SECTION 2 OCEAN-GOING VESSELS

This section presents emissions estimates for the OGV source category, including source description (2.1), geographical domain (2.2), data and information acquisition (2.3), operational profiles (2.4), emissions estimation methodology (2.5), and the emission estimates (2.6).

2.1 Source Description

Based on activity data obtained from the Marine Exchange of Southern California (MarEx), there were a total of 1,921 vessel calls (arrivals not including shifts) to the Port in 2013. The OGVs calling the port can be broadly divided into two groups: containerships, the predominant ship category for the Port, and non-containerships. These vessels are primarily used by shipping lines to transport retail goods and other containerized cargo in twenty- and forty-plus foot containers. The twenty-foot equivalent unit (TEU) is a standard unit for describing a container ship’s cargo-carrying capacity, and is based on the size of a twenty-foot shipping container. For example, a 2,000-TEU vessel can accommodate 2,000 20-foot containers or an equivalent combination of 20-foot containers and the more common 40-foot containers.

- Auto carrier
- Bulk carrier
- Containership
- Cruise vessel
- General cargo
- Ocean-going tugboat (ITB/ATB)
- Miscellaneous vessel
- Roll-on roll-off vessel (RoRo)
- Tanker
**Auto Carriers**
Auto carriers transport vehicles. They have drivable ramps and can have substantial ventilation systems to prevent vehicle fuel vapors from pooling in the lower decks.

**Bulk Carriers**
Bulk carriers have open holds with giant hatches to carry dry goods in bulk such as coal, petroleum coke, salt, sugar, cement, gypsum, and other similar fine-grained commodities.

**Containerships**
Containerships carry 20- and 40-foot containers on their decks and in their holds, and are primarily used by shipping lines to transport retail goods. Containerships are divided into subtypes based on their TEU capacity.

**Cruise Vessels**
Cruise vessels carry passengers for pleasure voyages. These vessels have significant auxiliary engine demands to provide hotel amenities such as heating, air conditioning and electricity for thousands of passengers.

**General Cargo Vessels**
General cargo vessels carry diverse cargos such as steel, palletized goods, large heavy-duty machinery, and other heavy loads. Containers can also be carried on the vessel’s top deck.
**Ocean-going Tugboats**
Commonly known as integrated tug barges (ITB) and articulated tug barges (ATB), the barge stern of the vessel is notched to accept a special tug which can be rigidly connected to the barge forming a single vessel. ITBs and ATBs are included in the ocean-going vessel inventory.

**Refrigerated Vessels**
Often called Reefers, these vessels are able to keep perishable cargo such as fruits, vegetables, and meats cool. Most of the cargo is stored below deck on pallets or transported inside refrigerated containers that are placed on top of the closed cargo hold.

**Roll-on roll-off Vessels**
RoRos, as they are typically known, are similar to automobile carriers, but can accommodate larger wheeled equipment, such as construction equipment.

**Tanker Vessels**
Tanker vessels transport liquids in bulk such as oil, chemicals, and specialty products such as tallow and molasses. Crude oil tankers are categorized into different categories depending on their dimensions.
Table 2.1 compares the total TEUs and vessel calls at the port in 2005 and 2013. In addition to TEU comparisons, this table compares the total number of calls by all OGV types, the total number of containership calls and the average container density, expressed as TEUs per containership call. There was relatively no change in TEU throughput when comparing 2013 and 2005. However, the total number of vessel calls at the port decreased 29% compared to 2005, which may be due to the larger vessels calling the port in 2013.

<table>
<thead>
<tr>
<th>Year</th>
<th>Container Throughput TEUs</th>
<th>All Arrivals</th>
<th>Containership Arrivals</th>
<th>Average TEUs/Call</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>6,709,818</td>
<td>2,690</td>
<td>1,332</td>
<td>5,037</td>
</tr>
<tr>
<td>2013</td>
<td>6,730,574</td>
<td>1,921</td>
<td>911</td>
<td>7,388</td>
</tr>
<tr>
<td>Change (%)</td>
<td>0.3%</td>
<td>-29%</td>
<td>-32%</td>
<td>47%</td>
</tr>
</tbody>
</table>

Figure 2.1 shows the percentage of calls by vessel type in 2013

**Figure 2.1: 2013 Distribution of Calls by Vessel Type**

Appendix B includes information about the vessels that called at the port, including vessel flags of convenience, vessel characteristics, and a summary of vessels classified as frequent callers to the port.
2.2 Shipping Routes

The geographical domain of the 2013 emissions inventory for commercial marine vessels is the same overwater boundary as in previous EIs. The CARB OGV Fuel Regulation’s expanded boundary is shown in Figure 2.2 along with the boundary of the study area and the major shipping routes. The 24-nautical-miles (nm) boundary in the original regulation was expanded to beyond the offshore islands (CARB Fuel Switch Boundary in the figure) in late 2011\(^8\).

Figure 2.2: Major Shipping Routes

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Table 2.2 presents distribution of arrivals and departures by route from 2008 through 2013.

### Table 2.2: 2008 - 2013 Distribution of Arrivals and Departures by Route

<table>
<thead>
<tr>
<th>Route</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northern</td>
<td>55%</td>
<td>38%</td>
<td>11%</td>
<td>9%</td>
<td>26%</td>
<td>29%</td>
</tr>
<tr>
<td>Western</td>
<td>9%</td>
<td>22%</td>
<td>51%</td>
<td>54%</td>
<td>34%</td>
<td>35%</td>
</tr>
<tr>
<td>Southern</td>
<td>35%</td>
<td>39%</td>
<td>37%</td>
<td>36%</td>
<td>40%</td>
<td>36%</td>
</tr>
<tr>
<td>Eastern</td>
<td>1%</td>
<td>1%</td>
<td>1%</td>
<td>1%</td>
<td>0.4%</td>
<td>0.4%</td>
</tr>
</tbody>
</table>

2.3 Data and Information Acquisition

Each source of data and information is detailed in the following subsections. Various sources of data and operational knowledge about the Port’s marine activities are used to compile the data necessary to estimate emissions from OGV:

- Marine Exchange of Southern California
- Vessel Speed Reduction Program speed data
- Jacobsen Pilot Service
- IHS Fairplay (Lloyd’s) - Lloyd’s Register of Ships
- Port Vessel Boarding Program data
- Terminal shore power data
- Port tanker loading data

2.3.1 Marine Exchange of Southern California

The Marine Exchange of Southern California (MarEx) operates the Vessel Traffic Service (VTS) in cooperation with the U.S. Coast Guard (USCG), the ports of Long Beach and Los Angeles, and the State of California. The VTS was established in 1994 to provide traffic safety, traffic monitoring and security functions for the ports of Long Beach and Los Angeles, and is the first private/public VTS partnership in the country that is funded by industry. MarEx tracks ship routes using radar and Automated Identification System (AIS) receivers and also requires ships to report their activities to the VTS upon arrival and departure.

The MarEx data evaluated in developing emission estimates includes vessel names, arrival and departure dates and times, transit speeds and directions, berth of destination, and route designation. Data from the MarEx provides the primary basis for establishing:

- Distribution of arrival and departure travel directions by route
- Number of ship calls
- Names of vessels and International Maritime Organization (IMO) number
- Vessel origination and destination
- Vessel speeds
- Determination of hotelling time
Vessel arrivals include inbound trips from the sea to a berth and inbound trips from the sea to an anchorage. An inbound trip from the sea to an anchorage is assigned to the port if the next port of call after the anchorage is a berth at the Port. A call is made up of an arrival to, shifts (if applicable), time at-berth, time at anchorage (if applicable), and a departure from the emissions inventory domain.

### 2.3.2 Vessel Speed Reduction Program Data

MarEx monitors OGV speeds in the four shipping routes as part of the Vessel Speed Reduction (VSR) program that began in May 2001. Vessel speed information is recorded for each shipping route at a series of waypoints, located on arcs emanating from Point Fermin. The vessel speeds are measured in 5 nm increments, from the Precautionary Zone to the 40 nm waypoint. The measurement of vessel speeds from the 25 nm to 40 nm waypoints began in April 2008; previously, only speeds up to the 20 nm waypoint were measured. Vessel speeds in the Precautionary Zone are not provided by MarEx (see section 2.5.3 for assigned Precautionary Zone speeds by vessel type); however, USCG regulation limits vessel speeds within the Precautionary Zone to 12 knots.

### 2.3.3 Jacobsen Pilot Service

The Jacobsen Pilot Service maintains an automated database that documents the times when the pilot boards the ship and when the pilot disembarks the ship. These dates and times have been used to estimate transit time profiles for harbor maneuvering from berth to the breakwater for the following movements:

- Inbound from sea
- Outbound to sea
- Anchorage shifts
- Other shifts including inter-port and intra-port shifts

Shifts are vessel movements within a port; please refer to section 2.4 for further explanation. Average in-harbor maneuvering times were used for each movement, ship type and terminal based on average trip times.

### 2.3.4 IHS Maritime- Lloyd's Register of Ships

The information source commonly known as HIS Maritime's "Lloyd's Register" (or Lloyd’s data) is considered to be the leading resource for ship characteristics such as build year, tonnage, rated speed and propulsion engine power, engine power plant configuration, age, and other parameters. The International Maritime Organization (IMO) and vessel classification societies do not require reporting of vessel auxiliary power characteristics therefore Lloyd’s Register is generally incomplete for this information.

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The Lloyd’s data used in this report were obtained from IHS Fairplay in January 2013. To establish the characteristics of each vessel that called the port in 2013, the vessel information from Lloyd’s is matched against the vessels reported by MarEx data that called the port in 2013. There was only one miscellaneous type vessel, that called the port in 2013 that did not match based on IMO number between the Lloyd’s and the MarEx data sets. For these vessels, the average propulsion engine power and speed of similar types of vessel have been used as defaults for specific data; these averages are provided in Appendix B. The auxiliary engine and boiler defaults are obtained from a separate data source and further detailed in sections 2.3.5, 2.3.7, 2.5.9 and 2.5.10.

2.3.5 Vessel Boarding Program Survey Data

The best sources to obtain local activity data and ship parameters are the shipping lines that own and/or operate the vessels. The Port’s Vessel Boarding Program (VBP) provides for an in-depth survey of OGVs during which Starcrest consultants board individual ships and interview the ship’s executive and engineering staff, which usually includes the captain and chief engineer. Data collected from individual vessels includes:

- Main engine power
- Auxiliary engine power
- Auxiliary engine load
- Boiler fuel consumption
- Vessels that switched fuels
- Emission reduction technologies such as slide valves

For this inventory, information gathered from previous years’ vessel boardings, along with new boarding data, has been used.

2.3.6 Vessel Shore Power Data

In 2013, several vessels calling at the Port used shore-side electrical power instead of running their diesel-powered auxiliary engines while at-berth. Terminal operators provided the number of vessel calls and corresponding berths that utilized shore power for hotelling operations. In 2013, shore power was used for 81 cruise vessel calls, 125 container vessel calls, and 16 liquid bulk vessel calls, representing about 11% of total vessel calls at the port.

2.3.7 Tanker Loading Data

Beginning in 2013, tanker activity data was collected to determine if a tanker was loading or discharging liquid bulk during time at berth. The mode of operation for a tanker at berth determines the auxiliary boiler engine load. The auxiliary boiler load demand is less during tanker loading operations than it is during discharging. Prior to this data being available in 2013, the default tanker auxiliary boiler load assumed that all tankers were discharging while at berth. In 2013, about 10% of the tanker calls used lower auxiliary boiler load.
2.4 Operational Profiles

Vessel activity is evaluated as the number of trips by trip type (e.g. arrival, departure, and shift) and trip segment. Trip segments are used for the portion of trip at-sea between the transit routes and the Precautionary Zone, within the Precautionary Zone, and within the breakwater. The following vessel operational modes are used to define the characteristics of a ship’s operation within the emission inventory domain:

**Transit**
Ship is operating in open water, also identified as “at sea mode”.

**Maneuvering**
Ship enters the breakwater. Additional power is typically brought online since the ship is traveling in restricted waters. Maneuvering time is based on the type of ship, associated speed, and distance traveled between the berth and the breakwater.

**At-Berth**
Ship is stationary at the dock/berth; typically during loading and unloading of cargo. Ship is typically still active, operating auxiliary engines and boilers, however not operating its propulsion engines.

**Anchorage**
Ship is anchored inside or just outside the breakwater waiting for reassignment, an open berth, or requires maintenance. Ship is typically still active, operating auxiliary engines and boilers, however not operating its propulsion engines.

**Shift**
Ship movement other than an arrival or departure. Ship moves from one berth to another berth within the Port or from the Port of Los Angeles, or from/to an anchorage. A ship can have zero to several shifts per call. There are 3 broad categories of shift movements:
- *Intra-port shifts*: within a port from one berth to another.
- *Inter-port shifts*: between adjacent ports. Common occurrence in co-located ports such as Long Beach and Los Angeles.
- *Anchorage shifts*: between a terminal and an anchorage. For example, a vessel receives a partial load, goes to anchorage, and then returns to the terminal (or to another terminal) to complete loading.
Table 2.3 presents the numbers of arrivals, departures, and shifts associated with vessels at the Port in 2013. The containerships are classified by TEU size. For example, a Container-2000 is a containership with a container capacity of 2,000 to 2,999 TEU and a Container-1000 is a containership with a container capacity up to 1,999 TEU. Arrivals and departures may not match because the OGV activity is based on a calendar year.

Table 2.3: 2013 Total OGV Movements

<table>
<thead>
<tr>
<th>Vessel Type</th>
<th>Arrival</th>
<th>Departure</th>
<th>Shift</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Auto Carrier</td>
<td>159</td>
<td>160</td>
<td>13</td>
<td>332</td>
</tr>
<tr>
<td>Bulk</td>
<td>202</td>
<td>210</td>
<td>225</td>
<td>637</td>
</tr>
<tr>
<td>Bulk - Heavy Load</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Bulk - Self Discharging</td>
<td>7</td>
<td>7</td>
<td>0</td>
<td>14</td>
</tr>
<tr>
<td>Container - 1000</td>
<td>82</td>
<td>82</td>
<td>7</td>
<td>171</td>
</tr>
<tr>
<td>Container - 2000</td>
<td>54</td>
<td>53</td>
<td>5</td>
<td>112</td>
</tr>
<tr>
<td>Container - 3000</td>
<td>60</td>
<td>61</td>
<td>1</td>
<td>122</td>
</tr>
<tr>
<td>Container - 4000</td>
<td>215</td>
<td>215</td>
<td>5</td>
<td>435</td>
</tr>
<tr>
<td>Container - 5000</td>
<td>169</td>
<td>171</td>
<td>8</td>
<td>348</td>
</tr>
<tr>
<td>Container - 6000</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Container - 7000</td>
<td>14</td>
<td>14</td>
<td>0</td>
<td>28</td>
</tr>
<tr>
<td>Container - 8000</td>
<td>177</td>
<td>178</td>
<td>3</td>
<td>358</td>
</tr>
<tr>
<td>Container - 9000</td>
<td>65</td>
<td>65</td>
<td>0</td>
<td>130</td>
</tr>
<tr>
<td>Container - 10000</td>
<td>17</td>
<td>17</td>
<td>0</td>
<td>34</td>
</tr>
<tr>
<td>Container - 11000</td>
<td>35</td>
<td>35</td>
<td>1</td>
<td>71</td>
</tr>
<tr>
<td>Container - 12000</td>
<td>7</td>
<td>7</td>
<td>0</td>
<td>14</td>
</tr>
<tr>
<td>Container - 13000</td>
<td>12</td>
<td>11</td>
<td>1</td>
<td>24</td>
</tr>
<tr>
<td>Container - 14000</td>
<td>3</td>
<td>3</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>Cruise</td>
<td>124</td>
<td>125</td>
<td>1</td>
<td>250</td>
</tr>
<tr>
<td>General Cargo</td>
<td>70</td>
<td>74</td>
<td>63</td>
<td>207</td>
</tr>
<tr>
<td>Ocean Tugs</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>9</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>RoRo</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Tanker - Aframax</td>
<td>97</td>
<td>100</td>
<td>187</td>
<td>384</td>
</tr>
<tr>
<td>Tanker - Chemical</td>
<td>146</td>
<td>142</td>
<td>206</td>
<td>494</td>
</tr>
<tr>
<td>Tanker - Handysize</td>
<td>6</td>
<td>6</td>
<td>7</td>
<td>19</td>
</tr>
<tr>
<td>Tanker - Panamax</td>
<td>79</td>
<td>86</td>
<td>151</td>
<td>316</td>
</tr>
<tr>
<td>Tanker - Suezmax</td>
<td>78</td>
<td>80</td>
<td>139</td>
<td>297</td>
</tr>
<tr>
<td>Tanker - ULCC</td>
<td>28</td>
<td>30</td>
<td>93</td>
<td>151</td>
</tr>
<tr>
<td>Tanker - VLCC</td>
<td>5</td>
<td>5</td>
<td>19</td>
<td>29</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1,921</strong></td>
<td><strong>1,947</strong></td>
<td><strong>1,140</strong></td>
<td><strong>5,008</strong></td>
</tr>
</tbody>
</table>
2.5 Emissions Estimation Methodology

In general, emissions from vessels’ propulsion (or main) engines, auxiliary engines, and auxiliary boilers are estimated as a function of energy demand required to power the vessel by mode multiplied by an emission factor. Emission factor adjustments are then applied to account for the type of fuel used in the engines and control factors are applied to account for any emissions reduction measures and technologies. Based on interviews with vessel operators and the marine industry, incinerators, in general, are not used within the geographical study area (at-berth or near coastal waters). Therefore, their emissions are not estimated in this inventory.

Equations 2.1 and 2.2 are the basic equations used in estimating emissions by mode from OGV for propulsion engines, auxiliary engines, and boilers.

Equation 2.1

\[ E_i = E_{\text{Energy},i} \times EF \times FCF \times CF \]

Where:
- \( E_i \) = Emissions, grams
- \( E_{\text{Energy},i} \) = Energy demand by mode, calculated using Equation 2.2 as the energy output of the engine (or engines) over the period of time, kW-hr
- \( EF \) = Emission factor, g/kW-hr
- \( FCF \) = Fuel correction factor, dimensionless
- \( CF \) = Control factors for emission reduction measures, dimensionless

Energy by mode is calculated using Equation 2.2

Equation 2.2

\[ E_{\text{Energy},i} = Load \times Act \]

Where:
- \( E_{\text{Energy},i} \) = Energy demand by mode, kW-hr
- \( Load \) = maximum continuous rated (MCR) times load factor (LF) for propulsion engine power (kW); reported operational load of the auxiliary engine(s), by mode (kW); or operational load of the auxiliary boiler, by mode (kW)
- \( Act \) = activity, hours in mode

2.5.1 Propulsion Engine Maximum Continuous Rated (MCR) Power

MCR power, reported in kW, is defined as the manufacturers’ rated continuous engine power output. For this study, it is assumed that the ‘Power’ value for each vessel’s propulsion engines listed in Lloyd’s is the MCR power. For diesel-electric configured ships, MCR is the combined rated electric propulsion motor(s) rating.
2.5.2 Propulsion Engine Load Factor

The load factor for propulsion engines is the ratio of actual speed compared to the ship’s maximum rated speed. The load factor is estimated using the Propeller Law, which states that the propulsion engine load varies with the cube of the vessel speed. Therefore, a vessel’s propulsion engine load at a given speed is estimated by taking the cube of that speed divided by the vessel's maximum speed, as shown by the following equation.

\[
LF = \left(\frac{\text{Speed}_{\text{Actual}}}{\text{Speed}_{\text{Maximum}}}\right)^3
\]

Equation 2.3

Where:

- \(LF\) = load factor, dimensionless
- \(\text{Speed}_{\text{Actual}}\) = actual speed, knots
- \(\text{Speed}_{\text{Maximum}}\) = maximum speed, knots

For the purpose of estimating emissions, the load factor has been capped at 1.0 so that there are no calculated propulsion engine load factors greater than 100% (i.e., calculated load factors above 1.0 are assigned a load factor of 1.0).

2.5.3 Propulsion Engine Activity

Engine activity is measured in terms of hours of operation by mode. At-berth and anchorage times are determined from MarEx activity data. Average harbor maneuvering times are developed from data provided by Pilot data. Actual speeds provided by MarEx (discussed in section 2.3.2) are used for estimating vessel transit time beyond the PZ to the geographic boundary. Under the Port’s Green Flag Program, many vessels reduce their speeds to 12 knots within 20 nm and 40 nm of Point Fermin.

Average vessel speeds in the precautionary zone by vessel type are presented in Table 2.4.

<table>
<thead>
<tr>
<th>Vessel Type</th>
<th>Vessel Class</th>
<th>Average Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Auto Carrier</td>
<td>Fast</td>
<td>11.0</td>
</tr>
<tr>
<td>Bulk</td>
<td>Slow</td>
<td>9.0</td>
</tr>
<tr>
<td>Containership</td>
<td>Fast</td>
<td>11.0</td>
</tr>
<tr>
<td>Cruise</td>
<td>Fast</td>
<td>11.0</td>
</tr>
<tr>
<td>General Cargo</td>
<td>Slow</td>
<td>9.0</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>Slow</td>
<td>9.0</td>
</tr>
<tr>
<td>Ocean Tug</td>
<td>Slow</td>
<td>9.0</td>
</tr>
<tr>
<td>Reefer</td>
<td>Slow</td>
<td>9.0</td>
</tr>
<tr>
<td>RoRo</td>
<td>Slow</td>
<td>9.0</td>
</tr>
<tr>
<td>Tanker</td>
<td>Slow</td>
<td>9.0</td>
</tr>
</tbody>
</table>
A vessel’s transit time (activity) in the precautionary zone and along the various routes outside the precautionary zone to the edge of the geographical boundary is estimated using equation 2.4.

\[ \text{Activity} = \frac{D}{\text{Speed}_{\text{Actual}}} \]

Where:
- Activity = activity, hours
- D = distance, nm
- Speed\text{Actual} = actual ship speed, knots

2.5.4 Propulsion Engine Emission Factors

OGV diesel propulsion engines are categorized into the following:

- **Slow speed diesel propulsion engines**: Engines with maximum speeds less than 130 revolutions per minute (rpm)
- **Medium speed diesel propulsion engines**: Engines with maximum speeds over 130 rpm (typically greater than 400 rpm) and less than 2,000 rpm.

Steamship vessels also called the port in 2013; however they represent a small percentage of the total vessel calls at the Port. The propulsion engine emission factors for pollutants evaluated in this EI, except for PM, were obtained from a study by ENTEC UK Limited’s (ENTEC) in 2002.\(^\text{11}\) The PM emission factors for slow- and medium-speed diesel propulsion engines were obtained from CARB.\(^\text{12}\) PM emission factors for gas turbine and steamship vessels are from a 2004 report prepared by the IVL Swedish Environmental Research Institute’s (IVL).\(^\text{13}\) The emission factors assume the use of residual fuel oil/ heavy fuel oil (HFO) which is intermediate fuel oil (IFO 380) or one with similar specifications, with an average sulfur content of 2.7%.

The 2012 emission inventory incorporated ship specific engine data provided on the IMO Engine International Air Pollution Prevention Certificate (EIAPP) for propulsion and auxiliary engines. For ships that provided the Port with EIAPP certificates as part of the Port’s Green Ship Incentive Program\(^\text{14}\) or collected through the VBP, ship specific NO\(_x\) emission factors are used for propulsion and auxiliary engines instead of default factors. This approach was adopted after obtaining consensus with the Technical Working Group (TWG). In 2013, there were a total 66 vessels for which EIAPP certificates were obtained, of which 18 vessels called the port.

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The default emission factors were used for vessels that did not have EIAPP certificates available for vessel specific NO\textsubscript{x} emission factors.

Tables 2.5 and 2.6 list the default emission factors for propulsion engines assuming the use of HFO containing 2.7% sulfur and 0.3% sulfur marine diesel oil (MDO), by propulsion engine IMO tier level.

To produce emission factors based on the use of MDO, the HFO emission factors are multiplied by a fuel correction factor (FCF), of 0.94 representing the NO\textsubscript{x} combustion differences between MDO and HFO.

Table 2.5: Emission Factors for OGV Propulsion Engines using HFO and MDO, g/kW-hr

<table>
<thead>
<tr>
<th>Engine Type</th>
<th>IMO Tier</th>
<th>Model Year</th>
<th>PM\textsubscript{10}</th>
<th>PM\textsubscript{2.5}</th>
<th>DPM</th>
<th>NO\textsubscript{x}</th>
<th>SO\textsubscript{x}</th>
<th>CO</th>
<th>HC</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>HFO 2.7% Sulfur</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slow speed diesel</td>
<td>Tier 0\textsuperscript{15}</td>
<td>≤ 1999</td>
<td>1.5</td>
<td>1.2</td>
<td>1.5</td>
<td>18.1</td>
<td>10.5</td>
<td>1.4</td>
<td>0.6</td>
</tr>
<tr>
<td>Medium speed diesel</td>
<td>Tier 0</td>
<td>≤ 1999</td>
<td>1.5</td>
<td>1.2</td>
<td>1.5</td>
<td>14.0</td>
<td>11.5</td>
<td>1.1</td>
<td>0.5</td>
</tr>
<tr>
<td>Slow speed diesel</td>
<td>Tier 1</td>
<td>2000 – 2010</td>
<td>1.5</td>
<td>1.2</td>
<td>1.5</td>
<td>17.0</td>
<td>10.5</td>
<td>1.4</td>
<td>0.6</td>
</tr>
<tr>
<td>Medium speed diesel</td>
<td>Tier 1</td>
<td>2000 – 2010</td>
<td>1.5</td>
<td>1.2</td>
<td>1.5</td>
<td>13.0</td>
<td>11.5</td>
<td>1.1</td>
<td>0.5</td>
</tr>
<tr>
<td>Slow speed diesel</td>
<td>Tier 2</td>
<td>2011 – 2015</td>
<td>1.5</td>
<td>1.2</td>
<td>1.5</td>
<td>15.3</td>
<td>10.5</td>
<td>1.4</td>
<td>0.6</td>
</tr>
<tr>
<td>Medium speed diesel</td>
<td>Tier 2</td>
<td>2011 – 2015</td>
<td>1.5</td>
<td>1.2</td>
<td>1.5</td>
<td>11.2</td>
<td>11.5</td>
<td>1.1</td>
<td>0.5</td>
</tr>
<tr>
<td>Gas turbine</td>
<td>na</td>
<td>all</td>
<td>0.05</td>
<td>0.04</td>
<td>0</td>
<td>6.1</td>
<td>16.5</td>
<td>0.2</td>
<td>0.1</td>
</tr>
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<td>all</td>
<td>0.80</td>
<td>0.64</td>
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<td>2.1</td>
<td>16.5</td>
<td>0.2</td>
<td>0.1</td>
</tr>
<tr>
<td><strong>MDO/MGO 0.3% S</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slow speed diesel</td>
<td>Tier 0</td>
<td>≤ 1999</td>
<td>0.32</td>
<td>0.29</td>
<td>0.32</td>
<td>17.0</td>
<td>1.2</td>
<td>1.4</td>
<td>0.6</td>
</tr>
<tr>
<td>Medium speed diesel</td>
<td>Tier 0</td>
<td>≤ 1999</td>
<td>0.32</td>
<td>0.29</td>
<td>0.32</td>
<td>13.2</td>
<td>1.3</td>
<td>1.1</td>
<td>0.5</td>
</tr>
<tr>
<td>Slow speed diesel</td>
<td>Tier 1</td>
<td>2000 – 2010</td>
<td>0.32</td>
<td>0.29</td>
<td>0.32</td>
<td>16.0</td>
<td>1.2</td>
<td>1.4</td>
<td>0.6</td>
</tr>
<tr>
<td>Medium speed diesel</td>
<td>Tier 1</td>
<td>2000 – 2010</td>
<td>0.32</td>
<td>0.29</td>
<td>0.32</td>
<td>12.2</td>
<td>1.3</td>
<td>1.1</td>
<td>0.5</td>
</tr>
<tr>
<td>Slow speed diesel</td>
<td>Tier 2</td>
<td>2011 – 2015</td>
<td>0.32</td>
<td>0.29</td>
<td>0.32</td>
<td>14.4</td>
<td>1.2</td>
<td>1.4</td>
<td>0.6</td>
</tr>
<tr>
<td>Medium speed diesel</td>
<td>Tier 2</td>
<td>2011 – 2015</td>
<td>0.32</td>
<td>0.29</td>
<td>0.32</td>
<td>10.5</td>
<td>1.3</td>
<td>1.1</td>
<td>0.5</td>
</tr>
<tr>
<td>Gas turbine</td>
<td>na</td>
<td>all</td>
<td>0.01</td>
<td>0.01</td>
<td>0</td>
<td>5.7</td>
<td>1.8</td>
<td>0.2</td>
<td>0.1</td>
</tr>
<tr>
<td>Steamship</td>
<td>na</td>
<td>all</td>
<td>0.17</td>
<td>0.15</td>
<td>0</td>
<td>2.0</td>
<td>1.8</td>
<td>0.2</td>
<td>0.1</td>
</tr>
</tbody>
</table>

\textsuperscript{15} Tier 0 refers to all ships constructed prior to January 1, 2000, which did not have an IMO Tier requirement at the time of construction.
The emission factors for greenhouse gases CO₂, CH₄ and N₂O were obtained from the 2004 IVL study and are provided in Table 2.6.

Table 2.6: GHG Emission Factors for OGV Propulsion Engines using HFO and MDO, g/kW-hr

<table>
<thead>
<tr>
<th>Engine</th>
<th>IMO Tier</th>
<th>Model Year</th>
<th>CO₂</th>
<th>N₂O</th>
<th>CH₄</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>HFO 2.7% Sulfur</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slow speed diesel</td>
<td>Tier 0</td>
<td>≤ 1999</td>
<td>620</td>
<td>0.031</td>
<td>0.012</td>
</tr>
<tr>
<td>Medium speed diesel</td>
<td>Tier 0</td>
<td>≤ 1999</td>
<td>683</td>
<td>0.031</td>
<td>0.010</td>
</tr>
<tr>
<td>Slow speed diesel</td>
<td>Tier 1</td>
<td>2000 – 2010</td>
<td>620</td>
<td>0.031</td>
<td>0.012</td>
</tr>
<tr>
<td>Medium speed diesel</td>
<td>Tier 1</td>
<td>2000 – 2010</td>
<td>683</td>
<td>0.031</td>
<td>0.010</td>
</tr>
<tr>
<td>Slow speed diesel</td>
<td>Tier 2</td>
<td>2011 – 2015</td>
<td>620</td>
<td>0.031</td>
<td>0.012</td>
</tr>
<tr>
<td>Medium speed diesel</td>
<td>Tier 2</td>
<td>2011 – 2015</td>
<td>683</td>
<td>0.031</td>
<td>0.010</td>
</tr>
<tr>
<td>Gas turbine</td>
<td>na</td>
<td>all</td>
<td>970</td>
<td>0.080</td>
<td>0.002</td>
</tr>
<tr>
<td>Steamship</td>
<td>na</td>
<td>all</td>
<td>970</td>
<td>0.080</td>
<td>0.002</td>
</tr>
<tr>
<td><strong>MDO/MGO 0.3% S</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slow speed diesel</td>
<td>Tier 0</td>
<td>≤ 1999</td>
<td>589</td>
<td>0.029</td>
<td>0.012</td>
</tr>
<tr>
<td>Medium speed diesel</td>
<td>Tier 0</td>
<td>≤ 1999</td>
<td>649</td>
<td>0.029</td>
<td>0.010</td>
</tr>
<tr>
<td>Slow speed diesel</td>
<td>Tier 1</td>
<td>2000 – 2010</td>
<td>589</td>
<td>0.029</td>
<td>0.012</td>
</tr>
<tr>
<td>Medium speed diesel</td>
<td>Tier 1</td>
<td>2000 – 2010</td>
<td>649</td>
<td>0.029</td>
<td>0.010</td>
</tr>
<tr>
<td>Slow speed diesel</td>
<td>Tier 2</td>
<td>2011 – 2015</td>
<td>589</td>
<td>0.029</td>
<td>0.012</td>
</tr>
<tr>
<td>Medium speed diesel</td>
<td>Tier 2</td>
<td>2011 – 2015</td>
<td>649</td>
<td>0.029</td>
<td>0.010</td>
</tr>
<tr>
<td>Gas turbine</td>
<td>na</td>
<td>all</td>
<td>922</td>
<td>0.075</td>
<td>0.002</td>
</tr>
<tr>
<td>Steamship</td>
<td>na</td>
<td>all</td>
<td>922</td>
<td>0.075</td>
<td>0.002</td>
</tr>
</tbody>
</table>

2.5.5 Propulsion Engines Low Load Emission Factors

When vessels travel at slower speeds, such as when traveling in the VSR zone or maneuvering in the harbor, the diesel propulsion engines operate at lower loads, therefore less efficiently. In 2000, Energy and Environmental Analysis, Inc. (EEAI) conducted a study for the EPA to evaluate marine engine testing data from Lloyd’s and the USCG. EEAI derived emissions factors for low engine load conditions using a regression equation that reflects the observation that with decreased vessel speeds and engine loads, mass emissions (i.e., tons) are also decreased, while the emission rates, or factors (i.e., g/kW-hr) increase.

---

To derive the emission factors for low engine loads EEAI used Equation 2.5 below:

$$ y = a(fractional\ load)^{-x} + b $$

Where:

- $y$ = engine low-load emission factors, g/kW-hr
- $a$ = coefficient
- $b$ = intercept
- $x$ = exponent (negative)
- fractional load = propulsion engine load factor (2% - 20%), derived by the Propeller Law, percent (see equation 2.3)

Table 2.7 presents the values for each of the variables in Equation 2.5, by pollutant.

**Table 2.7: Low-Load Engine Emission Factor Regression Equation Variables**

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Exponent (x)</th>
<th>Intercept (b)</th>
<th>Coefficient (a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM</td>
<td>1.5</td>
<td>0.2551</td>
<td>0.0059</td>
</tr>
<tr>
<td>NO$_x$</td>
<td>1.5</td>
<td>10.4946</td>
<td>0.1255</td>
</tr>
<tr>
<td>CO</td>
<td>1.0</td>
<td>0.1458</td>
<td>0.8378</td>
</tr>
<tr>
<td>HC</td>
<td>1.5</td>
<td>0.3859</td>
<td>0.0667</td>
</tr>
</tbody>
</table>
Table 2.8 presents the resulting low-load emission factors for propulsion engines based on Equation 2.5 and the variables in Table 2.7.

Table 2.8: EEAI Emission Factors, g/kW-hr

<table>
<thead>
<tr>
<th>Load</th>
<th>PM</th>
<th>NO_x</th>
<th>CO</th>
<th>HC</th>
</tr>
</thead>
<tbody>
<tr>
<td>2%</td>
<td>2.34</td>
<td>54.82</td>
<td>42.04</td>
<td>23.97</td>
</tr>
<tr>
<td>3%</td>
<td>1.39</td>
<td>34.60</td>
<td>28.07</td>
<td>13.22</td>
</tr>
<tr>
<td>4%</td>
<td>0.99</td>
<td>26.14</td>
<td>21.09</td>
<td>8.72</td>
</tr>
<tr>
<td>5%</td>
<td>0.78</td>
<td>21.67</td>
<td>16.90</td>
<td>6.35</td>
</tr>
<tr>
<td>6%</td>
<td>0.66</td>
<td>18.99</td>
<td>14.11</td>
<td>4.92</td>
</tr>
<tr>
<td>7%</td>
<td>0.57</td>
<td>17.23</td>
<td>12.11</td>
<td>3.99</td>
</tr>
<tr>
<td>8%</td>
<td>0.52</td>
<td>16.00</td>
<td>10.62</td>
<td>3.33</td>
</tr>
<tr>
<td>9%</td>
<td>0.47</td>
<td>15.10</td>
<td>9.45</td>
<td>2.86</td>
</tr>
<tr>
<td>10%</td>
<td>0.44</td>
<td>14.42</td>
<td>8.52</td>
<td>2.50</td>
</tr>
<tr>
<td>11%</td>
<td>0.42</td>
<td>13.89</td>
<td>7.76</td>
<td>2.21</td>
</tr>
<tr>
<td>12%</td>
<td>0.40</td>
<td>13.47</td>
<td>7.13</td>
<td>1.99</td>
</tr>
<tr>
<td>13%</td>
<td>0.38</td>
<td>13.13</td>
<td>6.59</td>
<td>1.81</td>
</tr>
<tr>
<td>14%</td>
<td>0.37</td>
<td>12.85</td>
<td>6.13</td>
<td>1.66</td>
</tr>
<tr>
<td>15%</td>
<td>0.36</td>
<td>12.61</td>
<td>5.73</td>
<td>1.53</td>
</tr>
<tr>
<td>16%</td>
<td>0.35</td>
<td>12.41</td>
<td>5.38</td>
<td>1.43</td>
</tr>
<tr>
<td>17%</td>
<td>0.34</td>
<td>12.24</td>
<td>5.07</td>
<td>1.34</td>
</tr>
<tr>
<td>18%</td>
<td>0.33</td>
<td>12.09</td>
<td>4.80</td>
<td>1.26</td>
</tr>
<tr>
<td>19%</td>
<td>0.33</td>
<td>11.96</td>
<td>4.56</td>
<td>1.19</td>
</tr>
</tbody>
</table>

The propulsion engine low load emission factors shown in Table 2.8 above are based on a set of factors that predate those used for vessel propulsion engines operating in average conditions shown in Table 2.5 (such as at-sea transit, 20% or greater engine load). Therefore, they cannot be used directly to estimate emissions at low load conditions. To estimate propulsion engine emissions in low load conditions, the emission factors shown in Table 2.8 are further adjusted, resulting in adjustment multipliers that are then applied to the emissions factors shown in Tables 2.5 and 2.6. The low load adjustment (LLA) multipliers are determined by dividing each of the EEAI emission factors at loads under 20% by the EEAI emission factor at 20% load as shown in Equation 2.6. At 20% engine load, the adjustment factor is exactly 1.0 since the 20% load emission factor is divided into itself.
\[ \text{LLA (at x \% load)} = \frac{y \text{ (at x \% load)}}{y \text{ (at 20\% load)}} \]

Where:
\[ \text{LLA} = \text{Low load adjustment multiplier} \]
\[ x = \text{engine load factor less than or equal to 20\%} \]
\[ y = \text{emission factor, g/kW-hr (see Table 2.9)} \]

Table 2.9 lists the low-load adjustment multipliers for diesel propulsion engines operating in low load engine conditions. The emission factors for N\(_2\)O and CH\(_4\) were adjusted based on the NO\(_x\) and HC low load adjustments, respectively. The LLA is not applied at engine loads greater than 20\%. For propulsion engine loads below 20\%, the LLA increases, reflecting the increased emission rates due to decreased engine efficiency. Low load emission factors are not applied to steamships or ships that have gas turbines because according to the EEAI study, the increase in emissions rates at low loads was only observed from diesel engines operating at slow speeds.

<table>
<thead>
<tr>
<th>Load</th>
<th>PM</th>
<th>NO(_x)</th>
<th>SO(_x)</th>
<th>CO</th>
<th>HC</th>
<th>CO(_2)</th>
<th>N(_2)O</th>
<th>CH(_4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2%</td>
<td>7.29</td>
<td>4.63</td>
<td>1.00</td>
<td>9.70</td>
<td>21.18</td>
<td>1.00</td>
<td>4.63</td>
<td>21.18</td>
</tr>
<tr>
<td>3%</td>
<td>4.33</td>
<td>2.92</td>
<td>1.00</td>
<td>6.49</td>
<td>11.68</td>
<td>1.00</td>
<td>2.92</td>
<td>11.68</td>
</tr>
<tr>
<td>4%</td>
<td>3.09</td>
<td>2.21</td>
<td>1.00</td>
<td>4.86</td>
<td>7.71</td>
<td>1.00</td>
<td>2.21</td>
<td>7.71</td>
</tr>
<tr>
<td>5%</td>
<td>2.44</td>
<td>1.83</td>
<td>1.00</td>
<td>3.90</td>
<td>5.61</td>
<td>1.00</td>
<td>1.83</td>
<td>5.61</td>
</tr>
<tr>
<td>6%</td>
<td>2.04</td>
<td>1.60</td>
<td>1.00</td>
<td>3.26</td>
<td>4.35</td>
<td>1.00</td>
<td>1.60</td>
<td>4.35</td>
</tr>
<tr>
<td>7%</td>
<td>1.79</td>
<td>1.45</td>
<td>1.00</td>
<td>2.80</td>
<td>3.52</td>
<td>1.00</td>
<td>1.45</td>
<td>3.52</td>
</tr>
<tr>
<td>8%</td>
<td>1.61</td>
<td>1.35</td>
<td>1.00</td>
<td>2.45</td>
<td>2.95</td>
<td>1.00</td>
<td>1.35</td>
<td>2.95</td>
</tr>
<tr>
<td>9%</td>
<td>1.48</td>
<td>1.27</td>
<td>1.00</td>
<td>2.18</td>
<td>2.52</td>
<td>1.00</td>
<td>1.27</td>
<td>2.52</td>
</tr>
<tr>
<td>10%</td>
<td>1.38</td>
<td>1.22</td>
<td>1.00</td>
<td>1.97</td>
<td>2.18</td>
<td>1.00</td>
<td>1.22</td>
<td>2.18</td>
</tr>
<tr>
<td>11%</td>
<td>1.30</td>
<td>1.17</td>
<td>1.00</td>
<td>1.79</td>
<td>1.96</td>
<td>1.00</td>
<td>1.17</td>
<td>1.96</td>
</tr>
<tr>
<td>12%</td>
<td>1.24</td>
<td>1.14</td>
<td>1.00</td>
<td>1.64</td>
<td>1.76</td>
<td>1.00</td>
<td>1.14</td>
<td>1.76</td>
</tr>
<tr>
<td>13%</td>
<td>1.19</td>
<td>1.11</td>
<td>1.00</td>
<td>1.52</td>
<td>1.60</td>
<td>1.00</td>
<td>1.11</td>
<td>1.60</td>
</tr>
<tr>
<td>14%</td>
<td>1.15</td>
<td>1.08</td>
<td>1.00</td>
<td>1.41</td>
<td>1.47</td>
<td>1.00</td>
<td>1.08</td>
<td>1.47</td>
</tr>
<tr>
<td>15%</td>
<td>1.11</td>
<td>1.06</td>
<td>1.00</td>
<td>1.32</td>
<td>1.36</td>
<td>1.00</td>
<td>1.06</td>
<td>1.36</td>
</tr>
<tr>
<td>16%</td>
<td>1.08</td>
<td>1.05</td>
<td>1.00</td>
<td>1.24</td>
<td>1.26</td>
<td>1.00</td>
<td>1.05</td>
<td>1.26</td>
</tr>
<tr>
<td>17%</td>
<td>1.06</td>
<td>1.03</td>
<td>1.00</td>
<td>1.17</td>
<td>1.18</td>
<td>1.00</td>
<td>1.03</td>
<td>1.18</td>
</tr>
<tr>
<td>18%</td>
<td>1.04</td>
<td>1.02</td>
<td>1.00</td>
<td>1.11</td>
<td>1.11</td>
<td>1.00</td>
<td>1.02</td>
<td>1.11</td>
</tr>
<tr>
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<td>1.01</td>
<td>1.00</td>
<td>1.05</td>
<td>1.05</td>
<td>1.00</td>
<td>1.01</td>
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</tr>
<tr>
<td>20%</td>
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<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
</tbody>
</table>
The low load emission factor is calculated for each pollutant using Equation 2.7. In keeping with the port's emission estimating practice of assuming a minimum main engine load of 2%, the table of LLA factors does not include values for 1% load.

\[ EF = \text{Base EF} \times \text{LLA} \]

Where:
- \( EF \) = Resulting low load emission factor
- \( \text{Base EF} \) = Emission factor for slow speed diesel propulsion engines (see Tables 2.6 and 2.7)
- \( \text{LLA} \) = Low load adjustment multiplier (see Table 2.9)

2.5.6 Propulsion Engine Harbor Maneuvering Loads
Propulsion engine loads for vessels operating within a harbor tend to be very low, especially on inbound trips when the propulsion engines are off for periods of time as the vessels are reducing speed and being maneuvered to their berths. During docking, the propulsion engines are typically off as assist tugboats perform most of the work to position the ship against the wharf. Propulsion engine maneuvering loads are estimated using the Propeller Law, with the over-riding assumption that the lowest average engine load is 2%. The low load adjustment multipliers previously discussed are applied to the slow speed diesel propulsion engines.

Harbor transit speeds (in knots) within the breakwater were developed from VBP information and are used to set conservative load factors. Vessel maneuvering time within the breakwater is determined from Pilot data

- **Inbound fast ships** (auto, container, cruise ships) 7 knots
- **Inbound slow ships** (any other vessel type) 5 knots
- **Outbound traffic** (all vessels) 8 knots

2.5.7 Propulsion Engine Power Defaults
Propulsion engine power from the most current Lloyd's data was used, with the exception of 1 vessel which had no propulsion engine power data listed in Lloyd's. A default average by similar vessel type was assumed for this vessel. The propulsion engine averages are found in the characteristics table in Appendix B.
2.5.8 Auxiliary Engine Emission Factors

Vessel specific NOx emission factors were calculated from EIAPP certificates collected from the VBP or through the Port’s Green Ship Incentive Program. For vessels that did not provide EIAPP certificates available, the default emission factors from ENTEC were applied. 17 The ENTEC auxiliary emission factors are presented in Tables 2.10 and 2.11.

Table 2.10: Emission Factors for Auxiliary Engines using HFO and MDO, g/kW-hr

<table>
<thead>
<tr>
<th>Model Year</th>
<th>IMO Tier</th>
<th>PM10</th>
<th>PM2.5</th>
<th>DPM</th>
<th>NOx</th>
<th>SOx</th>
<th>CO18</th>
<th>HC</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>HFO 2.7% Sulfur</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>≤ 1999</td>
<td>Tier 0</td>
<td>1.5</td>
<td>1.2</td>
<td>1.5</td>
<td>14.7</td>
<td>12.3</td>
<td>1.1</td>
<td>0.4</td>
</tr>
<tr>
<td>2000 - 2010</td>
<td>Tier 1</td>
<td>1.5</td>
<td>1.2</td>
<td>1.5</td>
<td>13.0</td>
<td>12.3</td>
<td>1.1</td>
<td>0.4</td>
</tr>
<tr>
<td>2011 - 2015</td>
<td>Tier 2</td>
<td>1.5</td>
<td>1.2</td>
<td>1.5</td>
<td>11.2</td>
<td>12.3</td>
<td>1.1</td>
<td>0.4</td>
</tr>
<tr>
<td><strong>MDO/MGO 0.3% S</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>≤ 1999</td>
<td>Tier 0</td>
<td>0.32</td>
<td>0.29</td>
<td>0.32</td>
<td>13.8</td>
<td>1.4</td>
<td>1.1</td>
<td>0.4</td>
</tr>
<tr>
<td>2000 - 2010</td>
<td>Tier 1</td>
<td>0.32</td>
<td>0.29</td>
<td>0.32</td>
<td>12.2</td>
<td>1.4</td>
<td>1.1</td>
<td>0.4</td>
</tr>
<tr>
<td>2011 - 2015</td>
<td>Tier 2</td>
<td>0.32</td>
<td>0.29</td>
<td>0.32</td>
<td>10.5</td>
<td>1.4</td>
<td>1.1</td>
<td>0.4</td>
</tr>
</tbody>
</table>

Table 2.11: GHG Emission Factors for Auxiliary Engines using HFO and MDO, g/kW-hr

<table>
<thead>
<tr>
<th>Model Year</th>
<th>CO2</th>
<th>N2O</th>
<th>CH4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>HFO 2.7% Sulfur</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>all</td>
<td>722</td>
<td>0.031</td>
<td>0.008</td>
</tr>
<tr>
<td><strong>MDO/MGO 0.3% S</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>all</td>
<td>686</td>
<td>0.029</td>
<td>0.008</td>
</tr>
</tbody>
</table>

2.5.9 Auxiliary Engine Load Defaults

Lloyd’s data contains limited information on vessels’ auxiliary engines because the IMO and vessel classification societies generally do not require reporting of vessel auxiliary power characteristics. For the vessels that called at the port in 2013, installed auxiliary engine power information is present in the Lloyd’s data for only 25% of the discrete vessels and there is no information about loads by mode in the data set. In addition, the Lloyd’s data provided is typically suspect based on corresponding visits under the VBP program, resulting in sometime significant differences to what’s onboard the vessel and what’s in the data set.

18 IVL 2004
The primary data source for auxiliary engine information is gathered from the VBP and sister ships. Sister ships are vessels built as a series and with near-identical characteristics, so it is assumed that the sister ships to a boarded vessel have the same auxiliary engine characteristics as the boarded vessel. The following hierarchy of data sources was established to determine OGV auxiliary engine power loads:

- **VBP ships**: Latest auxiliary engine data for the boarded vessel
- **VBP sister ships**: Latest auxiliary engine data based on the sister ship’s boarded vessel
- **Port Defaults**: Calculated average loads by vessel class for transit, hotelling, and maneuvering

Based on the hierarchy above, if auxiliary engine data were collected as part of the VBP, the most recent information is used. If a sister vessel is identified as part of the VBP survey or based on information from the shipping line, then the latest information collected is used for the sister ship. If a vessel has not been boarded and is not identified as a sister ship to a boarded vessel, or if there are gaps in the VBP data, then defaults by vessel class are used. The sources for auxiliary engine power information by vessel type are provided in Appendix B.

VBP data is used directly for all vessels that have called the Port and their applicable sister vessels. Typically, for those vessels not boarded, default auxiliary engine loads are calculated using the trip-weighted averages for each activity mode derived from the VBP dataset and applicable Lloyd’s data. Table 2.12 summarizes the auxiliary engine load defaults used for the 2013 EI, by vessel subtype and activity mode. For diesel-electric cruise ships, the calculated house load defaults are listed in Table 2.13.
Table 2.12: 2013 Average Auxiliary Engine Load Defaults, kW

<table>
<thead>
<tr>
<th>Vessel Type</th>
<th>Transit</th>
<th>Maneuvering</th>
<th>Berth Hotelling</th>
<th>Anchorage Hotelling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Auto Carrier</td>
<td>1079</td>
<td>2,391</td>
<td>1,284</td>
<td>1079</td>
</tr>
<tr>
<td>Bulk</td>
<td>312</td>
<td>825</td>
<td>208</td>
<td>312</td>
</tr>
<tr>
<td>Bulk - Self Discharging</td>
<td>462</td>
<td>1,223</td>
<td>272</td>
<td>462</td>
</tr>
<tr>
<td>Bulk - Wood Chips</td>
<td>305</td>
<td>807</td>
<td>179</td>
<td>305</td>
</tr>
<tr>
<td>Container - 1000</td>
<td>957</td>
<td>2,245</td>
<td>720</td>
<td>957</td>
</tr>
<tr>
<td>Container - 2000</td>
<td>985</td>
<td>2,188</td>
<td>1,039</td>
<td>985</td>
</tr>
<tr>
<td>Container - 3000</td>
<td>747</td>
<td>2,562</td>
<td>641</td>
<td>747</td>
</tr>
<tr>
<td>Container - 4000</td>
<td>1,403</td>
<td>2,472</td>
<td>1,136</td>
<td>1,403</td>
</tr>
<tr>
<td>Container - 5000</td>
<td>1,316</td>
<td>4,700</td>
<td>1,128</td>
<td>1,316</td>
</tr>
<tr>
<td>Container - 6000</td>
<td>1,162</td>
<td>2,591</td>
<td>804</td>
<td>1,162</td>
</tr>
<tr>
<td>Container - 7000</td>
<td>1,220</td>
<td>2,721</td>
<td>845</td>
<td>1,220</td>
</tr>
<tr>
<td>Container - 8000</td>
<td>1,457</td>
<td>3,249</td>
<td>1,008</td>
<td>1,457</td>
</tr>
<tr>
<td>Container - 9000</td>
<td>1,488</td>
<td>3,320</td>
<td>1,030</td>
<td>1,488</td>
</tr>
<tr>
<td>Container - 10000</td>
<td>1,375</td>
<td>1,675</td>
<td>1,075</td>
<td>1,375</td>
</tr>
<tr>
<td>Container - 11000</td>
<td>2,000</td>
<td>4,000</td>
<td>1,500</td>
<td>2,000</td>
</tr>
<tr>
<td>Container - 12000</td>
<td>2,500</td>
<td>4,500</td>
<td>2,000</td>
<td>2,500</td>
</tr>
<tr>
<td>Container - 13000</td>
<td>2,600</td>
<td>5,200</td>
<td>1,700</td>
<td>2,600</td>
</tr>
<tr>
<td>Container - 14000</td>
<td>3,000</td>
<td>5,500</td>
<td>3,000</td>
<td>3,000</td>
</tr>
<tr>
<td>Cruise</td>
<td>5,445</td>
<td>8,711</td>
<td>5,445</td>
<td>5,445</td>
</tr>
<tr>
<td>General Cargo</td>
<td>423</td>
<td>1,071</td>
<td>575</td>
<td>423</td>
</tr>
<tr>
<td>Ocean Tug</td>
<td>76</td>
<td>202</td>
<td>99</td>
<td>76</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>793</td>
<td>2,100</td>
<td>467</td>
<td>793</td>
</tr>
<tr>
<td>Reefer</td>
<td>630</td>
<td>1,889</td>
<td>1,091</td>
<td>630</td>
</tr>
<tr>
<td>RoRo</td>
<td>132</td>
<td>396</td>
<td>229</td>
<td>132</td>
</tr>
<tr>
<td>Tanker - Chemical</td>
<td>681</td>
<td>937</td>
<td>738</td>
<td>681</td>
</tr>
<tr>
<td>Tanker - Handysize</td>
<td>559</td>
<td>768</td>
<td>605</td>
<td>559</td>
</tr>
<tr>
<td>Tanker - Panamax</td>
<td>630</td>
<td>867</td>
<td>683</td>
<td>630</td>
</tr>
<tr>
<td>Tanker - Aframax</td>
<td>584</td>
<td>803</td>
<td>632</td>
<td>584</td>
</tr>
<tr>
<td>Tanker - Suezmax</td>
<td>718</td>
<td>988</td>
<td>778</td>
<td>718</td>
</tr>
<tr>
<td>Tanker - VLCC</td>
<td>1,080</td>
<td>1,486</td>
<td>1,171</td>
<td>1,080</td>
</tr>
<tr>
<td>Tanker - ULCC</td>
<td>1,080</td>
<td>1,486</td>
<td>1,171</td>
<td>1,080</td>
</tr>
</tbody>
</table>
Table 2.13: 2013 Diesel Electric Cruise Ship Average Auxiliary Engine Load Defaults, kW

<table>
<thead>
<tr>
<th>Passenger Count</th>
<th>Transit</th>
<th>Maneuvering</th>
<th>Berth</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;1,500</td>
<td>3,500</td>
<td>3,500</td>
<td>3,000</td>
</tr>
<tr>
<td>1,500 &lt; 2,000</td>
<td>7,000</td>
<td>7,000</td>
<td>6,500</td>
</tr>
<tr>
<td>2,000 &lt; 2,500</td>
<td>10,500</td>
<td>10,500</td>
<td>9,500</td>
</tr>
<tr>
<td>2,500 &lt; 3,000</td>
<td>11,000</td>
<td>11,000</td>
<td>10,000</td>
</tr>
<tr>
<td>3,000 &lt; 3,500</td>
<td>11,500</td>
<td>11,500</td>
<td>10,500</td>
</tr>
<tr>
<td>3,500 &lt; 4,000</td>
<td>12,000</td>
<td>12,000</td>
<td>11,000</td>
</tr>
<tr>
<td>4,000+</td>
<td>13,000</td>
<td>13,000</td>
<td>12,000</td>
</tr>
</tbody>
</table>

2.5.10 Auxiliary Boiler Emission Factors
OGVs have one or more fuel-fired boilers used for fuel heating and producing steam. Typically, the fuel-fired boilers are not used during transit at sea since many vessels are equipped with an exhaust gas recovery system or “economizer” that uses the heat of the main engine’s exhaust for heating fuel or water. However, in recent years, vessels have reduced their speeds to comply with the VSR program extending up to 40 nm from the port. At lower speeds, it is believed that auxiliary boilers are actually used more often during transit because the lower speeds result in the cooling of main engine exhausts, making the vessels’ economizers less effective. As such, it is assumed for the emission calculations that auxiliary boilers operate during maneuvering and transit when the main engine load factor is calculated to be less than 20%.

Table 2.14 and Table 2.15 show the emission factors from ENTEC’s 2002 report for the fuel-fired boilers.

Table 2.14: Emission Factors for OGV Auxiliary Boilers using HFO and MDO, g/kW-hr

<table>
<thead>
<tr>
<th>Type</th>
<th>PM_{10}</th>
<th>PM_{2.5}</th>
<th>DPM</th>
<th>NO_x</th>
<th>SO_x</th>
<th>CO</th>
<th>HC</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>HFO 2.7% Sulfur</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steam boilers</td>
<td>0.8</td>
<td>0.64</td>
<td>0</td>
<td>2.1</td>
<td>16.5</td>
<td>0.2</td>
<td>0.1</td>
</tr>
<tr>
<td><strong>MDO/MGO 0.3% S</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steam boilers</td>
<td>0.17</td>
<td>0.15</td>
<td>0</td>
<td>2.0</td>
<td>1.8</td>
<td>0.2</td>
<td>0.1</td>
</tr>
</tbody>
</table>
Table 2.15: GHG Emission Factors for OGV Auxiliary Boilers using HFO and MDO, g/kW-hr

<table>
<thead>
<tr>
<th>Type</th>
<th>CO₂</th>
<th>N₂O</th>
<th>CH₄</th>
</tr>
</thead>
<tbody>
<tr>
<td>HFO 2.7% Sulfur</td>
<td>970</td>
<td>0.080</td>
<td>0.002</td>
</tr>
<tr>
<td>Steam boilers</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MDO/MGO 0.3% S</td>
<td>922</td>
<td>0.075</td>
<td>0.002</td>
</tr>
<tr>
<td>Steam boilers</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2.5.11 Auxiliary Boiler Load Defaults

Because Lloyd’s data does not provide information on vessels’ boilers information on boiler fuel consumption is collected from vessels during the VBP. Reported fuel consumption rates for boilers have been converted to equivalent kW using average specific fuel consumption (SFC) factor for residual fuel of 305 grams of fuel per kW-hour as reported in ENTEC’s 2002 report\(^\text{19}\).

The average boiler loads were calculated using the following equation, where “daily fuel” is the reported average fuel consumption rate in tonnes per day.

\[
\text{Average kW} = \frac{((\text{daily fuel/24 hrs/day}) \times 1,000,000 \text{ g/tonne})/305 \text{ g/kWh}}
\]

Table 2.16 presents the calculated auxiliary boiler load defaults used for each vessel type. Compared to other vessel types, cruise ships have higher boiler usage due to the number of passengers on-board and the need for hot water, while tankers’ boilers provide steam for steam-powered liquid pumps, inert gas for storage tanks, and heat to keep fuel warm for pumping. Ocean tugboats do not have boilers; therefore their boiler load default is zero. As previously discussed, typically boilers are not used at sea during normal transit; therefore, if the main engine load is greater than 20%, the boiler load default at sea is zero. If the main engine load is less than or equal to 20%, the maneuvering boiler load defaults shown in Table 2.16 are used.

In addition, tanker loading data was incorporated to account for the difference in demand on the auxiliary boiler during loading or discharging operations while at berth. As of the 2013 EI, if a tanker is loading liquid bulk while at berth, a lower auxiliary boiler load of 875 kW is applied.

---

Table 2.16: 2013 Auxiliary Boiler Energy Defaults, kW

<table>
<thead>
<tr>
<th>Vessel Type</th>
<th>Transit</th>
<th>Maneuvering</th>
<th>Berth</th>
<th>Anchorage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Hotelling</td>
<td></td>
<td>Hotelling</td>
</tr>
<tr>
<td>Auto Carrier</td>
<td>351</td>
<td>351</td>
<td>351</td>
<td>351</td>
</tr>
<tr>
<td>Bulk</td>
<td>132</td>
<td>132</td>
<td>132</td>
<td>132</td>
</tr>
<tr>
<td>Bulk - Self Discharging</td>
<td>132</td>
<td>132</td>
<td>132</td>
<td>132</td>
</tr>
<tr>
<td>Bulk - Wood Chips</td>
<td>132</td>
<td>132</td>
<td>132</td>
<td>132</td>
</tr>
<tr>
<td>Container - 1000</td>
<td>241</td>
<td>241</td>
<td>241</td>
<td>241</td>
</tr>
<tr>
<td>Container - 2000</td>
<td>325</td>
<td>325</td>
<td>325</td>
<td>325</td>
</tr>
<tr>
<td>Container - 3000</td>
<td>474</td>
<td>474</td>
<td>474</td>
<td>474</td>
</tr>
<tr>
<td>Container - 4000</td>
<td>492</td>
<td>492</td>
<td>492</td>
<td>492</td>
</tr>
<tr>
<td>Container - 5000</td>
<td>630</td>
<td>630</td>
<td>630</td>
<td>630</td>
</tr>
<tr>
<td>Container - 6000</td>
<td>565</td>
<td>565</td>
<td>565</td>
<td>565</td>
</tr>
<tr>
<td>Container - 7000</td>
<td>551</td>
<td>551</td>
<td>551</td>
<td>551</td>
</tr>
<tr>
<td>Container - 8000</td>
<td>525</td>
<td>525</td>
<td>525</td>
<td>525</td>
</tr>
<tr>
<td>Container - 9000</td>
<td>547</td>
<td>547</td>
<td>547</td>
<td>547</td>
</tr>
<tr>
<td>Container - 10000</td>
<td>749</td>
<td>749</td>
<td>749</td>
<td>749</td>
</tr>
<tr>
<td>Container - 11000</td>
<td>600</td>
<td>600</td>
<td>600</td>
<td>600</td>
</tr>
<tr>
<td>Container - 12000</td>
<td>600</td>
<td>600</td>
<td>600</td>
<td>600</td>
</tr>
<tr>
<td>Container - 13000</td>
<td>600</td>
<td>600</td>
<td>600</td>
<td>600</td>
</tr>
<tr>
<td>Container - 14000</td>
<td>700</td>
<td>700</td>
<td>700</td>
<td>700</td>
</tr>
<tr>
<td>Cruise</td>
<td>1,393</td>
<td>1,393</td>
<td>1,393</td>
<td>1,393</td>
</tr>
<tr>
<td>General Cargo</td>
<td>137</td>
<td>137</td>
<td>137</td>
<td>137</td>
</tr>
<tr>
<td>Ocean Tug</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>137</td>
<td>137</td>
<td>137</td>
<td>137</td>
</tr>
<tr>
<td>Reefer</td>
<td>255</td>
<td>255</td>
<td>255</td>
<td>255</td>
</tr>
<tr>
<td>RoRo</td>
<td>243</td>
<td>243</td>
<td>243</td>
<td>243</td>
</tr>
<tr>
<td>Tanker - Chemical</td>
<td>371</td>
<td>371</td>
<td>3,000</td>
<td>371</td>
</tr>
<tr>
<td>Tanker - Handysize</td>
<td>371</td>
<td>371</td>
<td>3,000</td>
<td>371</td>
</tr>
<tr>
<td>Tanker - Panamax</td>
<td>371</td>
<td>371</td>
<td>3,000</td>
<td>371</td>
</tr>
<tr>
<td>Tanker - Aframax</td>
<td>371</td>
<td>371</td>
<td>3,000</td>
<td>371</td>
</tr>
<tr>
<td>Tanker - Suezmax</td>
<td>371</td>
<td>371</td>
<td>3,000</td>
<td>371</td>
</tr>
<tr>
<td>Tanker - VLCC</td>
<td>371</td>
<td>371</td>
<td>3,000</td>
<td>371</td>
</tr>
<tr>
<td>Tanker - ULCC</td>
<td>371</td>
<td>371</td>
<td>3,000</td>
<td>371</td>
</tr>
</tbody>
</table>
2.5.12 Fuel Correction Factors

Fuel correction factors are used to adjust the emission estimates to account for fuels or other parameters that are different from the conditions under which the emission factors were developed. As previously discussed, the emission factors are appropriate for engines using residual/HFO fuel with average sulfur content of 2.7%. Table 2.17 lists the fuel correction factors used when the emission factors that are based on 2.7% sulfur fuel are used for engines that burned fuel with a lower sulfur content. These fuel correction factors are consistent with those used by CARB in their emission estimations methodology for ocean-going vessels.\(^\text{20}\) The FCFs are applied to propulsion engines, auxiliary engines, and auxiliary boilers if they have switched fuel from the default residual fuel (2.7% average sulfur content) to a lower sulfur content fuel.

<table>
<thead>
<tr>
<th>Actual Fuel</th>
<th>Sulfur Content</th>
<th>PM</th>
<th>NO(_x)</th>
<th>SO(_x)</th>
<th>CO</th>
<th>HC</th>
<th>CO(_2)</th>
<th>N(_2)O</th>
<th>CH(_4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HFO</td>
<td>1.00%</td>
<td>0.73</td>
<td>1.00</td>
<td>0.370</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>MGO</td>
<td>0.30%</td>
<td>0.21</td>
<td>0.94</td>
<td>0.111</td>
<td>1.00</td>
<td>1.00</td>
<td>0.95</td>
<td>0.94</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Beginning July 1, 2009, the CARB OGV low sulfur fuel regulation, adopted in July 2008, requires vessel operators to use marine gas oil (MGO) with a sulfur content less than 1.5% by weight or marine diesel oil (MDO) with a sulfur content equal to or less than 0.5% by weight within 24-nm from California coast (and while at-berth) in their diesel powered propulsion engines, auxiliary engines and auxiliary boilers.\(^{21}\) Starting on August 1, 2013, the maximum fuel sulfur limit for MGO decreased from 1.5% to 1.0%, while the fuel sulfur limit for MDO remained at 0.5%.

Starting with the 2011 EI, based on worldwide fuel sample data, an average 0.3% sulfur fuel content was used for main and auxiliary engines and for auxiliary boilers. The 0.3% average sulfur content is consistent with a survey conducted by CARB to support their fuel switch regulation and was also incorporated into CARB’s OGV emissions inventory database. The TWG has agreed to continue the use of 0.3% sulfur fuel content as an average for distillate fuel for the 2013 EI.

In the 2013 calendar year, 100% compliance with CARB’s OGV low sulfur fuel regulation is assumed and confirmed by CARB. CARB issued several Essential Modification Executive Orders exempting individual vessels that were granted an exemption from the fuel use specifications described in the OGV low sulfur fuel regulation after demonstrating that is not feasible to use the specified fuels in their auxiliary boilers unless essential modification to the vessels are made.\(^\text{22}\) For these particular vessels, if the vessel called the port in 2013, the fuel switching was not included for the boilers; therefore, the emissions were estimated for the boilers as burning residual fuel.

\(^{20}\) CARB, [http://www.arb.ca.gov/regact/2008/fuelogv08/fuelogv08.htm](http://www.arb.ca.gov/regact/2008/fuelogv08/fuelogv08.htm); Appendix D, Tables II-6 to II-8.

\(^{21}\) CARB, [www.arb.ca.gov/ports/marinevess/ogv.htm](http://www.arb.ca.gov/ports/marinevess/ogv.htm).
Effective August 1, 2012, the North American Emission Control Area (ECA) required vessels traveling within the regulatory zone to use low sulfur fuel with a sulfur content of 1.0% or less.\textsuperscript{23} For the purpose of this inventory, vessels which were previously assigned CARB fuel exemptions for auxiliary boilers, were assigned HFO 1.0% S fuel upon entrance into the ECA regulatory zone.

2.5.13 Emission Reduction Technologies

Control factors are used to take into account the emissions benefits associated with emission reduction technologies such as slide valves and the use of shore side electrical power at berth.

*Shore Side Electrical Power*

As an additional emission reduction strategy, shore side electrical power was used for 222 vessel calls representing about 11% of all vessel calls. For all shore-powered events, a control factor of 0.05 or a 95% reduction is applied for all pollutant and GHG emissions from auxiliary engines while at-berth for that event. This reduction estimate accounts for the time necessary to connect and disconnect the electrical power and to start up the auxiliary engines prior to departure.

*Slide Valves*

In past inventories, a PM and NO\textsubscript{x} reduction was taken into account for fuel slide valves. Slide valve reductions are limited to two-stroke MAN main engines that are Tier 0 or Tier I. As part of the Technology Advancement Program (TAP), Man Diesel & Turbo A/S, Mitsui Engineering & Shipbuilding CO., Ltd., POLA, and POLB conducted a test at the Mitsui Tamano Works in Japan to determine if slide valves provide emission reduction benefits when ships are traveling below 25% load, as ship are doing when they are in compliance with the VSR program. The test was completed and the results are currently being used to develop load-based control factors for NO\textsubscript{x}, PM, PM\textsubscript{2.5}, DPM, HC, and N\textsubscript{2}O. The work will include working with MAN Diesel & Turbo A/S to determine the distribution of the type of valves typically used in two-stroke engines to help set baseline scenarios. The CFs will be developed in coordination with the TWG and incorporated in the 2014 inventory. For 2013, both ports decided to set the CFs for slide valves to 1.0 (essentially turning their reductions off) as to avoid taking credit for offsets that are not supported by the test results and to avoid setting an arbitrary interim CFs that would be changed in the next inventory. Once the new CFs have been developed and agreed upon with the TWG, they will be applied to 2014 inventory and all previous inventories.

\textsuperscript{23} The North American Emissions Control Area regulatory zone begins 200 nautical miles from the Pacific, Atlantic, and Gulf coasts of the United States (including 8 main Hawaiian Islands), Canada, and the French territories; it does not extend into marine areas subject to sovereignty or jurisdiction of other states.
2.5.14 Changes to methodology from previous years

The following improvements were made to the OGV emission calculation methodology in this inventory compared to the previous year methodology.

- There were no slide valve emission reductions taken for 2005-2013.
- CO₂ emission factors for auxiliary engines were changed from 683 to 722 g/kw-hr. This revision is consistent with CARB methodology.
- Hotelling time calculations were adjusted to account for a difference in the MarEx activity timestamp definition. It was determined that the arrival and departure timestamps indicate the time that a vessel enters or leaves the harbor, rather than the time a vessel arrives or departs berth, which had been the previous interpretation. The hotelling time calculations were adjusted to account for this difference.
- Tanker loading data was incorporated to account for the difference in demand on the auxiliary boiler during loading or discharging operations while at berth. If a tanker is loading liquid bulk while at berth, a lower auxiliary boiler load of 875 kW is applied.

2.6 Emission Estimates

A summary of the 2013 OGV emission estimates of all pollutants by vessel type is presented in Table 2.18 for criteria pollutants in tons and Table 2.19 for GHG emissions in metric tons. Ocean-going vessel data is presented in Appendix B.

Table 2.18: 2013 Ocean-going Vessel Emissions by Vessel Type, tons

<table>
<thead>
<tr>
<th>Vessel Type</th>
<th>PM₁₀</th>
<th>PM₂.₅</th>
<th>DPM</th>
<th>NOₓ</th>
<th>SOₓ</th>
<th>CO</th>
<th>HC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Auto Carrier</td>
<td>3.4</td>
<td>3.1</td>
<td>3.1</td>
<td>135.3</td>
<td>13.7</td>
<td>14.8</td>
<td>6.8</td>
</tr>
<tr>
<td>Bulk</td>
<td>5.7</td>
<td>5.2</td>
<td>5.0</td>
<td>222.9</td>
<td>26.8</td>
<td>20.7</td>
<td>8.7</td>
</tr>
<tr>
<td>Containership</td>
<td>56.7</td>
<td>51.8</td>
<td>50.4</td>
<td>2,069.0</td>
<td>224.8</td>
<td>259.4</td>
<td>135.4</td>
</tr>
<tr>
<td>Cruise</td>
<td>8.5</td>
<td>7.7</td>
<td>8.5</td>
<td>360.1</td>
<td>36.1</td>
<td>29.6</td>
<td>11.4</td>
</tr>
<tr>
<td>General Cargo</td>
<td>1.8</td>
<td>1.6</td>
<td>1.7</td>
<td>71.2</td>
<td>8.3</td>
<td>6.5</td>
<td>2.7</td>
</tr>
<tr>
<td>Ocean Tug</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>2.3</td>
<td>0.2</td>
<td>0.2</td>
<td>0.1</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>5.0</td>
<td>4.6</td>
<td>4.8</td>
<td>212.9</td>
<td>23.1</td>
<td>17.0</td>
<td>6.2</td>
</tr>
<tr>
<td>RoRo</td>
<td>0.3</td>
<td>0.3</td>
<td>0.0</td>
<td>4.4</td>
<td>3.1</td>
<td>0.4</td>
<td>0.2</td>
</tr>
<tr>
<td>Tanker</td>
<td>44.7</td>
<td>40.0</td>
<td>25.8</td>
<td>1,180.2</td>
<td>307.7</td>
<td>113.6</td>
<td>47.6</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>126.2</strong></td>
<td><strong>114.4</strong></td>
<td><strong>99.4</strong></td>
<td><strong>4,258.3</strong></td>
<td><strong>643.8</strong></td>
<td><strong>462.2</strong></td>
<td><strong>219.1</strong></td>
</tr>
</tbody>
</table>
Table 2.19: 2013 Ocean-going Vessel GHG Emissions by Vessel Type, metric tons

<table>
<thead>
<tr>
<th>Vessel Type</th>
<th>CO₂e</th>
<th>CO₂</th>
<th>N₂O</th>
<th>CH₄</th>
</tr>
</thead>
<tbody>
<tr>
<td>Auto Carrier</td>
<td>6,393</td>
<td>6,282</td>
<td>0.3</td>
<td>0.1</td>
</tr>
<tr>
<td>Bulk</td>
<td>12,494</td>
<td>12,281</td>
<td>0.7</td>
<td>0.2</td>
</tr>
<tr>
<td>Containership</td>
<td>104,866</td>
<td>102,849</td>
<td>6.3</td>
<td>2.5</td>
</tr>
<tr>
<td>Cruise</td>
<td>16,771</td>
<td>16,546</td>
<td>0.7</td>
<td>0.2</td>
</tr>
<tr>
<td>General Cargo</td>
<td>3,840</td>
<td>3,778</td>
<td>0.2</td>
<td>0.0</td>
</tr>
<tr>
<td>Ocean Tug</td>
<td>112</td>
<td>111</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>10,704</td>
<td>10,550</td>
<td>0.5</td>
<td>0.1</td>
</tr>
<tr>
<td>RoRo</td>
<td>1,472</td>
<td>1,437</td>
<td>0.1</td>
<td>0.0</td>
</tr>
<tr>
<td>Tanker</td>
<td>117,662</td>
<td>115,278</td>
<td>7.6</td>
<td>0.9</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>274,314</td>
<td>269,111</td>
<td>16.4</td>
<td>4.0</td>
</tr>
</tbody>
</table>

Figure 2.3 shows percentage of emissions of each pollutant by vessel type in 2013. Containerships have the highest percentage of overall emissions for the vessels (approximately 35 to 62%), followed by tankers (approximately 22 to 48%), cruise ships, bulk vessels, miscellaneous, auto carriers, and general cargo. The “other” category includes RoRos and ocean-going tugboats.
2.6.1 Emission Estimates by Engine Type

Tables 2.20 and 2.21 present summaries of the emission estimates by engine type.

**Table 2.20: 2013 Ocean-going Vessel Emissions by Engine Type, tons**

<table>
<thead>
<tr>
<th>Engine Type</th>
<th>PM₁₀</th>
<th>PM₂.₅</th>
<th>DPM</th>
<th>NOₓ</th>
<th>SOₓ</th>
<th>CO</th>
<th>HC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Auxiliary Engine</td>
<td>59.1</td>
<td>54.0</td>
<td>59.1</td>
<td>2,312.6</td>
<td>256.0</td>
<td>206.2</td>
<td>75.0</td>
</tr>
<tr>
<td>Auxiliary Boiler</td>
<td>26.6</td>
<td>23.4</td>
<td>0.0</td>
<td>248.7</td>
<td>286.2</td>
<td>25.0</td>
<td>12.5</td>
</tr>
<tr>
<td>Main Engine</td>
<td>40.4</td>
<td>36.9</td>
<td>40.3</td>
<td>1,696.8</td>
<td>101.8</td>
<td>231.0</td>
<td>131.5</td>
</tr>
<tr>
<td>Total</td>
<td>126.2</td>
<td>114.4</td>
<td>99.4</td>
<td>4,258.3</td>
<td>643.8</td>
<td>462.2</td>
<td>219.1</td>
</tr>
</tbody>
</table>

**Table 2.21: 2013 Ocean-going Vessel GHG Emissions by Engine Type, metric tons**

<table>
<thead>
<tr>
<th>Engine Type</th>
<th>CO₂ₑ</th>
<th>CO₂</th>
<th>N₂O</th>
<th>CH₄</th>
</tr>
</thead>
<tbody>
<tr>
<td>Auxiliary Engine</td>
<td>118,474</td>
<td>116,906</td>
<td>5.0</td>
<td>1.4</td>
</tr>
<tr>
<td>Auxiliary Boiler</td>
<td>108,083</td>
<td>105,409</td>
<td>8.6</td>
<td>0.2</td>
</tr>
<tr>
<td>Main Engine</td>
<td>47,757</td>
<td>46,796</td>
<td>2.9</td>
<td>2.4</td>
</tr>
<tr>
<td>Total</td>
<td>274,314</td>
<td>269,111</td>
<td>16.5</td>
<td>4.0</td>
</tr>
</tbody>
</table>

Figure 2.4 shows results in percentages for emission estimates by engine type.

**Figure 2.4: 2013 Ocean-going Vessel Emissions by Engine Type, %**
### 2.6.2 Emission Estimates by Engine Type

Tables 2.22 and 2.23 present summaries of emission estimates by the various modes.

#### Table 2.22: 2013 Ocean-going Vessel Emissions by Mode, tons

<table>
<thead>
<tr>
<th>Mode</th>
<th>Engine Type</th>
<th>PM₁₀</th>
<th>PM₂.₅</th>
<th>DPM</th>
<th>NOₓ</th>
<th>SOₓ</th>
<th>CO</th>
<th>HC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transit</td>
<td>Auxiliary Engine</td>
<td>10.0</td>
<td>9.1</td>
<td>10.0</td>
<td>402.7</td>
<td>43.2</td>
<td>34.8</td>
<td>12.6</td>
</tr>
<tr>
<td>Transit</td>
<td>Auxiliary Boiler</td>
<td>1.0</td>
<td>0.9</td>
<td>0.0</td>
<td>11.0</td>
<td>10.4</td>
<td>1.1</td>
<td>0.6</td>
</tr>
<tr>
<td>Transit</td>
<td>Main Engine</td>
<td>33.8</td>
<td>30.9</td>
<td>33.7</td>
<td>1,472.3</td>
<td>95.3</td>
<td>190.7</td>
<td>98.8</td>
</tr>
<tr>
<td><strong>Total Transit</strong></td>
<td></td>
<td>44.8</td>
<td>40.9</td>
<td>43.7</td>
<td>1,886.0</td>
<td>148.9</td>
<td>226.6</td>
<td>112.0</td>
</tr>
<tr>
<td>Maneuvering</td>
<td>Auxiliary Engine</td>
<td>3.8</td>
<td>3.5</td>
<td>3.8</td>
<td>149.5</td>
<td>16.4</td>
<td>13.2</td>
<td>4.8</td>
</tr>
<tr>
<td>Maneuvering</td>
<td>Auxiliary Boiler</td>
<td>0.4</td>
<td>0.4</td>
<td>0.0</td>
<td>4.0</td>
<td>4.5</td>
<td>0.4</td>
<td>0.2</td>
</tr>
<tr>
<td>Maneuvering</td>
<td>Main Engine</td>
<td>6.6</td>
<td>6.0</td>
<td>6.6</td>
<td>224.6</td>
<td>6.5</td>
<td>40.3</td>
<td>32.8</td>
</tr>
<tr>
<td><strong>Total Maneuvering</strong></td>
<td></td>
<td>10.8</td>
<td>9.9</td>
<td>10.4</td>
<td>378.1</td>
<td>27.4</td>
<td>53.9</td>
<td>37.8</td>
</tr>
<tr>
<td>Hotelling at Berth</td>
<td>Auxiliary Engine</td>
<td>33.8</td>
<td>30.9</td>
<td>33.8</td>
<td>1,321.1</td>
<td>146.6</td>
<td>118.1</td>
<td>43.0</td>
</tr>
<tr>
<td>Hotelling at Berth</td>
<td>Auxiliary Boiler</td>
<td>20.5</td>
<td>18.1</td>
<td>0.0</td>
<td>196.9</td>
<td>221.2</td>
<td>19.8</td>
<td>9.9</td>
</tr>
<tr>
<td>Hotelling at Berth</td>
<td>Main Engine</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td><strong>Total Hotelling - Berth</strong></td>
<td></td>
<td>54.3</td>
<td>49.0</td>
<td>33.8</td>
<td>1518.0</td>
<td>367.8</td>
<td>137.9</td>
<td>52.9</td>
</tr>
<tr>
<td>Hotelling at Anchorage</td>
<td>Auxiliary Engine</td>
<td>11.5</td>
<td>10.5</td>
<td>11.5</td>
<td>439.3</td>
<td>49.8</td>
<td>40.1</td>
<td>14.6</td>
</tr>
<tr>
<td>Hotelling at Anchorage</td>
<td>Auxiliary Boiler</td>
<td>4.7</td>
<td>4.0</td>
<td>0.0</td>
<td>36.7</td>
<td>50.2</td>
<td>3.7</td>
<td>1.8</td>
</tr>
<tr>
<td>Hotelling at Anchorage</td>
<td>Main Engine</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td><strong>Total Hotelling - Anchorage</strong></td>
<td></td>
<td>16.2</td>
<td>14.5</td>
<td>11.5</td>
<td>476.0</td>
<td>100.0</td>
<td>43.8</td>
<td>16.4</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td>126.2</td>
<td>114.4</td>
<td>99.4</td>
<td>4,258.3</td>
<td>643.8</td>
<td>462.2</td>
<td>219.1</td>
</tr>
</tbody>
</table>
### Table 2.23: 2013 Ocean-going Vessel Greenhouse Gas Emissions by Mode, metric tons

<table>
<thead>
<tr>
<th>Mode</th>
<th>Engine Type</th>
<th>CO₂e</th>
<th>CO₂</th>
<th>N₂O</th>
<th>CH₄</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transit</td>
<td>Auxiliary Engine</td>
<td>19,980</td>
<td>19,715</td>
<td>0.8</td>
<td>0.2</td>
</tr>
<tr>
<td>Transit</td>
<td>Auxiliary Boiler</td>
<td>4,777</td>
<td>4,659</td>
<td>0.4</td>
<td>0.0</td>
</tr>
<tr>
<td>Transit</td>
<td>Main Engine</td>
<td>44,634</td>
<td>43,804</td>
<td>2.6</td>
<td>1.8</td>
</tr>
<tr>
<td><strong>Total Transit</strong></td>
<td></td>
<td>69,391</td>
<td>68,178</td>
<td>3.8</td>
<td>2.0</td>
</tr>
<tr>
<td>Maneuvering</td>
<td>Auxiliary Engine</td>
<td>7,582</td>
<td>7,482</td>
<td>0.3</td>
<td>0.1</td>
</tr>
<tr>
<td>Maneuvering</td>
<td>Auxiliary Boiler</td>
<td>1,753</td>
<td>1,710</td>
<td>0.1</td>
<td>0.0</td>
</tr>
<tr>
<td>Maneuvering</td>
<td>Main Engine</td>
<td>3,123</td>
<td>2,992</td>
<td>0.4</td>
<td>0.6</td>
</tr>
<tr>
<td><strong>Total Maneuvering</strong></td>
<td></td>
<td>12,458</td>
<td>12,184</td>
<td>0.8</td>
<td>0.6</td>
</tr>
<tr>
<td>Hotelling at Berth</td>
<td>Auxiliary Engine</td>
<td>67,854</td>
<td>66,956</td>
<td>2.8</td>
<td>0.8</td>
</tr>
<tr>
<td>Hotelling at Berth</td>
<td>Auxiliary Boiler</td>
<td>83,611</td>
<td>83,493</td>
<td>6.8</td>
<td>0.2</td>
</tr>
<tr>
<td>Hotelling at Berth</td>
<td>Main Engine</td>
<td>0</td>
<td>0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td><strong>Total Hotelling - Berth</strong></td>
<td></td>
<td>153,465</td>
<td>150,449</td>
<td>9.6</td>
<td>1.0</td>
</tr>
<tr>
<td>Hotelling at Anchorage</td>
<td>Auxiliary Engine</td>
<td>23,058</td>
<td>22,753</td>
<td>1.0</td>
<td>0.3</td>
</tr>
<tr>
<td>Hotelling at Anchorage</td>
<td>Auxiliary Boiler</td>
<td>15,942</td>
<td>15,547</td>
<td>1.3</td>
<td>0.0</td>
</tr>
<tr>
<td>Hotelling at Anchorage</td>
<td>Main Engine</td>
<td>0</td>
<td>0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td><strong>Total Hotelling - Anchorage</strong></td>
<td></td>
<td>39,000</td>
<td>38,300</td>
<td>2.3</td>
<td>0.3</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td>274,314</td>
<td>269,111</td>
<td>16.5</td>
<td>4.0</td>
</tr>
</tbody>
</table>

Figure 2.5 summarizes the percentage of emissions by mode.

**Figure 2.5: 2013 Ocean-going Vessel Emissions by Mode, %**