SECTION 2 OCEAN-GOING VESSELS

This section presents emissions estimates for the ocean-going vessels source category, including source description (2.1), geographical delineation (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

Ocean-going vessels are categorized by the following main vessel types for purposes of this EI:

- Auto carrier
- Bulk carrier
- Containership
- Passenger cruise vessel
- General cargo
- Ocean-going Tugboat (ITBs)
- Miscellaneous Vessel
- Refrigerated Vessel (Reefer)
- Roll-on roll-off Vessel (RoRo)
- Tanker

Based on 2009 Marine Exchange of Southern California (MarEx) data, there were 2,287 inbound calls to the port in 2009. Containerships made the majority (49%) of the calls followed by tankers (23%), bulk carriers (9%), cruise (8%), auto carrier (6%), and general cargo vessels (3%). Ocean-going tugs, reefers, RoRos and miscellaneous vessels account for the remaining two percent. Figure 2.1 shows the percentage of the inbound calls by vessel type.

Figure 2.1: Distribution of Inbound Calls by Vessel Type
2.2 Geographical Delineation

The geographical extent of the emissions inventory for marine vessels is the same boundary that was used in previous marine vessel inventories for the SoCAB. The portion of the study area outside the Port's breakwater is four-sided, and geographically defined by the following:

- The northwest corner is located where the Ventura County and Los Angeles County lines intersect the Pacific Ocean [34°02'42.4” north (N) latitude by 118°56'41.2” west (W) longitude]

- The southwest corner is located over the water, just south of the Territorial Sea boundary, south of San Nicolas Island (33°00'00.0” N latitude by 119°30'00.0” W longitude)

- The southeast corner is located over the water, south of the Territorial Sea, south of San Clemente Island (32°30'00.0” N latitude by 118°30'00.0” W longitude)

- The northeast corner is located where the Orange County and San Diego County lines intersect the Pacific Ocean (33°23'12.7” N latitude by 117°35'46.4” W longitude)

Figure 2.2 shows this portion of the study area as well as the major shipping routes. The MarEx ship routes were used along with their estimates of travel distances offshore from Point Fermin. These trip segments were organized into four routes (each comprised of both inbound and outbound traffic) reflecting north, east (El Segundo), west, and south routes, as designated by the MarEx.\(^\text{29}\)

- North: The predominant trade route for OGVs in terms of ship calls, involving coastwise trade to the U.S. continental ports and the Far East (Great Circle Route).

- South: The second most traveled direction for ship calls, serving not only Mexico and other ports but also traffic through the Panama Canal.

- West: Mainly involved with travel to Hawaii and some trips to the Channel Islands

- East: This is a short trip between the Port and El Segundo petrochemical complex.

For Port of Long Beach, the distances in nautical miles (nm) for the various routes are listed in Table 2.1. The distances shown are from the precautionary zone (PZ) to the basin boundary and from the breakwater (BW) to the PZ.

Table 2.1: Route Distances, nm

<table>
<thead>
<tr>
<th>Route</th>
<th>PZ to Boundary Distance, nm</th>
<th>BW to PZ Distance, nm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Inbound</td>
<td>Outbound</td>
</tr>
<tr>
<td>North</td>
<td>43.3</td>
<td>42.4</td>
</tr>
<tr>
<td>East</td>
<td>25.7</td>
<td>25.7</td>
</tr>
<tr>
<td>South</td>
<td>31.3</td>
<td>32.5</td>
</tr>
<tr>
<td>West</td>
<td>40.0</td>
<td>40.0</td>
</tr>
</tbody>
</table>
Figure 2.3 shows the precautionary zone which is a designated area where ships are preparing to enter or exit a port. In this zone the pilots are picked up or dropped off. The harbor is located within the breakwater and is characterized by the slowest vessel speeds.

**Figure 2.3: Precautionary Zone**

### 2.3 Data and Information Acquisition

Various sources of data and operational knowledge about the Port’s marine activities were used to compile the data necessary to prepare emission estimates. These sources included:

- Marine Exchange of Southern California
- VSR Program speed data
- Jacobsen Pilot Service
- Lloyd’s Register of Ships
- Port Vessel Boarding Program data
- Terminals (shore power)
- Nautical charts and maps
Each data source is detailed in the following subsections.

2.3.1 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 two ports, and is the first private/public VTS partnership in the country that is funded by industry. MarEx requires ships to report their activities to the VTS upon arrival and departure and tracks ship route taken.

The MarEx data that was evaluated in developing the emission estimates includes vessel names, arrival and departure dates and times, transit speeds and directions, berth of destination, and other information. This data source was the primary basis for establishing:

- calculated hotelling time
- distribution of arrival and departure travel directions by route
- number of ship calls
- names of vessels
- vessel origination and destination

2.3.2 Vessel Speed Reduction Program Data
MarEx monitors OGV speeds over the four routes into and out of the Port as part of a VSR program that was started in May 2001. Speeds are recorded on each route at a series of waypoints that are located on arcs emanating from Point Fermin, at the following nautical mile distances: 10, 15, 20, 25, 30, 35, and 40. The measured speeds from the 10 nm waypoint outside the precautionary zone to the 40 nm waypoint are used in estimating emissions, so the full effect of the VSR program is reflected in the OGV emission estimates. The measurement of speeds from 25 nm to 40 nm began in April 2008; prior to then, only speeds up to the 20 nm waypoint were measured. The speed in the precautionary zone is not monitored by MarEx (see section 2.5.3 for assigned PZ speeds by vessel type); however, Coast Guard regulation limits speed within the PZ to 12 knots.

In preparing the MarEx speed data for use in estimating emissions, the data is first reviewed for blanks, zeros, and values that are likely not accurate, such as recorded speeds over 40 knots. These missing speeds or inaccurate values are marked as blanks and are filled in using the methodology based on available speed from other waypoints.
In the 2007 and earlier inventories, when speeds were not monitored past the 20 nm marker, the speeds for the waypoints between 25 and 40 nm were assumed to be 94% of Lloyd’s speed. For the 2008 EI, when the Marine Exchange expanded speed monitoring to include the area out to 40 nm, a different approach was phased in to fill in missing speeds for the 25 to 40 nm waypoints, and this approach has also been used to estimate 2009 emissions. In this approach, the 25 nm to 40 nm speed data is used to develop adjustment factors that correlate average speeds at the 40 nm waypoint with the maximum speed value reported by Lloyd’s for each vessel. Adjustment factors are developed for each vessel subtype, and separate factors are developed for vessel trips that complied with the VSR speed limit over the 20 nm to 10 nm distance and for vessel trips that did not comply. The adjustment factors are applied to a vessel's Lloyd's speed when there are missing MarEx speeds at the 40 nm waypoint. They are applied on a trip-by-trip basis by first determining whether a vessel complied with the VSR limit over the 20 nm to 10 nm distance, then by multiplying the vessel’s Lloyd’s speed by the appropriate adjustment factor (i.e., based on the waypoint that is missing a speed, the vessel subtype, and whether the vessel was compliant or noncompliant in the 20-10 nm zones on that trip). The method described here has also been used in preparing estimates of 2005 emissions for direct comparison with the 2009 emissions (see Section 8).

Once all speeds are filled in for each waypoint, the speeds for each segment are calculated by averaging the two waypoint speeds at each end of the zone (i.e., the speed for the 20 nm zone equals (speed at 15 + speed at 20)/2). This method for estimating average speeds for the zone or leg of transit is consistent with the propulsion engine activity methodology for calculating load and time (see section 2.5.3).

2.3.3 Jacobsen Pilot Service
The Jacobsen Pilot Service maintains an automated database which documents the time when the pilot took control of the ship’s bridge and when the pilot relinquished control back to the ship’s officers. The date and time data was used to estimate transit time profiles for maneuvering from berth to the precautionary zone for the following movements:

- Inbound from sea
- Outbound to sea
- Anchorage shifts
- Other shifts (e.g., inter-port and intra-port shifts)

Average in-harbor maneuvering times were used for each movement, ship type and terminal based on average trip times.
2.3.4 Lloyd’s Register of Ships

Lloyd’s\(^{30}\) is considered to be the leading resource for obtaining ship characteristics such as tonnage, speed, engine power plant configuration, age, and other parameters. The company is known as a classification society for the purpose of insuring many of the vessels on an international basis; for the vessels classified by Lloyd’s the data are quite complete, however, for other ships using a different insurance certification authority, the data are less complete and/or accurate. Lloyd’s was used for obtaining information such as main and auxiliary engine power and vessel speed ratings because it is the best available source of such information. The survey results from the Vessel Boarding Program suggest that the current Lloyd’s data are fairly accurate for propulsion horsepower and vessel speed.

The company Fairplay has the rights to Lloyd’s ship data and sells the software containing information on commercial marine vessels, which include ocean-going vessels. Lloyd’s data used in this report was obtained in January 2010. The worldwide fleet of OGVs was assembled in a common database and a query was completed to match with the MarEx vessel data. There was nearly a 100% match between the Lloyd’s data and MarEx data with the exception of ocean tugboats (ATB/ITB) that are normally not found in Lloyd’s.

2.3.5 Vessel Boarding Program Survey Data

The best source of local activity data and ship parameters is from the individuals who own and/or operate the vessels. The Vessel Boarding Program (VBP) provided for an in-depth survey of OGVs during which Starcrest consultants boarded the ship and interviewed the ship’s executive and engineering staff, which usually included the Captain and Chief Engineer. For this inventory, the information from previous boardings along with new data received from companies were used.

The following VBP survey data was used specifically for emission estimation methodology in this study:

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

The specific values used for emission estimation methodology are discussed in Section 2.5, such as defaults for auxiliary engines and boilers. A comparison of main engine data provided by Lloyd’s and VBP data indicated a 100% correspondence between the two datasets, so defaults for main engine power were not required, with the exception of ocean tugs. Figure 2.4 presents the percent of vessels by vessel type for the 43 vessels boarded at the Port between 2003 and 2008.

Figure 2.4: Percent by Vessel Type of Vessels Boarded in 2003-2008
**Auxiliary Engine Load Data**

Due to the fact that auxiliary engine information is usually not provided to Lloyd’s by vessel owners, since it is not required by IMO or the classification societies, Lloyd’s contains minimal auxiliary engine information. For the vessels that called at the Port in 2009, 21% of the discrete vessels had auxiliary engine installed power information from Lloyd's data and an additional 8% of the discrete vessels had information gathered from vessel boardings and sister ships. Sister ships are known vessels with similar engine information. The following hierarchy was used for the auxiliary engine power loads:

- ✓ VBP Ships - latest reported load for the boarded vessel by IMO number by mode
- ✓ VBP Sister Ships - latest reported load based on the boarded vessel by IMO number by mode
- ✓ Port Defaults - average loads (auxiliary engine installed power \( \times \) load factor) by vessel class, by mode

Based on the above hierarchy, if a vessel was boarded as part of the VBP and auxiliary engine loads by mode were collected, then the latest of those loads based on the latest boarding of the vessel were used directly. If a sister vessel (i.e., vessel with identical characteristics) was identified as part of the VBP survey or based on information from the shipping line, then the latest boarded vessel's auxiliary engine loads by mode were used for the sister ship. Finally, if a vessel was not boarded and didn't have a sister ship that was identified, or if there were data gaps in the VBP data, then defaults by vessel class by mode were used. Defaults for auxiliary engine loads were developed based on the vessel class averages of the installed auxiliary engine power (trip-weighted by vessel subclass using the Lloyds and VBP data) and multiplied by load factors by vessel class by mode, which were derived from historical VBP data. See section 2.5.9 for auxiliary engine default discussion. Table 2.2 provides a summary of the auxiliary engine data used by vessel type. The table shows the distribution of the auxiliary engine’s source of information used for 776 unique or discrete number of vessels associated with the Port of Long Beach in 2009.
Table 2.2: Auxiliary Engine Source of Information for Vessels Visiting the Port in 2009

<table>
<thead>
<tr>
<th>Vessel Type</th>
<th>VBP</th>
<th>Sister Ships</th>
<th>Lloyds</th>
<th>Default</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Auto Carrier</td>
<td>12</td>
<td>0</td>
<td>8</td>
<td>56</td>
<td>76</td>
</tr>
<tr>
<td>Bulk</td>
<td>0</td>
<td>0</td>
<td>19</td>
<td>134</td>
<td>153</td>
</tr>
<tr>
<td>Bulk - Heavy Load</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Bulk - Self Discharging</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Bulk Wood Chips</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Container - 1000</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>22</td>
<td>25</td>
</tr>
<tr>
<td>Container - 2000</td>
<td>4</td>
<td>1</td>
<td>3</td>
<td>36</td>
<td>44</td>
</tr>
<tr>
<td>Container - 3000</td>
<td>4</td>
<td>0</td>
<td>2</td>
<td>14</td>
<td>20</td>
</tr>
<tr>
<td>Container - 4000</td>
<td>10</td>
<td>1</td>
<td>11</td>
<td>29</td>
<td>51</td>
</tr>
<tr>
<td>Container - 5000</td>
<td>7</td>
<td>1</td>
<td>10</td>
<td>31</td>
<td>49</td>
</tr>
<tr>
<td>Container - 6000</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>3</td>
<td>7</td>
</tr>
<tr>
<td>Container - 7000</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>9</td>
<td>10</td>
</tr>
<tr>
<td>Container - 8000</td>
<td>4</td>
<td>3</td>
<td>1</td>
<td>15</td>
<td>23</td>
</tr>
<tr>
<td>Cruise</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>General Cargo</td>
<td>2</td>
<td>1</td>
<td>19</td>
<td>48</td>
<td>70</td>
</tr>
<tr>
<td>Ocean Tugs</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Reefer</td>
<td>0</td>
<td>1</td>
<td>4</td>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td>RoRo</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Tanker - Aframax</td>
<td>0</td>
<td>0</td>
<td>11</td>
<td>5</td>
<td>16</td>
</tr>
<tr>
<td>Tanker - Chemical</td>
<td>0</td>
<td>0</td>
<td>15</td>
<td>53</td>
<td>68</td>
</tr>
<tr>
<td>Tanker - Handyboat</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>14</td>
<td>15</td>
</tr>
<tr>
<td>Tanker - Panamax</td>
<td>1</td>
<td>3</td>
<td>30</td>
<td>33</td>
<td>67</td>
</tr>
<tr>
<td>Tanker - Suezmax</td>
<td>4</td>
<td>0</td>
<td>5</td>
<td>14</td>
<td>23</td>
</tr>
<tr>
<td>Tanker - VLCC</td>
<td>1</td>
<td>0</td>
<td>10</td>
<td>10</td>
<td>21</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>52</td>
<td>11</td>
<td>160</td>
<td>553</td>
<td>776</td>
</tr>
</tbody>
</table>

**Percentage of total**

- VBP: 7%
- Sister Ships: 1%
- Lloyds: 21%
- Default: 71%
- Total: 100%
2.3.6 Vessels’ Shore Power Data

In 2009, several vessels calling at the Port used shore side electrical power at berth instead of running their diesel-powered auxiliary engines. Information regarding the number of vessel calls and corresponding berths that utilized shore power for hotelling operations was obtained by contacting terminal operators. In 2009, shore power was used for 70 vessel calls at a container terminal and a liquid bulk terminal representing about 3% of all vessel calls.

2.4 Operational Profiles

Vessel activity is defined as the number of ship trips by trip type and segment. Trip segments are used for the at-sea portion of the ship trip between the open ocean and the precautionary zone. These trips are then processed so as to define time in mode and geographic segment. The purpose of this step is to estimate power demand for that mode of operation and multiply it by the amount of time spent in that particular mode, which estimates available energy expressed as power times unit of time (e.g., kilowatt-hours, kW-hrs). A vessel-by-vessel analysis was conducted. The only need for average power or time-in-mode was for vessels that lacked data for those fields. Vessel activity was drawn from three sources:

- MarEx trip tables which define arrivals, departures, and shifts
- MarEx speed tables which define speeds for the VSR Program at 10, 15, 20 and 40 nm
- Jacobsen Pilot Services data which provides transit times for harbor maneuvering

Hotelling

Hotelling time is calculated by subtracting departure time from arrival time while at berth or anchorage. Ship movements are tracked by MarEx as to:

- Arrivals (inbound trip)
- Departures (outbound trip)
- Shifts (inter-port, intra-port, and anchorage shifts)
- Total movements (sum of all the above)

Arrivals

For this study, 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 is a berth at the Port.

Departures

For this study, departures include outbound trips from a berth or anchorage to the sea.
Shifts
While many vessels make only one arrival and departure at a time, some vessels make multiple stops within a port. To assist with preparation of the marine emissions inventory, all shifts were grouped together, since they do not have an “at-sea” component as with arrivals and departures. When a vessel shifts from one berth to another or from an anchorage to a berth, the emissions associated with that shift (transit emissions from/to berth) are allocated to the “to berth” or “arriving berth”.

There are three broad categories of shifts:

- **Intra-port shifts** – movements within a port from one berth to another.
- **Inter-port shifts** – movements between adjacent ports. This is a common occurrence in co-located ports such as Long Beach and Los Angeles.
- **Anchorage shifts** – movements between a terminal and anchorage. For example, a vessel receives a partial load, goes to anchorage, and then returns to the terminal to complete loading.
Table 2.3 presents the arrivals, departures, and shifts for vessels at the Port in 2009.

Table 2.3: 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>127</td>
<td>126</td>
<td>33</td>
<td>286</td>
</tr>
<tr>
<td>Bulk</td>
<td>184</td>
<td>188</td>
<td>181</td>
<td>553</td>
</tr>
<tr>
<td>Bulk - Heavy Load</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>7</td>
</tr>
<tr>
<td>Bulk - Self Discharging</td>
<td>15</td>
<td>15</td>
<td>4</td>
<td>34</td>
</tr>
<tr>
<td>Bulk Wood Chips</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>11</td>
</tr>
<tr>
<td>Container - 1000</td>
<td>225</td>
<td>225</td>
<td>66</td>
<td>516</td>
</tr>
<tr>
<td>Container - 2000</td>
<td>176</td>
<td>178</td>
<td>25</td>
<td>379</td>
</tr>
<tr>
<td>Container - 3000</td>
<td>130</td>
<td>131</td>
<td>7</td>
<td>268</td>
</tr>
<tr>
<td>Container - 4000</td>
<td>155</td>
<td>154</td>
<td>16</td>
<td>325</td>
</tr>
<tr>
<td>Container - 5000</td>
<td>182</td>
<td>173</td>
<td>16</td>
<td>371</td>
</tr>
<tr>
<td>Container - 6000</td>
<td>46</td>
<td>9</td>
<td>8</td>
<td>63</td>
</tr>
<tr>
<td>Container - 7000</td>
<td>65</td>
<td>65</td>
<td>3</td>
<td>133</td>
</tr>
<tr>
<td>Container - 8000</td>
<td>153</td>
<td>155</td>
<td>12</td>
<td>320</td>
</tr>
<tr>
<td>Cruise</td>
<td>172</td>
<td>174</td>
<td>2</td>
<td>348</td>
</tr>
<tr>
<td>General Cargo</td>
<td>73</td>
<td>78</td>
<td>70</td>
<td>221</td>
</tr>
<tr>
<td>Ocean Tugs</td>
<td>30</td>
<td>34</td>
<td>42</td>
<td>106</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>3</td>
<td>3</td>
<td>5</td>
<td>11</td>
</tr>
<tr>
<td>Reefer</td>
<td>3</td>
<td>7</td>
<td>7</td>
<td>17</td>
</tr>
<tr>
<td>RoRo</td>
<td>18</td>
<td>17</td>
<td>2</td>
<td>37</td>
</tr>
<tr>
<td>Tanker - Aframax</td>
<td>49</td>
<td>49</td>
<td>83</td>
<td>181</td>
</tr>
<tr>
<td>Tanker - Chemical</td>
<td>162</td>
<td>156</td>
<td>186</td>
<td>504</td>
</tr>
<tr>
<td>Tanker - Handyboat</td>
<td>42</td>
<td>44</td>
<td>33</td>
<td>119</td>
</tr>
<tr>
<td>Tanker - Panamax</td>
<td>152</td>
<td>159</td>
<td>287</td>
<td>598</td>
</tr>
<tr>
<td>Tanker - Suezmax</td>
<td>78</td>
<td>78</td>
<td>125</td>
<td>281</td>
</tr>
<tr>
<td>Tanker - VLCC</td>
<td>41</td>
<td>42</td>
<td>81</td>
<td>164</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>2,287</strong></td>
<td><strong>2,266</strong></td>
<td><strong>1,300</strong></td>
<td><strong>5,853</strong></td>
</tr>
</tbody>
</table>
2.5 Emissions Estimation Methodology

Emissions are estimated as a function of vessel power demand (energy expressed in kW-hrs) multiplied by an emission factor, where the emission factor is expressed in terms of grams per kilowatt-hour (g/kW-hr). Emission factors and emission factor adjustments for low propulsion engine load are then applied to the various activity data. The process for estimating emissions from propulsion engines is illustrated as a process flow diagram in Figure 2.5. This diagram indicates the sources of information discussed in the previous subsection and how they are used to develop the components of the emission calculations, described below.

Equations 2.1 and 2.2 report the basic equations used in estimating emissions, and are labeled in Figure 2.6.

\[ E = Energy \times EF \times FCF \times CF \]  

Equation 2.1

Where:

- \( E \) = Emissions from the engine(s)
- \( Energy \) = Energy demand, in kW-hrs, calculated using Equation 2.2 below as the energy output of the engine (or engines) over the period of time
- \( EF \) = Emission factor, usually expressed in terms of g/kW-hr
- \( FCF \) = Fuel correction factor
- \( CF \) = Correction factors for emission reduction measures

The ‘Energy’ term of the equation is where most of the location-specific information is used. Energy is calculated using Equation 2.2:

\[ Energy = MCR \times LF \times Act \]  

Equation 2.2

Where:

- \( MCR \) = maximum continuous rated engine power, kW
- \( LF \) = load factor (unitless)
- \( Act \) = actual activity, hours

The emissions estimation methodology section discusses methodology used for propulsion engines (subsections 2.5.1 to 2.5.7), auxiliary engines (subsections 2.5.8 and 2.5.9) and auxiliary boilers (subsections 2.5.10). Propulsion engines are also referred to as main engines. Incinerators are not included in the emissions estimates because incinerators are not used within the study area. Interviews with the vessel operators and marine industry, in general, report that vessels do not use their incinerators while at berth or near coastal waters.
Figure 2.5: Propulsion Engine Emission Estimation Flow Diagram

- **Lloyd’s Data**
  - Power, kW
  - kW-hrs
  - Emission Estimate
  - Lloyd’s Data - Kilowatts, numbers of engines/vessel, speeds

- **Survey Data**
  - Load Factor
  - Emission Factor
  - Survey Data – Eng pwr (kW), Load Factor, speed (knots); survey data is from Vessel Boarding Program (VBP)

- **Technical Literature**
  - Activity, hours
  - Emission Estimate
  - Technical Literature – Emissions Factor

- **MarEx Data**
  - Trip or Dwell Duration, hours
  - Distance, nm
  - Actual Speed, knots
  - MarEx Data – Number of calls, vessel ID, dwell time, travel distances

- **Pilot Data**
  - Maneuvering time
  - Pilot Data – Maneuvering time
2.5.1 Propulsion Engine Maximum Continuous Rated Power
MCR power is defined as the manufacturer's tested engine power; for this study, it is assumed that the Lloyd's 'Power' value is the best surrogate for MCR power. The international specification is to report MCR in kilowatts, and it is related to the highest power available from a ship engine during average cargo and sea conditions. However, operating a vessel at 100% of its MCR power is very costly from a fuel consumption and engine maintenance perspective, so most operators limit their maximum power to about 83% of MCR.

2.5.2 Propulsion Engine Load Factor
Load factor is the ratio of an engine's power output at a given speed to the engine's MCR power. Propulsion engine load factor is estimated using the Propeller Law, which says that propulsion engine load varies with the cube of vessel speed. Therefore, propulsion engine load at a given speed is estimated by taking the cube of that speed divided by the vessel's maximum speed, as illustrated by the following equation.

Equation 2.3

\[ LF = \left(\frac{AS}{MS}\right)^3 \]

Where:
- \( LF \) = load factor, percent
- \( AS \) = actual speed, knots
- \( MS \) = maximum speed, knots

For a few instances, the calculated load factor using the actual speed data recorded and provided by MarEx, has exceeded the 83% MCR. This may be due to vessels traveling faster than the maximum rated speed due to wind conditions or currents. For the purpose of estimating emissions, the load factor has been capped to 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
Activity is measured in hours of operation. Actual in-harbor maneuvering times are taken from Pilot data. The transit time in precautionary zone and the fairway, from outside the PZ to the edge of the geographical boundary, is estimated using equation 2.4.

Equation 2.4

\[ Act = \frac{D}{AS} \]

Where:
- \( Act \) = activity, hours
- \( D \) = distance, nautical miles
- \( AS \) = ship speed, knots
Actual speeds provided by MarEx (discussed in section 2.3.2) are used for estimating the fairway transit time. Vessel speeds are recorded by the Marine Exchange at 10, 15, 20, 25, 30, 35, and 40 nm. Under the Port’s Green Flag Program, vessels reduce their speeds to 12 knots within 40 nm of the harbor.

The PZ uses assigned speeds based on VBP data, as found in Table 2.4.

### Table 2.4: Precautionary Zone Speed, knots

<table>
<thead>
<tr>
<th>Vessel Type</th>
<th>Class</th>
<th>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>

#### 2.5.4 Propulsion Engine Emission Factors

The main engine emission factors used in this study were reported in a 2002 ENTEC study, except for PM emission factors. CARB provided the PM EF for slow and medium speed diesel engines. IVL 2004 study was the source for the PM EF for gas turbine and steamship vessels. The greenhouse gas emission factors for CO₂, CH₄ and N₂O were reported in an IVL 2004 study. The emission factors are based on residual oil (RO) which is intermediate fuel oil (IFO 380) or one with similar specifications, with an average sulfur content of 2.7%.

The two predominant propulsion engine types are:

- Slow speed diesel engines, having maximum engine speeds less than 130 rpm
- Medium speed diesel engines, having maximum engine speeds over 130 rpm (and typically greater than 400 rpm).

---

Tables 2.5 and 2.6 list the emission factors for propulsion power using residual fuel.

Table 2.5: Emission Factors for OGV Propulsion Power using Residual Oil, g/kW-hr

<table>
<thead>
<tr>
<th>Engine</th>
<th>Model Year</th>
<th>PM$_{10}$</th>
<th>PM$_{2.5}$</th>
<th>DPM</th>
<th>NO</th>
<th>SO</th>
<th>CO</th>
<th>HC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slow speed diesel</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>≤ 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>2000 +</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>2000 +</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>Gas turbine</td>
<td>all</td>
<td>0.05</td>
<td>0.04</td>
<td>0.0</td>
<td>6.1</td>
<td>16.5</td>
<td>0.2</td>
<td>0.1</td>
</tr>
<tr>
<td>Steamship</td>
<td>all</td>
<td>0.8</td>
<td>0.6</td>
<td>0.0</td>
<td>2.1</td>
<td>16.5</td>
<td>0.2</td>
<td>0.1</td>
</tr>
</tbody>
</table>

Table 2.6: GHG Emission Factors for OGV Propulsion Power using Residual Oil, g/kW-hr

<table>
<thead>
<tr>
<th>Engine</th>
<th>Model Year</th>
<th>CO$_2$</th>
<th>N$_2$O</th>
<th>CH$_4$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slow speed diesel</td>
<td>≤ 1999</td>
<td>620</td>
<td>0.031</td>
<td>0.012</td>
</tr>
<tr>
<td>Medium speed diesel</td>
<td>≤ 1999</td>
<td>683</td>
<td>0.031</td>
<td>0.010</td>
</tr>
<tr>
<td>Slow speed diesel</td>
<td>2000 +</td>
<td>620</td>
<td>0.031</td>
<td>0.012</td>
</tr>
<tr>
<td>Medium speed diesel</td>
<td>2000 +</td>
<td>683</td>
<td>0.031</td>
<td>0.010</td>
</tr>
<tr>
<td>Gas turbine</td>
<td>all</td>
<td>970</td>
<td>0.08</td>
<td>0.002</td>
</tr>
<tr>
<td>Steamship</td>
<td>all</td>
<td>970</td>
<td>0.08</td>
<td>0.002</td>
</tr>
</tbody>
</table>

2.5.5 Propulsion Engines Low Load Emission Factors

In general terms, diesel-cycle engines are not as efficient when operated at low loads. An EPA study$^{34}$ prepared by Energy and Environmental Analysis, Inc. (EEIA) has established a formula for calculating emission factors for low engine load conditions such as those encountered during harbor maneuvering and when traveling slowly at sea such as in the reduced speed zone. While mass emissions (e.g., pounds per hour) tend to go down as vessel speeds and engine loads decrease, the emission factors (e.g., g/kW-hr) increase. This is based on observations that compression-cycle combustion engines are less efficient at low loads.

---

The following equations describe the low-load effect where emission rates can increase, based on a limited set of data from Lloyd’s Maritime Program and the U.S. Coast Guard. The low load effect was described in a study conducted for the EPA by ENVIRON.35

Equation 2.5 is the EEIA formula used to generate emission factors for the range of load factors from 2% to 20% for each pollutant:

\[ y = a(fractional \ load)^x + b \]  

Where:

- \( y \) = emission factors in g/kW-hr
- \( a \) = coefficient
- \( b \) = intercept
- \( x \) = exponent (negative)
- fractional load = derived by the Propeller Law (see equation 2.3)

Table 2.7 provides the variables for Equation 2.5. These variables are slightly different from previous inventory reports due to slight modification for rounding. The modified variables reflect 4 decimal places of precision.

Table 2.7: Low-Load Emission Factor Regression Equation Variables as Modified

<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\textsubscript{X}</td>
<td>1.5</td>
<td>10.4496</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 provides the emission factors based on Equation 2.5 and variables in Table 2.7 at 2% to 20% loads.

### Table 2.8: EEIA Emission Factors, g/kW-hr

<table>
<thead>
<tr>
<th>Load</th>
<th>PM</th>
<th>NO&lt;sub&gt;x&lt;/sub&gt;</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>
<tr>
<td>20%</td>
<td>0.32</td>
<td>11.85</td>
<td>4.33</td>
<td>1.13</td>
</tr>
</tbody>
</table>

The low load adjustment (LLA) multipliers that are applied to the propulsion engine g/kW-hr emission factors are then determined by dividing each of the EEIA emission factors by the emission factor at 20% load using Equation 2.6. This results in positive numbers greater than one, since emissions increase as load is decreased. At 20% load, the value is exactly 1.0 since it is divided into itself.

**Equation 2.6**

\[
LLA \text{ (at \% load)} = \frac{y \text{ (at \% load)}}{y \text{ (at 20\% load)}}
\]

Where:

- \( LLA \) = Low load adjustment multiplier
- \( y \) = emission factor in g/kW-hr from equation 2.5 (see Table 2.8)
Table 2.9 lists the resulting low-load adjustment factors for diesel propulsion engines. Adjustments to N\textsubscript{2}O and CH\textsubscript{4} emission factors are made on the basis of the NO\textsubscript{x} and HC low load adjustments, respectively. The LLA is not applied at engine loads greater than 20%. For main engine loads below 20 percent, the LLA increases so as to reflect increased emissions (on a g/kW-hr basis) due to engine inefficiency. Low load emission factors are not applied to steamships or ships having gas turbines because the EPA study only observed a rise in emissions from diesel engines.

### Table 2.9: Low Load Adjustment Multipliers for Emission Factors

<table>
<thead>
<tr>
<th>Load</th>
<th>PM</th>
<th>NO\textsubscript{x}</th>
<th>SO\textsubscript{x}</th>
<th>CO</th>
<th>HC</th>
<th>CO\textsubscript{2}</th>
<th>N\textsubscript{2}O</th>
<th>CH\textsubscript{4}</th>
</tr>
</thead>
<tbody>
<tr>
<td>2%</td>
<td>7.29</td>
<td>4.63</td>
<td>1.00</td>
<td>9.68</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>6.46</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>3.89</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>3.25</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>2.79</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>1.96</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>
<td>19%</td>
<td>1.02</td>
<td>1.01</td>
<td>1.00</td>
<td>1.05</td>
<td>1.05</td>
<td>1.00</td>
<td>1.01</td>
<td>1.05</td>
</tr>
<tr>
<td>20%</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>
<td>1.00</td>
<td>1.00</td>
</tr>
</tbody>
</table>

The LLA multipliers are applied to the at-sea emission factors for diesel propulsion engines only. 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.

**Equation 2.7**

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

Where:

- \(\text{EF}\) = Resulting emission factor
- Base EF = Emission factor for diesel propulsion engines (see Tables 2.5 and 2.6)
- LLA = Low load adjustment multiplier (see Table 2.9)
2.5.6 Propulsion Engine Harbor Maneuvering Loads
Main engine loads within a harbor tend to be very light, especially on in-bound trips when the main engines are off for periods of time as the vessels are being maneuvered to their berths. During docking, when the ship is being positioned against the wharf, the assist tugboats do most of the work and the main engines are off. Main engine maneuvering loads are estimated using the Propeller Law, with the over-riding assumption that the lowest average engine load is 2%.

Harbor transit speeds within the breakwater were profiled from VBP information as follows:
- Inbound fast ships (auto, container, cruise ships) at 7 knots
- Inbound slow ships (any other vessel type) at 5 knots
- Outbound traffic for all vessels at 8 knots

The departure speed, and hence the departure load, is typically higher than on arrival because on departure the engine power is used to accelerate the vessel away from the berth, while on arrival the vessel usually travels slower and spends some time with the main engine off.

2.5.7 Propulsion Engine Defaults
All the vessels that called the Port in 2009 were matched for main engine power using the most current Lloyd’s data and VBP information, except for ocean tugs. Therefore, defaults were only used for ocean tugs’ main engine power.

2.5.8 Auxiliary Engine Emission Factors
The ENTEC auxiliary engine emission factors used in this study are presented in Table 2.10.

Table 2.10: Emission Factors for Auxiliary Engines using Residual Oil, g/kW-hr

<table>
<thead>
<tr>
<th>Engine</th>
<th>MY</th>
<th>PM_{10}</th>
<th>PM_{2.5}</th>
<th>DPM</th>
<th>NOx</th>
<th>SOx</th>
<th>CO</th>
<th>HC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medium speed</td>
<td>≤ 1999</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>Medium speed</td>
<td>2000+</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>
</tbody>
</table>

Table 2.11: GHG Emission Factors for Auxiliary Engines using Residual Oil, g/kW-hr

<table>
<thead>
<tr>
<th>Engine</th>
<th>MY</th>
<th>CO₂</th>
<th>N₂O</th>
<th>CH₄</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medium speed</td>
<td>all</td>
<td>683</td>
<td>0.031</td>
<td>0.008</td>
</tr>
</tbody>
</table>

3⁶ IVL 2004.
2.5.9 Auxiliary Engine Defaults
Lloyd’s database contains limited auxiliary engine’s installed power information because IMO or the classification societies do not require vessel owners to provide this information. Therefore, auxiliary engine load data for each vessel follows the hierarchy described in section 2.3.5 (i.e., VBP, sister ships, Port defaults). Defaults for auxiliary engine loads were based on the vessel class averages of the installed auxiliary engine power from Lloyds and VBP data and load factors by vessel class by mode, which were derived from historical VBP data. Since the defaults are based on the vessels that visit the Port that year, defaults will vary slightly from year to year due to changes in Lloyd’s data or the type of vessels that visit the port. Table 2.12 summarizes the auxiliary engine load defaults used for this study by vessel subtype. For diesel electric cruise ships, house load defaults are listed in Table 2.13.

Table 2.12: Auxiliary Engine Load Defaults

<table>
<thead>
<tr>
<th>Vessel Type</th>
<th>Auxiliary Engine Load Defaults (kW)</th>
<th>Berth</th>
<th>Anchorage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sea</td>
<td>Maneuvering</td>
<td>Hotelling</td>
</tr>
<tr>
<td>Auto Carrier</td>
<td>605</td>
<td>1,814</td>
<td>1,048</td>
</tr>
<tr>
<td>Bulk</td>
<td>282</td>
<td>746</td>
<td>166</td>
</tr>
<tr>
<td>Bulk - Heavy Load</td>
<td>318</td>
<td>841</td>
<td>187</td>
</tr>
<tr>
<td>Bulk - Self Discharging</td>
<td>461</td>
<td>1,220</td>
<td>271</td>
</tr>
<tr>
<td>Bulk - Wood Chips</td>
<td>282</td>
<td>746</td>
<td>166</td>
</tr>
<tr>
<td>Container - 1000</td>
<td>395</td>
<td>1,520</td>
<td>547</td>
</tr>
<tr>
<td>Container - 2000</td>
<td>507</td>
<td>1,676</td>
<td>857</td>
</tr>
<tr>
<td>Container - 3000</td>
<td>897</td>
<td>2,966</td>
<td>1,518</td>
</tr>
<tr>
<td>Container - 4000</td>
<td>893</td>
<td>3,434</td>
<td>1,236</td>
</tr>
<tr>
<td>Container - 5000</td>
<td>1,116</td>
<td>4,207</td>
<td>1,288</td>
</tr>
<tr>
<td>Container - 6000</td>
<td>1,669</td>
<td>6,421</td>
<td>1,926</td>
</tr>
<tr>
<td>Container - 7000</td>
<td>1,404</td>
<td>5,400</td>
<td>1,620</td>
</tr>
<tr>
<td>Container - 8000</td>
<td>1,573</td>
<td>6,051</td>
<td>1,815</td>
</tr>
<tr>
<td>Cruise</td>
<td>5,510</td>
<td>9,367</td>
<td>5,510</td>
</tr>
<tr>
<td>General Cargo</td>
<td>334</td>
<td>883</td>
<td>432</td>
</tr>
<tr>
<td>Ocean Tug</td>
<td>71</td>
<td>188</td>
<td>92</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>798</td>
<td>2,112</td>
<td>1,033</td>
</tr>
<tr>
<td>Reefer</td>
<td>467</td>
<td>1,400</td>
<td>995</td>
</tr>
<tr>
<td>RoRo</td>
<td>595</td>
<td>1,784</td>
<td>1,031</td>
</tr>
<tr>
<td>Tanker - Aframax</td>
<td>612</td>
<td>842</td>
<td>663</td>
</tr>
<tr>
<td>Tanker - Chemical</td>
<td>694</td>
<td>954</td>
<td>752</td>
</tr>
<tr>
<td>Tanker - Handyboat</td>
<td>465</td>
<td>640</td>
<td>504</td>
</tr>
<tr>
<td>Tanker - Panamax</td>
<td>611</td>
<td>841</td>
<td>662</td>
</tr>
<tr>
<td>Tanker - Suezmax</td>
<td>1,415</td>
<td>1,946</td>
<td>1,533</td>
</tr>
<tr>
<td>Tanker - VLCC</td>
<td>1,099</td>
<td>1,511</td>
<td>1,191</td>
</tr>
</tbody>
</table>
Table 2.13: Diesel Electric Cruise Ship Auxiliary Engine Load Defaults

<table>
<thead>
<tr>
<th>Vessel Type</th>
<th>Passenger Count</th>
<th>Auxiliary Engine Load Defaults (kW)</th>
<th>Berth</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Sea</td>
<td>Maneuvering</td>
</tr>
<tr>
<td>Cruise, Diesel Electric</td>
<td>0-1,500</td>
<td>3,500</td>
<td>3,500</td>
</tr>
<tr>
<td>Cruise, Diesel Electric</td>
<td>1,500-2,000</td>
<td>7,000</td>
<td>7,000</td>
</tr>
<tr>
<td>Cruise, Diesel Electric</td>
<td>2,000-3,000</td>
<td>10,500</td>
<td>10,500</td>
</tr>
<tr>
<td>Cruise, Diesel Electric</td>
<td>3,000-3,500</td>
<td>11,000</td>
<td>11,000</td>
</tr>
<tr>
<td>Cruise, Diesel Electric</td>
<td>3,500-4,000</td>
<td>11,500</td>
<td>11,500</td>
</tr>
<tr>
<td>Cruise, Diesel Electric</td>
<td>4,000+</td>
<td>12,000</td>
<td>12,000</td>
</tr>
</tbody>
</table>

2.5.10 Auxiliary Boilers Emission Factors

In addition to the auxiliary engines that are used to generate electricity for on-board uses, most OGVs have one or more boilers used for fuel heating and for producing hot water. Boilers are typically 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. Therefore, the boilers are not needed when the main engines are used. Vessel speeds have been reduced in recent years due to increased compliance with the VSR program extending up to 40 nm. Because of these lower speeds, it is believed that auxiliary boilers are used during transit when the lower speeds result in the cooling of main engine exhausts, making the vessels’ economizers less effective. As such, it is assumed that auxiliary boilers operate when the main engine power load is less than 20% during maneuvering and transit.

Table 2.14 and Table 2.15 shows the emission factors used for the steam boilers based on ENTEC’s emission factors for steam boilers.

Table 2.14: Emission Factors for OGV Auxiliary Boilers using Residual Oil, g/kW-hr

<table>
<thead>
<tr>
<th></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>Steam boilers</td>
<td>0.8</td>
<td>0.6</td>
<td>0.0</td>
<td>2.1</td>
<td>16.5</td>
<td>0.2</td>
<td>0.1</td>
</tr>
</tbody>
</table>

Table 2.15: GHG Emission Factors for OGV Auxiliary Boilers using Residual Oil, g/kW-hr

<table>
<thead>
<tr>
<th></th>
<th>CO$_2$</th>
<th>N$_2$O</th>
<th>CH$_4$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steam boilers</td>
<td>970</td>
<td>0.08</td>
<td>0.002</td>
</tr>
</tbody>
</table>
2.5.11 Auxiliary Boilers Defaults

The boiler fuel consumption data collected from vessels during the VBP was converted to equivalent kilowatts using Specific Fuel Consumption (SFC) factors found in the ENTEC report\textsuperscript{37}. The average SFC value for using residual fuel is 305 grams of fuel per kW-hour. Using the following equation, the average kW for auxiliary boilers was calculated.

\begin{equation}
\text{Average kW} = \frac{((\text{daily fuel/24}) \times 1,000,000)}{305}
\end{equation}

Auxiliary boiler energy defaults in kilowatts used for each vessel type are presented in Table 2.16. The cruise ships and tankers (except for diesel electric tankers and cruise ships) have much higher auxiliary boiler usage rates than the other vessel types. Cruise ships have higher boiler usage due to the number of passengers and need for hot water. Tankers provide steam for steam-powered liquid pumps, inert gas in fuel tanks, and to heat fuel for pumping. Ocean tugboats do not have boilers; therefore their boiler energy default is zero. As mentioned earlier, boilers are not typically used at sea during normal transit; therefore the boiler energy default at sea is zero (if main engine load is greater than 20\%). If the main engine load is less than or equal to 20\%, the maneuvering boiler load defaults shown in the table are used which are similar to hotelling defaults, except for the tankers. The auxiliary boiler load defaults are based on the latest available VBP data, and therefore, are different from the defaults used in previous inventories.

Table 2.16: Auxiliary Boiler Energy Defaults

<table>
<thead>
<tr>
<th>Vessel Type</th>
<th>Sea</th>
<th>Maneuvering</th>
<th>Berth</th>
<th>Anchorage</th>
<th>Hotelling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Auto Carrier</td>
<td>0</td>
<td>254</td>
<td>254</td>
<td>254</td>
<td></td>
</tr>
<tr>
<td>Bulk</td>
<td>0</td>
<td>130</td>
<td>130</td>
<td>130</td>
<td></td>
</tr>
<tr>
<td>Bulk - Heavy Load</td>
<td>0</td>
<td>130</td>
<td>130</td>
<td>130</td>
<td></td>
</tr>
<tr>
<td>Bulk - Self Discharging</td>
<td>0</td>
<td>130</td>
<td>130</td>
<td>130</td>
<td></td>
</tr>
<tr>
<td>Bulk - Wood Chips</td>
<td>0</td>
<td>130</td>
<td>130</td>
<td>130</td>
<td></td>
</tr>
<tr>
<td>Container - 1000</td>
<td>0</td>
<td>298</td>
<td>298</td>
<td>298</td>
<td></td>
</tr>
<tr>
<td>Container - 2000</td>
<td>0</td>
<td>253</td>
<td>253</td>
<td>253</td>
<td></td>
</tr>
<tr>
<td>Container - 3000</td>
<td>0</td>
<td>537</td>
<td>537</td>
<td>537</td>
<td></td>
</tr>
<tr>
<td>Container - 4000</td>
<td>0</td>
<td>578</td>
<td>578</td>
<td>578</td>
<td></td>
</tr>
<tr>
<td>Container - 5000</td>
<td>0</td>
<td>722</td>
<td>722</td>
<td>722</td>
<td></td>
</tr>
<tr>
<td>Container - 6000</td>
<td>0</td>
<td>667</td>
<td>667</td>
<td>667</td>
<td></td>
</tr>
<tr>
<td>Container - 7000</td>
<td>0</td>
<td>462</td>
<td>462</td>
<td>462</td>
<td></td>
</tr>
<tr>
<td>Container - 8000</td>
<td>0</td>
<td>705</td>
<td>705</td>
<td>705</td>
<td></td>
</tr>
<tr>
<td>Cruise</td>
<td>0</td>
<td>1,705</td>
<td>1,705</td>
<td>1,705</td>
<td></td>
</tr>
<tr>
<td>General Cargo</td>
<td>0</td>
<td>130</td>
<td>130</td>
<td>130</td>
<td></td>
</tr>
<tr>
<td>Ocean Tug</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>0</td>
<td>137</td>
<td>137</td>
<td>137</td>
<td></td>
</tr>
<tr>
<td>Reefer</td>
<td>0</td>
<td>464</td>
<td>464</td>
<td>464</td>
<td></td>
</tr>
<tr>
<td>RoRo</td>
<td>0</td>
<td>248</td>
<td>248</td>
<td>248</td>
<td></td>
</tr>
<tr>
<td>Tanker - Aframax</td>
<td>0</td>
<td>371</td>
<td>3,000</td>
<td>371</td>
<td></td>
</tr>
<tr>
<td>Tanker - Chemical</td>
<td>0</td>
<td>371</td>
<td>3,000</td>
<td>371</td>
<td></td>
</tr>
<tr>
<td>Tanker - Handyboat</td>
<td>0</td>
<td>371</td>
<td>3,000</td>
<td>371</td>
<td></td>
</tr>
<tr>
<td>Tanker - Panamax</td>
<td>0</td>
<td>371</td>
<td>3,000</td>
<td>371</td>
<td></td>
</tr>
<tr>
<td>Tanker - Suezmax</td>
<td>0</td>
<td>371</td>
<td>3,000</td>
<td>371</td>
<td></td>
</tr>
<tr>
<td>Tanker - VLCC</td>
<td>0</td>
<td>371</td>
<td>3,000</td>
<td>371</td>
<td></td>
</tr>
</tbody>
</table>
2.5.12 Fuel Correction Factors

Fuel correction factors are used to adjust the emission rates from the fuel. As discussed earlier, emission factors were given for engines using residual fuel with an average 2.7% sulfur content or marine diesel oil with an average 1.5% sulfur content. Table 2.17 lists the fuel correction factors for fuels with different sulfur content. These fuel correction factors are consistent with CARB’s emission estimations methodology for ocean-going vessels. The FCFs are applied to propulsion and auxiliary engines and auxiliary boilers if they switch fuel from the default residual fuel (2.7% S average).

Table 2.17: Fuel Correction Factors

<table>
<thead>
<tr>
<th>Actual Fuel</th>
<th>Sulfur Content</th>
<th>PM</th>
<th>NO&lt;sub&gt;x&lt;/sub&gt;</th>
<th>SO&lt;sub&gt;x&lt;/sub&gt;</th>
<th>CO</th>
<th>HC</th>
<th>CO&lt;sub&gt;2&lt;/sub&gt;</th>
<th>N&lt;sub&gt;2&lt;/sub&gt;O</th>
<th>CH&lt;sub&gt;4&lt;/sub&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>HFO</td>
<td>1.5%</td>
<td>0.82</td>
<td>1.00</td>
<td>0.56</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>MDO</td>
<td>1.5%</td>
<td>0.47</td>
<td>0.90</td>
<td>0.56</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>0.90</td>
<td>1.00</td>
</tr>
<tr>
<td>MGO</td>
<td>0.5%</td>
<td>0.25</td>
<td>0.94</td>
<td>0.18</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>0.94</td>
<td>1.00</td>
</tr>
<tr>
<td>MGO</td>
<td>0.2%</td>
<td>0.19</td>
<td>0.94</td>
<td>0.07</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>0.94</td>
<td>1.00</td>
</tr>
<tr>
<td>MGO</td>
<td>0.1%</td>
<td>0.17</td>
<td>0.94</td>
<td>0.04</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>0.94</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Beginning July 1, 2009, CARB’s marine auxiliary engine fuel regulation (adopted in July 2008) required vessel operators to use MGO with a sulfur content less than 1.5% by weight or 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 main, auxiliary and auxiliary boilers. For the period of July 1, 2009 to December 31, 2009, a 100% compliance is assumed with CARB’s regulation (and confirmed by CARB). During this period, an average 0.5% sulfur fuel content is assumed for both main and auxiliary engines and auxiliary boilers.

From January 1, 2009 to June 30, 2009, the Port continued to implement its Vessel Fuel Incentive Program which provided incentives to vessel operators switching to low-sulfur marine fuel (i.e., fuel with sulfur content of 0.2% or less) in their auxiliary engines (while at berth) and main engines within at least 20 nm and up to 40 nm of the Port and also complying with the Port’s VSR program. For vessels that participated in the Vessel Fuel Incentive Program in 2009, the emissions benefits due to the use of lower sulfur fuel (0.2% S) are reflected during this period.

The fuel switches accounted for in the Port’s program for the first half of 2009 represents a conservative approach as there may have been other companies that switched to lower sulfur fuel during this period that the Port was not aware of because they did not enroll or participate in the Port’s Fuel Incentive Program.

30 See http://www.arb.ca.gov/Regact/2008/fuelogv08/fuelogv08.htm; Appendix D, Tables II-6 to II-8.
2.5.13 Emission Reduction Technologies
Control factors are used to take into account the emissions benefits associated with emission reduction technologies installed on vessels. One such technology for marine main engines is the fuel slide valve. This new type of fuel valve leads to a better combustion process, less smoke, and lower fuel consumption, which results in reduced overall emissions for NO\textsubscript{x} (30% reduction) and PM (25% reduction). The newer MAN B&W engines (2004+ model year vessels) are equipped with the fuel slide valves. Some companies are also retrofitting their vessels equipped with MAN B&W main engines with slide valves. Since information on slide valve retrofits has primarily been collected through VBP surveys, the inventory may not have captured all the vessels that have been retrofitted with slide valves. The emission reduction estimates for the slide valves are based on MAN B&W Diesel A/S emission measurements. In order to obtain the latest information on the applicability and control effectiveness of slide valves, the representative from MAN B&W in Denmark was recently contacted. Based on the recent communication with MAN B&W and preliminary information provided, for the 2009 inventory, the current emission reduction benefits (i.e., 30% NOx and 25% PM reductions) are applied to 2004 and newer vessels equipped with MAN B&W engines as well as to existing engines known to be retrofitted with slide valves. The ports will continue to work with MAN B&W and the Technical Working Group (TWG) to refine the emission benefits for slide valves used in new engines and as retrofits for future EIs to ensure that the latest available information is used.

In 2009, slide fuel valves were used by 300 vessels that made 860 calls to the Port, representing 38% of all vessel calls. This includes the 2004 and newer vessels with MAN B&W engines and the known vessels that retrofitted their main engines with slide valves.

In addition, shore side electrical power was used for 70 vessel calls representing about 3% of all vessel calls. At-berth reduction of 95% in all pollutants for auxiliary engines emissions is assumed for ships that used shore side electrical power. This reduction estimate accounts for the time necessary to connect and disconnect the electrical power and start-up the auxiliary engines.

2.5.14 Changes to methodology from previous years
There were no changes to the ocean going vessels emission calculation methodology in this inventory compared to the 2008 methodology. For comparison of 2009 emissions to 2005 emissions, refer to Section 8.
2.6 Emission Estimates

A summary of the ocean-going vessel emission estimates by vessel type for all pollutants for the year 2009 is presented in Tables 2.18 and 2.19. Ocean-going vessel data is presented in Appendix A.

Table 2.18: 2009 Ocean-going Vessel Emissions by Vessel Type, tpy

<table>
<thead>
<tr>
<th>Vessel 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>Auto Carrier</td>
<td>11.6</td>
<td>9.3</td>
<td>10.3</td>
<td>144.8</td>
<td>104.7</td>
<td>13.8</td>
<td>5.7</td>
</tr>
<tr>
<td>Bulk</td>
<td>11.4</td>
<td>9.1</td>
<td>10.1</td>
<td>157.3</td>
<td>104.7</td>
<td>14.3</td>
<td>6.0</td>
</tr>
<tr>
<td>Containership</td>
<td>157.7</td>
<td>126.1</td>
<td>138.5</td>
<td>2,166.6</td>
<td>1,266.1</td>
<td>249.7</td>
<td>119.3</td>
</tr>
<tr>
<td>Cruise</td>
<td>32.0</td>
<td>25.6</td>
<td>32.0</td>
<td>648.0</td>
<td>226.0</td>
<td>53.0</td>
<td>20.0</td>
</tr>
<tr>
<td>General Cargo</td>
<td>4.9</td>
<td>3.9</td>
<td>4.5</td>
<td>70.1</td>
<td>41.4</td>
<td>6.0</td>
<td>2.5</td>
</tr>
<tr>
<td>Ocean Tug</td>
<td>0.5</td>
<td>0.4</td>
<td>0.5</td>
<td>18.5</td>
<td>3.1</td>
<td>1.7</td>
<td>0.7</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>10.0</td>
<td>8.0</td>
<td>9.6</td>
<td>350.9</td>
<td>66.1</td>
<td>28.1</td>
<td>10.3</td>
</tr>
<tr>
<td>Reefer</td>
<td>1.4</td>
<td>1.1</td>
<td>1.1</td>
<td>12.1</td>
<td>13.5</td>
<td>1.0</td>
<td>0.4</td>
</tr>
<tr>
<td>RoRo</td>
<td>1.1</td>
<td>0.8</td>
<td>0.9</td>
<td>14.5</td>
<td>9.5</td>
<td>1.1</td>
<td>0.4</td>
</tr>
<tr>
<td>Tanker</td>
<td>157.0</td>
<td>125.6</td>
<td>107.9</td>
<td>1,565.9</td>
<td>1,818.4</td>
<td>143.3</td>
<td>57.9</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>387.6</strong></td>
<td><strong>310.1</strong></td>
<td><strong>315.6</strong></td>
<td><strong>5,148.8</strong></td>
<td><strong>3,651.3</strong></td>
<td><strong>512.0</strong></td>
<td><strong>223.2</strong></td>
</tr>
</tbody>
</table>

Table 2.19: 2009 Ocean-going Vessel GHG Emissions by Vessel Type, metric tons per year

<table>
<thead>
<tr>
<th>Vessel Type</th>
<th>CO$_2$</th>
<th>CO$_2$</th>
<th>N$_2$O</th>
<th>CH$_4$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Equivalent</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Auto Carrier</td>
<td>7,920.7</td>
<td>7,789.4</td>
<td>0.4</td>
<td>0.1</td>
</tr>
<tr>
<td>Bulk</td>
<td>8,782.9</td>
<td>8,638.6</td>
<td>0.5</td>
<td>0.1</td>
</tr>
<tr>
<td>Containership</td>
<td>120,134.0</td>
<td>118,008.2</td>
<td>6.7</td>
<td>2.2</td>
</tr>
<tr>
<td>Cruise</td>
<td>30,338.4</td>
<td>29,928.0</td>
<td>1.3</td>
<td>0.4</td>
</tr>
<tr>
<td>General Cargo</td>
<td>3,538.2</td>
<td>3,481.6</td>
<td>0.2</td>
<td>0.0</td>
</tr>
<tr>
<td>Ocean Tug</td>
<td>879.0</td>
<td>867.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>17,352.1</td>
<td>17,105.2</td>
<td>0.8</td>
<td>0.2</td>
</tr>
<tr>
<td>Reefer</td>
<td>714.4</td>
<td>701.3</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>RoRo</td>
<td>828.6</td>
<td>815.2</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Tanker</td>
<td>149,987.3</td>
<td>147,040.8</td>
<td>9.4</td>
<td>1.1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>340,475.8</strong></td>
<td><strong>334,375.3</strong></td>
<td><strong>19.4</strong></td>
<td><strong>4.1</strong></td>
</tr>
</tbody>
</table>
Figure 2.6 shows percentage of emissions by vessel type for each pollutant. Containerships have the highest percentage of overall emissions for the vessels (approximately 35 to 50%), followed by tankers (approximately 25 to 50%), cruise ships, bulk vessels, auto carriers, miscellaneous vessels, general cargo, ocean tugs, reefers, and RoRos. The “other” category includes reefers, ocean-going tugboats and RoRos.

![Figure 2.6: 2009 Ocean-going Vessel Emissions by Vessel Type, %](image)

### 2.6.1 Emission Estimates by Engine Type
Tables 2.20 and 2.21 present summaries of emission estimates by engine type in tons per year.

**Table 2.20: 2009 Ocean-going Vessel Emissions by Engine Type, tpy**

<table>
<thead>
<tr>
<th>Engine 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>Auxiliary Engine</td>
<td>216.5</td>
<td>173.2</td>
<td>216.5</td>
<td>3,350.0</td>
<td>1,654.7</td>
<td>281.3</td>
<td>102.3</td>
</tr>
<tr>
<td>Auxiliary Boiler</td>
<td>71.6</td>
<td>57.2</td>
<td>0.0</td>
<td>284.1</td>
<td>1,409.5</td>
<td>27.9</td>
<td>13.9</td>
</tr>
<tr>
<td>Main Engine</td>
<td>99.5</td>
<td>79.6</td>
<td>99.1</td>
<td>1,514.7</td>
<td>587.1</td>
<td>202.8</td>
<td>107.0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>387.6</td>
<td>310.1</td>
<td>315.6</td>
<td>5,148.8</td>
<td>3,651.3</td>
<td>512.0</td>
<td>223.2</td>
</tr>
</tbody>
</table>
Table 2.21: 2009 Ocean-going Vessel GHG Emissions by Engine Type, metric tons

<table>
<thead>
<tr>
<th>Engine Type</th>
<th>CO₂</th>
<th>CO₂</th>
<th>N₂O</th>
<th>CH₄</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Equivalent</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Auxiliary Engine</td>
<td>160,999.5</td>
<td>158,803.1</td>
<td>7.0</td>
<td>1.9</td>
</tr>
<tr>
<td>Auxiliary Boiler</td>
<td>125,888.4</td>
<td>122,832.4</td>
<td>9.8</td>
<td>0.3</td>
</tr>
<tr>
<td>Main Engine</td>
<td>53,587.9</td>
<td>52,739.7</td>
<td>2.6</td>
<td>1.9</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>340,475.8</strong></td>
<td><strong>334,375.3</strong></td>
<td><strong>19.4</strong></td>
<td><strong>4.1</strong></td>
</tr>
</tbody>
</table>

Figure 2.7 shows results in percentages for emission estimates by engine type.

**Figure 2.7:** 2009 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 in tons per year.

#### Table 2.22: 2009 Ocean-going Vessel Emissions by Mode, tpy

<table>
<thead>
<tr>
<th>Mode</th>
<th>Engine 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>Transit</td>
<td>Auxiliary Engine</td>
<td>28.0</td>
<td>22.4</td>
<td>28.0</td>
<td>400.4</td>
<td>218.1</td>
<td>32.8</td>
<td>11.9</td>
</tr>
<tr>
<td>Transit</td>
<td>Auxiliary Boiler</td>
<td>2.5</td>
<td>2.0</td>
<td>0.0</td>
<td>10.1</td>
<td>48.3</td>
<td>1.0</td>
<td>0.5</td>
</tr>
<tr>
<td>Transit</td>
<td>Main Engine</td>
<td>87.1</td>
<td>69.7</td>
<td>86.7</td>
<td>1,359.7</td>
<td>556.3</td>
<td>172.9</td>
<td>84.1</td>
</tr>
<tr>
<td><strong>Total Transit</strong></td>
<td></td>
<td><strong>117.5</strong></td>
<td><strong>94.0</strong></td>
<td><strong>114.6</strong></td>
<td><strong>1,770.1</strong></td>
<td><strong>822.6</strong></td>
<td><strong>206.8</strong></td>
<td><strong>96.5</strong></td>
</tr>
<tr>
<td>Maneuvering</td>
<td>Auxiliary Engine</td>
<td>11.7</td>
<td>9.3</td>
<td>11.7</td>
<td>163.6</td>
<td>90.8</td>
<td>13.7</td>
<td>5.0</td>
</tr>
<tr>
<td>Maneuvering</td>
<td>Auxiliary Boiler</td>
<td>0.9</td>
<td>0.7</td>
<td>0.0</td>
<td>3.7</td>
<td>18.0</td>
<td>0.4</td>
<td>0.2</td>
</tr>
<tr>
<td>Maneuvering</td>
<td>Main Engine</td>
<td>12.4</td>
<td>9.9</td>
<td>12.4</td>
<td>155.0</td>
<td>30.8</td>
<td>29.8</td>
<td>22.9</td>
</tr>
<tr>
<td><strong>Total Maneuvering</strong></td>
<td></td>
<td><strong>25.0</strong></td>
<td><strong>20.0</strong></td>
<td><strong>24.0</strong></td>
<td><strong>322.3</strong></td>
<td><strong>139.6</strong></td>
<td><strong>43.9</strong></td>
<td><strong>28.1</strong></td>
</tr>
<tr>
<td>Hotelling - Berth</td>
<td>Auxiliary Engine</td>
<td>115.9</td>
<td>92.7</td>
<td>115.9</td>
<td>2,053.4</td>
<td>861.2</td>
<td>172.3</td>
<td>62.7</td>
</tr>
<tr>
<td>Hotelling - Berth</td>
<td>Auxiliary Boiler</td>
<td>58.1</td>
<td>46.5</td>
<td>0.0</td>
<td>233.1</td>
<td>1,143.4</td>
<td>22.9</td>
<td>11.4</td>
</tr>
<tr>
<td>Hotelling - 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><strong>174.0</strong></td>
<td><strong>139.2</strong></td>
<td><strong>115.9</strong></td>
<td><strong>2,286.5</strong></td>
<td><strong>2,004.6</strong></td>
<td><strong>195.2</strong></td>
<td><strong>74.1</strong></td>
</tr>
<tr>
<td>Hotelling - Anchorage</td>
<td>Auxiliary Engine</td>
<td>61.1</td>
<td>48.9</td>
<td>61.1</td>
<td>732.6</td>
<td>484.6</td>
<td>62.5</td>
<td>22.7</td>
</tr>
<tr>
<td>Hotelling - Anchorage</td>
<td>Auxiliary Boiler</td>
<td>10.1</td>
<td>8.0</td>
<td>0.0</td>
<td>37.2</td>
<td>199.8</td>
<td>3.6</td>
<td>1.8</td>
</tr>
<tr>
<td>Hotelling - 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><strong>71.1</strong></td>
<td><strong>56.9</strong></td>
<td><strong>61.1</strong></td>
<td><strong>769.8</strong></td>
<td><strong>684.4</strong></td>
<td><strong>66.1</strong></td>
<td><strong>24.5</strong></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>387.6</strong></td>
<td><strong>310.1</strong></td>
<td><strong>315.6</strong></td>
<td><strong>5,148.8</strong></td>
<td><strong>3,651.3</strong></td>
<td><strong>512.0</strong></td>
<td><strong>223.2</strong></td>
</tr>
</tbody>
</table>
Table 2.23: 2009 Ocean-going Vessel Greenhouse Gas Emissions by Mode, metric tons

<table>
<thead>
<tr>
<th>Mode</th>
<th>Engine Type</th>
<th>CO₂</th>
<th>CO₂</th>
<th>N₂O</th>
<th>CH₄</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Equivalent</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transit</td>
<td>Auxiliary Engine</td>
<td>18,791.4</td>
<td>18,533.9</td>
<td>0.8</td>
<td>0.2</td>
</tr>
<tr>
<td>Transit</td>
<td>Auxiliary Boiler</td>
<td>4,479.4</td>
<td>4,370.8</td>
<td>0.3</td>
<td>0.0</td>
</tr>
<tr>
<td>Transit</td>
<td>Main Engine</td>
<td>50,688.2</td>
<td>49,929.4</td>
<td>2.3</td>
<td>1.5</td>
</tr>
<tr>
<td>Total Transit</td>
<td></td>
<td>73,958.9</td>
<td>72,834.0</td>
<td>3.5</td>
<td>1.8</td>
</tr>
<tr>
<td>Maneuvering</td>
<td>Auxiliary Engine</td>
<td>7,850.4</td>
<td>7,742.8</td>
<td>0.3</td>
<td>0.1</td>
</tr>
<tr>
<td>Maneuvering</td>
<td>Auxiliary Boiler</td>
<td>1,631.7</td>
<td>1,592.1</td>
<td>0.1</td>
<td>0.0</td>
</tr>
<tr>
<td>Maneuvering</td>
<td>Main Engine</td>
<td>2,899.7</td>
<td>2,810.3</td>
<td>0.3</td>
<td>0.4</td>
</tr>
<tr>
<td>Total Maneuvering</td>
<td></td>
<td>12,381.8</td>
<td>12,145.3</td>
<td>0.7</td>
<td>0.5</td>
</tr>
<tr>
<td>Hotelling - Berth</td>
<td>Auxiliary Engine</td>
<td>98,588.9</td>
<td>97,251.4</td>
<td>4.2</td>
<td>1.1</td>
</tr>
<tr>
<td>Hotelling - Berth</td>
<td>Auxiliary Boiler</td>
<td>103,341.7</td>
<td>100,834.4</td>
<td>8.1</td>
<td>0.2</td>
</tr>
<tr>
<td>Hotelling - Berth</td>
<td>Main Engine</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Total Hotelling - Berth</td>
<td></td>
<td>201,930.5</td>
<td>198,085.8</td>
<td>12.3</td>
<td>1.3</td>
</tr>
<tr>
<td>Hotelling - Anchorage</td>
<td>Auxiliary Engine</td>
<td>35,768.8</td>
<td>35,275.0</td>
<td>1.6</td>
<td>0.4</td>
</tr>
<tr>
<td>Hotelling - Anchorage</td>
<td>Auxiliary Boiler</td>
<td>16,435.6</td>
<td>16,035.1</td>
<td>1.3</td>
<td>0.0</td>
</tr>
<tr>
<td>Hotelling - Anchorage</td>
<td>Main Engine</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Total Hotelling - Anchorage</td>
<td></td>
<td>52,204.5</td>
<td>51,310.1</td>
<td>2.9</td>
<td>0.4</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>340,475.8</td>
<td>334,375.3</td>
<td>19.4</td>
<td>4.1</td>
</tr>
</tbody>
</table>
Figure 2.8 summarizes the percentage of emissions by mode.

Figure 2.8: 2009 Ocean-going Vessel Emissions by Mode

2.7 Facts and Findings

Table 2.24 summarizes the number of incoming calls and total TEUs handled by the Port in 2005 and 2009 as well as the average TEUs per containership call. In 2009, about 5.07 million total TEUs were handled at the Port compared to 6.7 million total TEUs in 2005, representing a 24% reduction in 2009, reflective of the recent global economic conditions. The number of vessel calls decreased by 15% for all vessel types including containerships. The 2009 average TEUs per containership call also decreased by 11% from 2005 possibly due to containerships either running less full, calling at more west-coast berths per service, or discharging more cargo at other ports.

Table 2.24: TEUs and Vessel Call Comparison, %

<table>
<thead>
<tr>
<th>Year</th>
<th>All Inbound Call</th>
<th>Containership Calls</th>
<th>TEUs</th>
<th>Average TEUs/Call</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>2,690</td>
<td>1,332</td>
<td>6,709,818</td>
<td>5,037</td>
</tr>
<tr>
<td>2009</td>
<td>2,287</td>
<td>1,132</td>
<td>5,067,597</td>
<td>4,477</td>
</tr>
<tr>
<td>Change (%)</td>
<td>-15%</td>
<td>-15%</td>
<td>-24%</td>
<td>-11%</td>
</tr>
</tbody>
</table>
2.7.1 Flags of Convenience

Most OGVs are foreign flagged ships, whereas harbor craft are almost exclusively domestic. Approximately 94% of the OGVs that visited the Port in 2009 were registered outside the U.S. Although only 6% of the individual OGVs are registered in the U.S., representing 14% of all calls. This is most likely because the U.S. flagged OGVs make shorter, more frequent stops along the west coast. Figures 2.9 and 2.10 show the breakdown of the ships registered by country or flag, by discrete vessel, and by the number of calls, respectively.

Figure 2.9: Flag of Registry, Discrete Vessel

Figure 2.10: Flag of Registry, Vessel Call
2.7.2 Next and Last Port of Call
Figures 2.11 and 2.12 summarize the next (to) port and last (from) port, respectively, for vessels that called in 2009.

**Figure 2.11: Next (To) Port**

- Other 40%
- Oakland 30%
- Manzanillo 5%
- Ensenada 5%
- Vancouver 4%
- Cherry Point 3%
- San Francisco 3%
- Yokohama 2%
- Auckland 2%
- Kaohsiung 2%

**Figure 2.12: Last (From) Port**

- Other 46%
- Pusan 7%
- Ensenada 6%
- Vancouver 6%
- Oakland 5%
- Tokyo 5%
- Shanghai 5%
- Lazaro Cardenas 3%
- Yantian 3%
- Cherry Point 3%
- Cabo San Lucas 2%
- Valdez 2%
- Prince Rupert 2%
- Kingston 2%
- Manzanillo (Mex) 3%
### 2.7.3 Vessel Characteristics

Table 2.25 summarizes the average vessel and engine characteristics by vessel type. The average values for year built, deadweight (DWT), speed, and main engine power are based on the specific vessels that called at the Port. Due to the large number of containerships and tankers that call at the Port and their variety, the vessels were divided by vessel types.

#### Table 2.25: Port of Long Beach 2009 Vessel Type Characteristics

<table>
<thead>
<tr>
<th>Vessel Type</th>
<th>Year Built</th>
<th>Age (Years)</th>
<th>DWT (tons)</th>
<th>Max Speed (knots)</th>
<th>Main Eng (kW)</th>
<th>Aux Eng (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Auto Carrier</td>
<td>2000</td>
<td>9</td>
<td>21,078</td>
<td>19.8</td>
<td>14,518</td>
<td>4,030</td>
</tr>
<tr>
<td>Bulk - General</td>
<td>2001</td>
<td>8</td>
<td>49,804</td>
<td>14.4</td>
<td>7,937</td>
<td>1,658</td>
</tr>
<tr>
<td>Bulk - Heavy Load</td>
<td>1995</td>
<td>14</td>
<td>11,416</td>
<td>15.6</td>
<td>7,210</td>
<td>1,869</td>
</tr>
<tr>
<td>Bulk - Self Discharging</td>
<td>1979</td>
<td>30</td>
<td>32,487</td>
<td>14.9</td>
<td>8,525</td>
<td>2,711</td>
</tr>
<tr>
<td>Bulk Wood Chips</td>
<td>1993</td>
<td>16</td>
<td>47,864</td>
<td>14.6</td>
<td>7,497</td>
<td>1,658</td>
</tr>
<tr>
<td>Container - 1000</td>
<td>2000</td>
<td>9</td>
<td>22,259</td>
<td>19.9</td>
<td>14,043</td>
<td>3,039</td>
</tr>
<tr>
<td>Container - 2000</td>
<td>2001</td>
<td>8</td>
<td>35,166</td>
<td>21.7</td>
<td>22,897</td>
<td>3,897</td>
</tr>
<tr>
<td>Container - 3000</td>
<td>1992</td>
<td>17</td>
<td>40,592</td>
<td>23.1</td>
<td>30,432</td>
<td>6,898</td>
</tr>
<tr>
<td>Container - 4000</td>
<td>2001</td>
<td>8</td>
<td>60,486</td>
<td>24.0</td>
<td>39,824</td>
<td>6,867</td>
</tr>
<tr>
<td>Container - 5000</td>
<td>2002</td>
<td>7</td>
<td>67,704</td>
<td>25.0</td>
<td>52,441</td>
<td>8,586</td>
</tr>
<tr>
<td>Container - 6000</td>
<td>2005</td>
<td>4</td>
<td>80,699</td>
<td>25.2</td>
<td>65,527</td>
<td>12,842</td>
</tr>
<tr>
<td>Container - 7000</td>
<td>2005</td>
<td>4</td>
<td>93,583</td>
<td>25.2</td>
<td>68,732</td>
<td>10,800</td>
</tr>
<tr>
<td>Container - 8000</td>
<td>2005</td>
<td>4</td>
<td>102,076</td>
<td>25.1</td>
<td>67,975</td>
<td>12,102</td>
</tr>
<tr>
<td>Cruise</td>
<td>2001</td>
<td>8</td>
<td>7,711</td>
<td>21.3</td>
<td>32,718</td>
<td>11,020</td>
</tr>
<tr>
<td>General Cargo</td>
<td>1997</td>
<td>12</td>
<td>31,867</td>
<td>14.8</td>
<td>8,142</td>
<td>1,962</td>
</tr>
<tr>
<td>Ocean Tugs</td>
<td>2006</td>
<td>3</td>
<td>801</td>
<td>13.5</td>
<td>7,214</td>
<td>418</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>1989</td>
<td>20</td>
<td>7,656</td>
<td>18.6</td>
<td>16,139</td>
<td>4,694</td>
</tr>
<tr>
<td>Reefer</td>
<td>1983</td>
<td>26</td>
<td>11,732</td>
<td>19.9</td>
<td>9,333</td>
<td>3,110</td>
</tr>
<tr>
<td>RoRo</td>
<td>1995</td>
<td>14</td>
<td>12,889</td>
<td>16.0</td>
<td>6,924</td>
<td>3,965</td>
</tr>
<tr>
<td>Tanker - Aframax</td>
<td>2002</td>
<td>7</td>
<td>109,575</td>
<td>14.7</td>
<td>13,330</td>
<td>2,550</td>
</tr>
<tr>
<td>Tanker - Chemical</td>
<td>2003</td>
<td>6</td>
<td>39,977</td>
<td>14.7</td>
<td>8,300</td>
<td>2,891</td>
</tr>
<tr>
<td>Tanker - Handyboat</td>
<td>1994</td>
<td>15</td>
<td>41,612</td>
<td>15.0</td>
<td>9,391</td>
<td>1,939</td>
</tr>
<tr>
<td>Tanker - Panamax</td>
<td>2004</td>
<td>5</td>
<td>70,795</td>
<td>14.9</td>
<td>11,373</td>
<td>2,547</td>
</tr>
<tr>
<td>Tanker - Suezmax</td>
<td>2004</td>
<td>5</td>
<td>181,854</td>
<td>15.3</td>
<td>17,791</td>
<td>5,896</td>
</tr>
<tr>
<td>Tanker - VLCC</td>
<td>2002</td>
<td>7</td>
<td>305,469</td>
<td>15.4</td>
<td>27,200</td>
<td>4,580</td>
</tr>
</tbody>
</table>
Figures 2.13 through 2.17 show the characteristics of vessels visiting the Port in 2009. As shown in Figure 2.13, the larger containerships (7,000+TEU) and several tanker types (Panamax, Suezmax, and Chemical) that called the Port were the newer vessels. The self discharging bulk vessels and reefers were the older vessels. Also, larger containerships had the highest maximum rated speeds, as shown in Figure 2.14.

**Figure 2.13: Average Age of Vessels that Called the Port in 2009, years**

![Average Age of Vessels](image)

**Figure 2.14: Average Max Speed of Vessels that Called the Port in 2009, knots**

![Average Max Speed of Vessels](image)
The Suezmax and VLCC tankers had the largest average deadweight tonnage (Figure 2.15), and the larger containerships had the highest main engine installed power (Figure 2.16).

**Figure 2.15: Average Deadweight of Vessels that Called the Port in 2009, tons**

![Figure 2.15: Average Deadweight of Vessels that Called the Port in 2009, tons](image)

**Figure 2.16: Average Main Engine Total Installed Power of Vessels that Called the Port in 2009, kilowatts**

![Figure 2.16: Average Main Engine Total Installed Power of Vessels that Called the Port in 2009, kilowatts](image)
The 6000+ TEU container ships had the highest auxiliary engine total installed power.

**Figure 2.17: Average Auxiliary Engine Total Installed Power of Vessels that Called the Port in 2009, kilowatts**

![Bar chart showing average auxiliary engine total installed power for different types of vessels.]

**2.7.4 Frequent Callers**

For purpose of this discussion, a frequent caller is a vessel that made six or more calls in one year. The vessels that made an inbound call to a berth or anchorage at the Port were included. The total number of discrete vessels in Table 2.26 does not match the total number of discrete vessels in Table 2.2 because the auxiliary engine table shows all vessels included in the inventory (not just those making inbound calls).
Table 2.26 shows 13% of vessels that called the Port in 2009 are frequent callers. Container vessels and cruise ships had the highest percentage of frequent callers in 2009.

### Table 2.26: Percentage of Frequent Callers in 2009

<table>
<thead>
<tr>
<th>Vessel Type</th>
<th>Frequent Vessels</th>
<th>Total Vessels</th>
<th>Percent Frequent Vessels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Auto Carrier</td>
<td>2</td>
<td>76</td>
<td>3%</td>
</tr>
<tr>
<td>Bulk</td>
<td>0</td>
<td>149</td>
<td>0%</td>
</tr>
<tr>
<td>Bulk - Heavy Load</td>
<td>0</td>
<td>2</td>
<td>0%</td>
</tr>
<tr>
<td>Bulk - Self Discharging</td>
<td>1</td>
<td>3</td>
<td>33%</td>
</tr>
<tr>
<td>Bulk Wood Chips</td>
<td>0</td>
<td>4</td>
<td>0%</td>
</tr>
<tr>
<td>Container - 1000</td>
<td>14</td>
<td>24</td>
<td>58%</td>
</tr>
<tr>
<td>Container - 2000</td>
<td>10</td>
<td>44</td>
<td>23%</td>
</tr>
<tr>
<td>Container - 3000</td>
<td>8</td>
<td>20</td>
<td>40%</td>
</tr>
<tr>
<td>Container - 4000</td>
<td>4</td>
<td>49</td>
<td>8%</td>
</tr>
<tr>
<td>Container - 5000</td>
<td>11</td>
<td>48</td>
<td>23%</td>
</tr>
<tr>
<td>Container - 6000</td>
<td>5</td>
<td>7</td>
<td>0%</td>
</tr>
<tr>
<td>Container - 7000</td>
<td>5</td>
<td>10</td>
<td>50%</td>
</tr>
<tr>
<td>Container - 8000</td>
<td>15</td>
<td>22</td>
<td>68%</td>
</tr>
<tr>
<td>Cruise</td>
<td>3</td>
<td>6</td>
<td>50%</td>
</tr>
<tr>
<td>General Cargo</td>
<td>0</td>
<td>60</td>
<td>0%</td>
</tr>
<tr>
<td>Ocean Tug</td>
<td>3</td>
<td>6</td>
<td>50%</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>0</td>
<td>3</td>
<td>0%</td>
</tr>
<tr>
<td>Reefer</td>
<td>0</td>
<td>3</td>
<td>0%</td>
</tr>
<tr>
<td>RoRo</td>
<td>1</td>
<td>8</td>
<td>13%</td>
</tr>
<tr>
<td>Tanker - Aframax</td>
<td>2</td>
<td>16</td>
<td>13%</td>
</tr>
<tr>
<td>Tanker - Chemical</td>
<td>5</td>
<td>64</td>
<td>8%</td>
</tr>
<tr>
<td>Tanker - Handyboat</td>
<td>2</td>
<td>14</td>
<td>14%</td>
</tr>
<tr>
<td>Tanker - Panamax</td>
<td>3</td>
<td>65</td>
<td>5%</td>
</tr>
<tr>
<td>Tanker - Suezmax</td>
<td>4</td>
<td>23</td>
<td>17%</td>
</tr>
<tr>
<td>Tanker - VLCC</td>
<td>1</td>
<td>21</td>
<td>5%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>99</strong></td>
<td><strong>747</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td></td>
<td></td>
<td><strong>13%</strong></td>
</tr>
</tbody>
</table>
2.7.5 Hotelling Time at Berth and Anchorage

Tables 2.27 and 2.28 show the range and average hotelling times at berth and anchorage, respectively. The hotelling times for miscellaneous vessels were extremely high due to two unique ships serving missile launch operations that are home ported at the Port. The maximum hotelling time for Container 1000 vessel type also had higher than normal maximum hours at berth which is attributed to vessels with engine malfunctions that required longer stay for maintenance purposes. The following tables are for information only and the averages shown are not used in emissions calculations since actual data is known for every vessel call.

Table 2.27: Hotelling Times at Berth for Vessels that Called the Port of Long Beach in 2009 by Vessel Type

<table>
<thead>
<tr>
<th>Vessel Type</th>
<th>Berth Hotelling Time, hours</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Min</td>
</tr>
<tr>
<td>Auto Carrier</td>
<td>6.6</td>
</tr>
<tr>
<td>Bulk - General</td>
<td>9.1</td>
</tr>
<tr>
<td>Bulk - Heavy Load</td>
<td>50.9</td>
</tr>
<tr>
<td>Bulk - Self Discharging</td>
<td>14.3</td>
</tr>
<tr>
<td>Bulk Wood Chips</td>
<td>38.4</td>
</tr>
<tr>
<td>Container - 1000</td>
<td>9.2</td>
</tr>
<tr>
<td>Container - 2000</td>
<td>7.7</td>
</tr>
<tr>
<td>Container - 3000</td>
<td>10.3</td>
</tr>
<tr>
<td>Container - 4000</td>
<td>12.4</td>
</tr>
<tr>
<td>Container - 5000</td>
<td>11.3</td>
</tr>
<tr>
<td>Container - 6000</td>
<td>48.0</td>
</tr>
<tr>
<td>Container - 7000</td>
<td>36.6</td>
</tr>
<tr>
<td>Container - 8000</td>
<td>10.7</td>
</tr>
<tr>
<td>Cruise</td>
<td>1.3</td>
</tr>
<tr>
<td>General Cargo</td>
<td>6.0</td>
</tr>
<tr>
<td>Ocean Tugs</td>
<td>0.6</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>144.3</td>
</tr>
<tr>
<td>Reefer</td>
<td>24.9</td>
</tr>
<tr>
<td>RoRo</td>
<td>12.1</td>
</tr>
<tr>
<td>Tanker - Aframax</td>
<td>15.6</td>
</tr>
<tr>
<td>Tanker - Chemical</td>
<td>8.2</td>
</tr>
<tr>
<td>Tanker - Handyboat</td>
<td>9.9</td>
</tr>
<tr>
<td>Tanker - Panamax</td>
<td>11.9</td>
</tr>
<tr>
<td>Tanker - Suezmax</td>
<td>5.4</td>
</tr>
<tr>
<td>Tanker - VLCC</td>
<td>13.2</td>
</tr>
</tbody>
</table>
Table 2.28 shows the range and average hotelling times at anchorage with the actual vessel calls for each vessel subtype that visited the anchorages.

**Table 2.28: 2009 Hotelling Times at Anchorage by Vessel Type**

<table>
<thead>
<tr>
<th>Vessel Type</th>
<th>Min</th>
<th>Max</th>
<th>Avg</th>
<th>Anchor Call Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Auto Carrier</td>
<td>2.3</td>
<td>950.7</td>
<td>129.4</td>
<td>33</td>
</tr>
<tr>
<td>Bulk - General</td>
<td>1.2</td>
<td>350.3</td>
<td>40.4</td>
<td>155</td>
</tr>
<tr>
<td>Bulk - Heavy Load</td>
<td>2.8</td>
<td>22.7</td>
<td>11.1</td>
<td>3</td>
</tr>
<tr>
<td>Bulk - Self Discharging</td>
<td>14.7</td>
<td>44.9</td>
<td>28.7</td>
<td>3</td>
</tr>
<tr>
<td>Bulk Wood Chips</td>
<td>10.6</td>
<td>120.3</td>
<td>65.4</td>
<td>2</td>
</tr>
<tr>
<td>Container - 1000</td>
<td>2.8</td>
<td>81.2</td>
<td>18.0</td>
<td>52</td>
</tr>
<tr>
<td>Container - 2000</td>
<td>1.7</td>
<td>299.4</td>
<td>24.0</td>
<td>20</td>
</tr>
<tr>
<td>Container - 3000</td>
<td>5.8</td>
<td>38.4</td>
<td>15.9</td>
<td>6</td>
</tr>
<tr>
<td>Container - 4000</td>
<td>0.6</td>
<td>21.3</td>
<td>11.6</td>
<td>14</td>
</tr>
<tr>
<td>Container - 5000</td>
<td>1.0</td>
<td>32.7</td>
<td>14.4</td>
<td>15</td>
</tr>
<tr>
<td>Container - 6000</td>
<td>1.5</td>
<td>5.3</td>
<td>3.4</td>
<td>8</td>
</tr>
<tr>
<td>Container - 7000</td>
<td>7.3</td>
<td>46.9</td>
<td>22.2</td>
<td>3</td>
</tr>
<tr>
<td>Container - 8000</td>
<td>2.2</td>
<td>17.7</td>
<td>8.3</td>
<td>10</td>
</tr>
<tr>
<td>Cruise</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0</td>
</tr>
<tr>
<td>General Cargo</td>
<td>1.9</td>
<td>277.3</td>
<td>48.1</td>
<td>52</td>
</tr>
<tr>
<td>Ocean Tugs</td>
<td>3.6</td>
<td>39.6</td>
<td>18.6</td>
<td>12</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>0.6</td>
<td>2.2</td>
<td>1.2</td>
<td>5</td>
</tr>
<tr>
<td>Reefer</td>
<td>2.7</td>
<td>2.7</td>
<td>2.7</td>
<td>1</td>
</tr>
<tr>
<td>RoRo</td>
<td>6.1</td>
<td>46.2</td>
<td>26.1</td>
<td>2</td>
</tr>
<tr>
<td>Tanker - Aframax</td>
<td>2.1</td>
<td>412.0</td>
<td>64.8</td>
<td>76</td>
</tr>
<tr>
<td>Tanker - Chemical</td>
<td>0.6</td>
<td>449.2</td>
<td>34.7</td>
<td>151</td>
</tr>
<tr>
<td>Tanker - Handyboat</td>
<td>3.1</td>
<td>127.2</td>
<td>29.6</td>
<td>25</td>
</tr>
<tr>
<td>Tanker - Panamax</td>
<td>0.4</td>
<td>445.2</td>
<td>62.6</td>
<td>261</td>
</tr>
<tr>
<td>Tanker - Suezmax</td>
<td>3.3</td>
<td>413.9</td>
<td>48.4</td>
<td>111</td>
</tr>
<tr>
<td>Tanker - VLCC</td>
<td>6.6</td>
<td>351.9</td>
<td>82.5</td>
<td>65</td>
</tr>
</tbody>
</table>

1,085
Figure 2.18 shows the average hotelling time at berth for vessels that called the Port. The miscellaneous vessels have the highest at berth hotelling time in 2009 with an average 3,752 hours.

**Figure 2.18: Average Hotelling Time at Berth for Vessels that Called the Port in 2009, hours**
Figure 2.19 shows the average hotelling time at anchorage indicating that auto carriers and tankers spent the most time at anchorage in 2009.

**Figure 2.19: Average Hotelling Time at Anchorage for Vessels that Called the Port in 2009, hours**