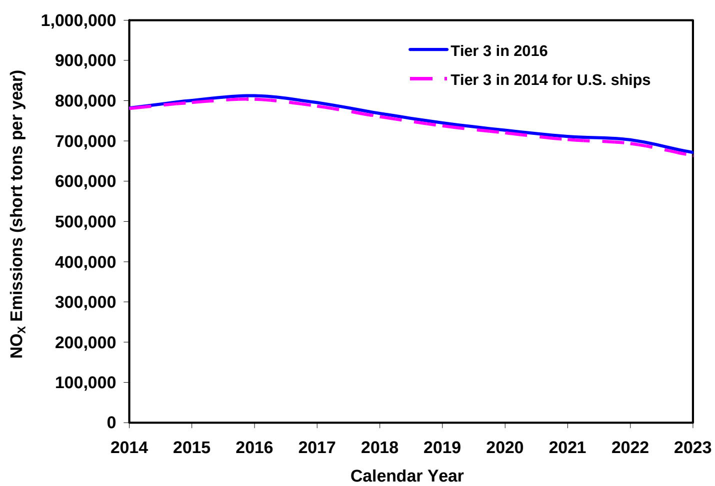

Figure 3B-1 NO_X Emissions with the Primary Case (Tier 3 in 2016) versus the Alternative Case (Tier 3 in 2014 for U.S. vessels only)

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