December 18, 2015

NOTE: This is a draft document that will be incorporated into the final 2014NEI documentation. It summarizes how the EPA estimates were derived and will be updated to include information on state/local/tribal submittals to the NEI and QA analysis.

#### 4.3.4 EPA-developed commercial marine vessel activity and emissions data

This section summarizes the approach used to estimate emissions including compilation of 1) activity data (kilowatt hours or kW), 2) engine operating load factors, and 3) emission factors HAP speciation profiles.

Regarding vessel activities, the following data sources were used to develop vessel characteristics and quantify traffic patterns:

> **Entrance and Clearance** (E&C) – This data set captures vessels involved in international trade, documenting where a vessel came from and its next port of call (U.S. Army Corps of Engineers, 2015a). These vessel-specific ship movements were linked to their individual engine characteristics (IHS, 2014) to calculate kilowatt hours. Most of the vessels in this data set are equipped with Category 3 propulsion engines, although some vessels were identified that are equipped with Category 1 and 2 propulsion engines.
>
> **Waterborne Commerce** (WC) – The U.S. Army Corps of Engineers provided a data set of domestic vessel movements for tugs and barges, bulk carriers, tankers, and other vessels (U.S. Army Corps of Engineers 2015b). These data are provided as domestic trips along a defined route and mapped to the NEI ports and shipping lane segments. Typical vessel speeds by vessel type were used in conjunction with the distance associated with each trip to estimate the hours of operation which were applied to the vessels' propulsion power to get kilowatt hours.
>
> **Category 1 and 2 Study** – For this inventory, the EPA's 2007 Category 1 and 2 vessels census was updated with more recent data, specifically for ferries, survey vessels, ships involved with offshore oil and gas activities, dredging, and U.S. Coast Guard operations. For these smaller vessels, less detailed information was available about their characteristics or traffic patterns, therefore, the kilowatt hours were estimated based on typical operations and applied to typical vessel power ratings.

Note all activity data were adjusted for typical engine loads for the modes of operation included in this study (i.e., cruising, reduced speed zone (RSZ), maneuvering, and hoteling). The adjusted kilowatt hours were applied to EPA emission factors by engine category as follows:

$$\text{Emissions} = \text{EF}\left(\frac{\text{g}}{\text{kWh}}\right) \times \frac{\text{D (NM)}}{\text{Vs}\,\frac{\text{NM}}{\text{hr}}} \times \text{LF} \times \text{Vp (kW)}$$

Where:

| | | |
|---|---|---|
| EF | = | EPA Emission factor, in grams per kilowatt-hour (kWh) |
| D | = | Distance along segment or RSZ (NM) |
| Vs | = | 0.94 x maximum vessel speed = cruising speed or RSZ speed limit (NM/hr) |
| LF | = | Load Factor (fraction less than 1) |
| Vp | = | Vessel Power (kW) |

D/Vs is used to estimate operating hours for E&C data and WC data. For C1/C2 study, typical operating hours are used instead. Also, if vessel speed is unknown, typical speed by vessel type was used (nautical miles/hr or knots). More detailed equations are available in Appendix A.

#### *4.3.4.1 Activity Data*

**Entrance and Clearance**

Vessel-specific routing data were available from the U.S. Army Corps of Engineers' 2012 E&C data (U.S. Army Corps of Engineers 2015a) for approximately 11,000 U.S. and foreign flagged vessels involved in international trade that complies with U.S. Customs and Clearance reporting requirements, as summarized in Table 4-4.

**Table 4-4:** Vessel-Specific Routing Data

| Standard Type | Total Vessel Count | Domestic Flagged | Foreign Flagged |
|---|---|---|---|
| Barge | 350 | 244 | 106 |
| Bulk Carrier | 3,294 | 11 | 3,283 |
| Bulk Carrier, Laker | 89 | 35 | 54 |
| Buoy Tender | 4 | 0 | 4 |
| Container | 1,319 | 51 | 1,268 |
| Crude Oil Tanker | 754 | 8 | 746 |
| Dredger | 2 | 1 | 1 |
| Drilling | 51 | 7 | 44 |
| Fishing | 248 | 142 | 106 |
| FPSO | 2 | 0 | 2 |
| General Cargo | 1,086 | 24 | 1,062 |
| Icebreaker | 2 | 0 | 2 |
| Jackup | 4 | 3 | 1 |
| LNG Tanker | 45 | 0 | 45 |
| LPG Tanker | 156 | 0 | 156 |
| Misc. | 47 | 17 | 30 |
| Passenger | 173 | 7 | 166 |

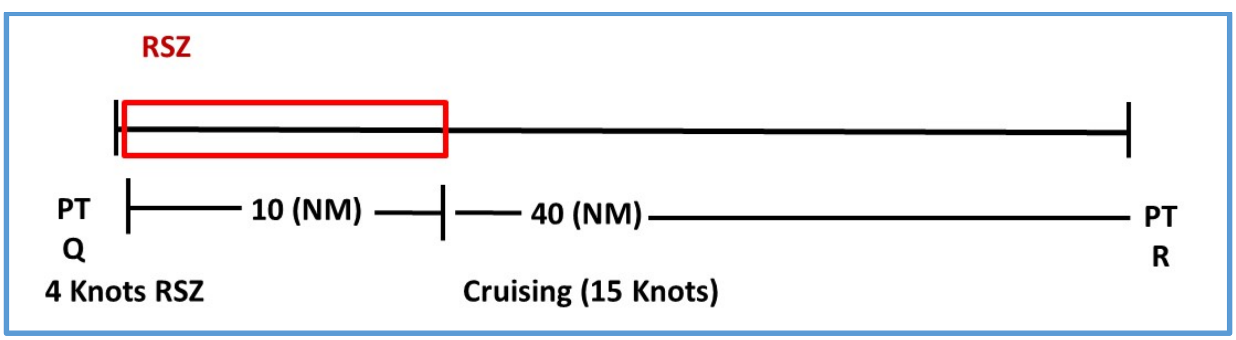
**Table 4-4:** Vessel-Specific Routing Data

| Standard Type | Total Vessel Count | Domestic Flagged | Foreign Flagged |
|---|---|---|---|
| Pipelaying | 14 | 0 | 14 |
| Reefer | 185 | 0 | 185 |
| Research | 61 | 31 | 30 |
| RORO | 92 | 7 | 85 |
| Supply | 255 | 197 | 58 |
| Support | 75 | 34 | 41 |
| Tanker | 1,428 | 14 | 1,414 |
| Tug | 679 | 533 | 146 |
| Vehicle Carrier | 465 | 20 | 445 |
| Well Stimulation | 3 | 1 | 2 |
| **Total** | **10,883** | **1,387** | **9,496** |

These vessels were linked to their individual routes based on the originating port and the destination port. For the 2014 NEI, the E&C data were mapped to 7,176 routes comprising 410 unique ports, 174 of which are domestic U.S. ports. The waterway network was also edited to include 1,005 segments associated with RSZs based on the EPA's Regulatory Impact Assessment (US EPA 2003) for Category 3 vessels summarized Appendix B. Where the RSZ speed was unknown, a typical value of 10 knots was used.

To calculate hours of operation, the length of each route was divided by the vessel speed. Where a vessel travels through a RSZ, the vessel speed was reduced, thus increasing the hours of operation along that segment. Figure 4-2 provides an example of a vessel traveling from port Q to port R, moving through a 10 NM RSZ segment followed by a 40 NM normal cruising segment.

**Figure 4-2:** Example Route for Ship Movement from Port A to Port B via a RSZ




Hours to transit each segment were estimated for each vessel based on the distance traveled and the vessel cruising speed, which was assumed to be 94 percent of the vessel's maximum speed as obtained from Information Handling Services' (IHS 2015) Register of Ships. These cruising speeds were additionally reduced based on the latest International Maritime

Organization (IMO) Greenhouse Gas emission inventory (IMO 2014) that quantifies actual vessel speeds and engine operating loads for select vessel types, accounting for recent practices to reduce fuel consumption known as slow steaming. The IMO data are presented in Table 4-5.

**Table 4-5:** IMO Vessel Speed Data

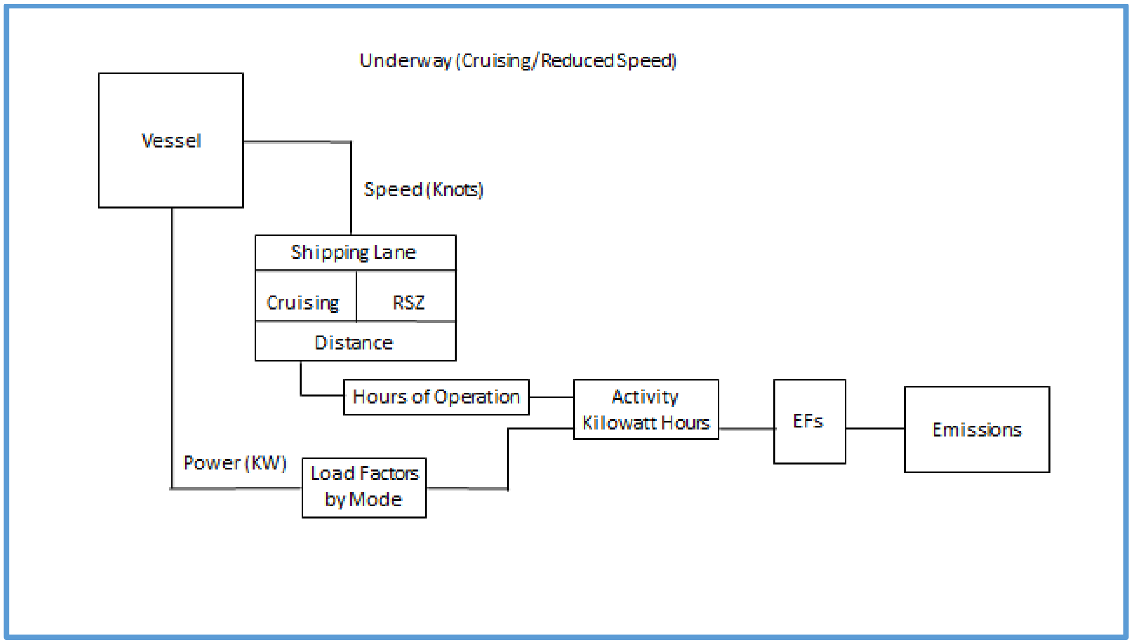
| Ship Type | Size Category | Size Units | Ratio of average at-sea speed to design speed | Percent of total population | Weight amount | Weighted Cruising Speed Factor |
|---|---|---|---|---|---|---|
| Bulk Carrier | 0-9999 | dwt | 0.84 | 0.9% | 0.007403 | 0.822751023 |
| | 10000-34999 | | 0.82 | 25.1% | 0.20571 | |
| | 35000-59999 | | 0.82 | 36.0% | 0.295272 | |
| | 60000-99999 | | 0.83 | 31.7% | 0.263082 | |
| | 100000-199999 | | 0.81 | 6.2% | 0.050227 | |
| | 200000+ | | 0.84 | 0.1% | 0.001058 | |
| Container | 0-999 | TEU | 0.77 | 4.9% | 0.038087 | 0.681508656 |
| | 1000-1999 | | 0.73 | 11.8% | 0.086059 | |
| | 2000-2999 | | 0.7 | 12.5% | 0.087716 | |
| | 3000-4999 | | 0.68 | 32.8% | 0.223116 | |
| | 5000-7999 | | 0.65 | 28.6% | 0.185944 | |
| | 8000-11999 | | 0.65 | 9.0% | 0.058409 | |
| | 12000-14500 | | 0.66 | 0.3% | 0.002176 | |
| | 14500+ | | 0.6 | 0.0% | 0 | |
| Oil Tanker | 0-4999 | dwt | 0.8 | 0.1% | 0.001094 | 0.782982216 |
| | 5000-9999 | | 0.75 | 0.3% | 0.002052 | |
| | 10000-19999 | | 0.76 | 0.0% | 0 | |
| | 20000-59999 | | 0.8 | 3.6% | 0.028454 | |
| | 60000-79999 | | 0.81 | 15.6% | 0.12632 | |
| | 80000-11999 | | 0.78 | 43.4% | 0.338249 | |
| | 120000-199999 | | 0.77 | 32.6% | 0.250698 | |
| | 200000+ | | 0.8 | 4.5% | 0.036115 | |

dwt = dead weight tonnage; TEU = twenty foot equivalent units

For RSZs, a vessel's speed was assumed to be the zone's speed unless the vessel's cruising speed was lower. For example, a vessel with a cruising speed of 12 knots traveling through a waterway segment with a reduced speed of 14 knots was assumed to be operating at 12 knots.

The hours of operation were applied to the vessel's power, which was adjusted for typical engine operating loads to get kilowatt hours. In turn, the kilowatt hours were applied to the appropriate EPA emission factor based on the vessel engine's category to estimate criteria pollutant emissions. The flow of emissions calculations for underway vessels is illustrated in Figure 4-3.

**Figure 4-3:** Emission Calculations for Underway Operations




Vessel characteristics data were compiled from IHS Register of Ships (IHS 2014) and linked to vessels included in the 2012 E&C data. The vessel characteristics included the following data:

- Vessel identification codes
- Vessel name
- Country of registry
- Call sign
- Vessel type
- Gross/net tonnage
- Vessel power
- Auxiliary engine power
- Piston stroke length/cylinder diameter (to calculate vessel category)
- Maximum vessel speed.

Approximately 89 percent of the E&C vessels could be matched to their characteristics by cross referencing multiple attributes such as IMO identification code, country of registry, gross tonnage, net tonnage, vessel type, and vessel name. For the remaining vessels that could not be matched, vessel attributes were developed for each vessel type based on the matched vessel in the IHS data. If the vessel type was unknown, aggregate attributes derived from all matched vessels in the IHS data set were developed and used. Note that the auxiliary engine data in the IHS data set was poorly populated; therefore, vessel type surrogates were developed based on vessels that reported auxiliary engine power. The vessel power data used in this study are presented in Table 4-6.

**Table 4-6:** Vessel Power Attributes by Vessel Type

| Standard Type | Count | Avg Main hrs | Avg Aux kW | Avg Max Speed | Default Vessel Category |
|---|---|---|---|---|---|
| Bulk Carrier | 3,177 | 8,990 | 1,935 | 14.3 | 3 |
| Bulk Carrier, Laker | 80 | 7,069 | 2,216 | 13.7 | 3 |
| Buoy Tender | 4 | 4,266 | | 12.6 | 2 |
| Container | 1,218 | 39,284 | 7,851 | 23.2 | 3 |
| Crude Oil Tanker | 731 | 15,070 | 2,888 | 15.1 | 3 |
| Drilling | 7 | 15,806 | 12,840 | 11.7 | 2 |
| Fishing | 123 | 1,262 | 272 | 2.3 | 1 |
| FPSO | 2 | 18,123 | | 11.5 | 3 |
| General Cargo | 1,020 | 6,130 | 1,619 | 14.6 | 3 |
| Icebreaker | 2 | 21,844 | | 12.0 | 2 |
| Jackup | 4 | 1,643 | 270 | 3.5 | 1 |
| LNG Tanker | 44 | 29,607 | 8,129 | 19.2 | 3 |
| LPG Tanker | 151 | 8,557 | 3,021 | 15.8 | 3 |
| Misc. | 35 | 2,805 | 631 | 10.0 | 1 |
| Passenger | 168 | 45,760 | 4,477 | 20.4 | 3 |
| Pipelaying | 14 | 11,355 | 5,037 | 12.6 | 2 |
| Reefer | 182 | 8,930 | 3,328 | 18.9 | 3 |
| Research | 55 | 5,395 | 1,905 | 11.2 | 2 |
| RORO | 72 | 9,479 | 4,006 | 16.7 | 3 |
| Supply | 255 | 3,201 | 662 | 10.1 | 1 |
| Support | 73 | 6,590 | 2,305 | 9.7 | 2 |
| Tanker | 1,423 | 8,474 | 2,730 | 14.5 | 3 |
| Tug | 396 | 3,440 | 348 | 7.7 | 2 |
| Vehicle Carrier | 441 | 13,829 | 3,729 | 19.8 | 3 |
| Well Stimulation | 3 | 7,697 | 340 | 8.2 | 3 |

Individual vessel movements were compiled as origination and destination pairs for each U.S. port included in the E&C data. The E&C data includes only vessels that enter or leave U.S. waters at some point in the trip. Over 49 percent of the records were for vessels that visit a single U.S. port during a single trip. Similarly, over 49 percent of the records were for vessels that visited multiple U.S. ports in one trip and less than one percent of the records were only between domestic U.S. ports.

Because the E&C data report the departure of a vessel from a U.S. port and the arrival of the same vessel in the destination port associated with the trip, it was necessary to adjust the vessel movement data to avoid double counting of trips. To avoid the double counting only the entrance or clearance of the trip and not both are counted. Evaluating the duplicate trips was also an important quality check on the E&C data—ideally there should be a duplicate departure and arrival record for every trip, thus validating the completeness of the data. For example, for a vessel traveling from Long Beach to San Diego would typically have four E&C records:

- Arrival at Long Beach
- Departure from Long Beach (to San Diego)
- Arrival at San Diego (from Long Beach)
- Departure from San Diego.

Of the 23,008 unique ship movements for domestic origination and destination pairs, 85 percent of the vessel movements had corresponding arrivals and departures; 3,481 (15 percent) had an odd number of records, indicating that a vessel movement may be missing.

In many cases, the missing vessel movements were associated with an arrival in one port and a departure from an adjacent port, suggesting that the missing vessel movement was between the two adjacent ports. For example, the data may show only three records:

- Arrival at Long Beach
- Departure from Los Angeles (to San Diego)
- Arrival at San Diego (from Los Angeles)
- Departure from San Diego.

This dataset would thus suggest a missing Los Angeles to Long Beach trip.

To account for this type of error, adjacent ports were aggregated, reducing the unique vessel routes or movements to 19,883. Of the final 19,883 routes, only 4 percent of the vessel movements (attributed to 815 routes) had a missing arrival or departure. Many of the remaining missing ship movements were associated with the U.S. protectorates in the

Caribbean Sea, where the arrival and departure information occasionally appeared to be switched.

The issue of duplicate trips was not a concern for foreign vessel movements because the E&C documents arrivals and departures for only U.S. ports, which means that a departure from a U.S. port to a foreign port or an arrival from a foreign port to a U.S. port would always be a unique trip.

Adjustments were also made for Alaskan trips. The E&C data reported activity for 52 Alaskan ports, however, the vast majority of those are small ports and have very little traffic. To capture the majority of emissions, only the top 13 Alaska ports, which accounted for 94 percent of the Alaska traffic, were included. Table 4-7 lists the Alaska ports and associated vessel calls.

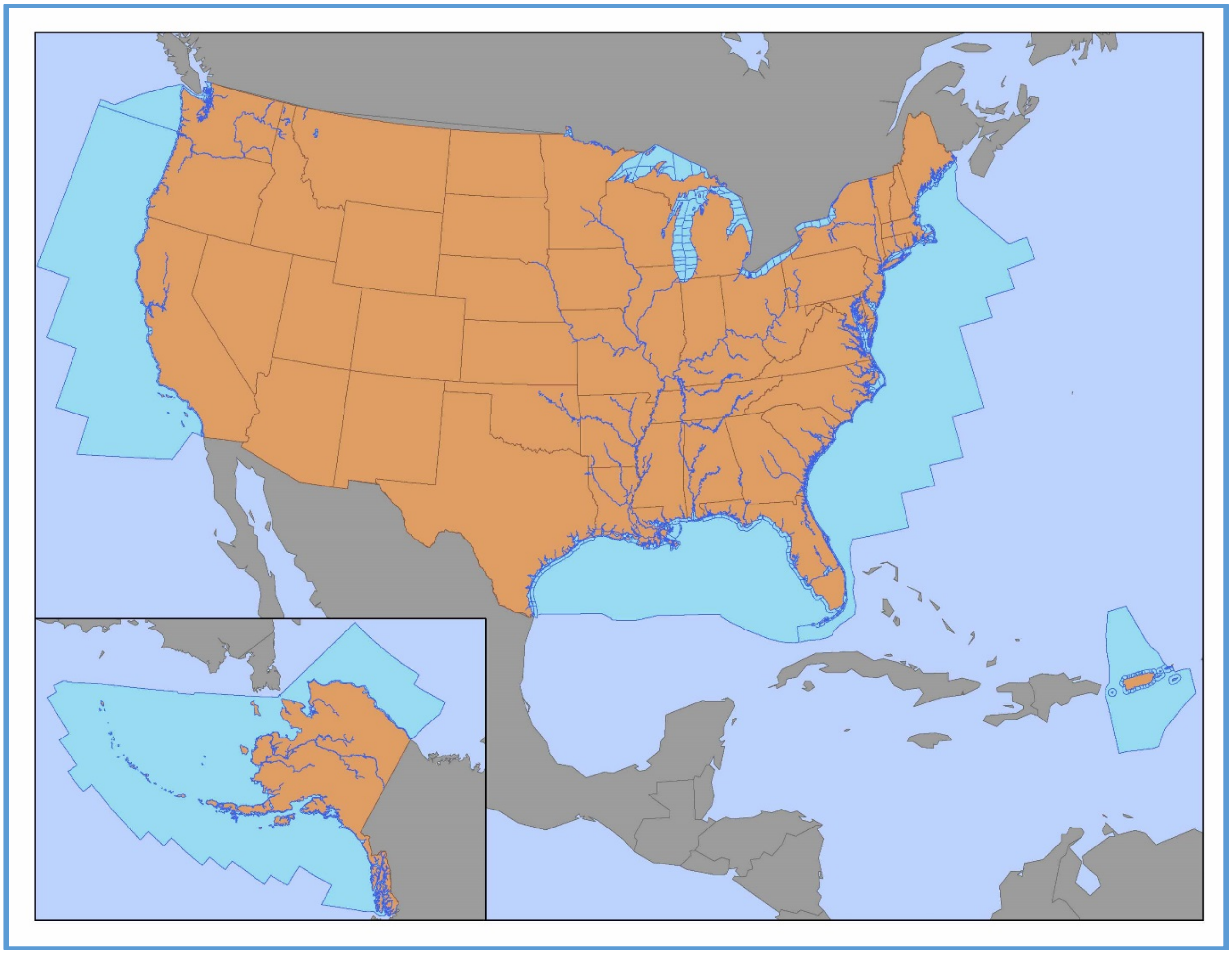
**Table 4-7:** Alaska Ports and Vessel Calls

| Ports | Total of Count | Domestic | Foreign | Fraction of Alaska Total |
|---|---|---|---|---|
| Juneau, AK | 1,892 | 1,812 | 80 | 0.27 |
| Ketchikan, AK | 1,699 | 1,136 | 563 | 0.20 |
| Skagway, AK | 1,390 | 1,330 | 60 | 0.20 |
| Anchorage, AK | 563 | 526 | 37 | 0.08 |
| Kivalina, AK | 481 | | 481 | 0.03 |
| Sitka, AK | 326 | 302 | 24 | 0.05 |
| Iliuliuk Harbor, AK | 212 | 76 | 136 | 0.02 |
| Dutch Harbor, AK | 196 | 84 | 112 | 0.02 |
| Whittier, AK | 182 | 65 | 117 | 0.02 |
| Seward, AK | 149 | 109 | 40 | 0.02 |
| Icy Strait, AK | 132 | 110 | 22 | 0.02 |
| Wrangell, AK | 88 | 15 | 73 | 0.01 |
| Haines, AK | 82 | 81 | 1 | 0.01 |

Once the E&C origination and destination port pairs were defined, trips were routed over a custom waterway network based on the U.S. Army Corps of Engineers' navigable waterway network using a Geographic Information System (GIS) and network analysis. The routes were then intersected with EPA's NEI shapefiles of ports and shipping lanes. Shipping lanes associated with RSZs were coded to allow for adjustment in vessel speed, time spent transiting the RSZ, and engine operating load.

Because U.S. territorial waters extend out 200 nautical miles from the coast (Figure 4-4)[1], international vessel routes were mapped only to the U.S. federal waters/international waters boundary. The distance traveled was calculated based on the route the vessel was assigned. Each waterway segment was coded to differentiate normal cruising versus RSZ operations.

**Figure 4-4:** State and Federal Waters of the United States



Blue/Light Blue = state and federal water boundaries

### Activity data for Entrance & Clearance time spent maneuvering/dockside

E&C data do not include details about time spent in each ship movement mode. Typical maneuvering times by vessel type were used to estimate time spent in this mode. Maneuvering durations for different vessel types were obtained from Entec's European emission inventory

[1] These are the official US territorial waters from NOAA, which are generally 200nm but do vary in some places due to foreign entities, etc. Spreading/condensing of emissions depends more on how the emissions were developed than the shapes we use here and is a frequent topic of conversation with modelers.

(Entec 2002) and are presented in Table 4-8. Note half of the maneuvering time presented in Table 4-8 was assumed to be approaching the terminal and half departing from the terminal.

**Table 4-8:** Estimated Maneuvering Time by Vessel Type

| Vessel Type | Maneuvering Time (hours) |
|---|---:|
| Bulk Carrier | 1 |
| Bulk Carrier, Laker | 1 |
| Buoy Tender | 1.7 |
| Container | 1 |
| Crude Oil Tanker | 1.5 |
| General Cargo | 1 |
| LNG Tanker | 1 |
| LPG Tanker | 1 |
| Misc. | 1 |
| Passenger | 0.8 |
| Reefer | 1 |
| RORO | 1 |
| Tanker | 1 |
| Tug | 1.7 |
| Vehicle Carrier | 1 |

To quantify the duration a vessel spends dockside, the E&C data were organized chronologically for individual vessels to determine when a vessel arrives at the dock and when it leaves. Some of the dockside durations seemed unreasonably high, indicating that either an arrival or departure was missing or out of sequence. These anomalies were identified and removed from the analysis. The data were then averaged by vessel type to develop port specific dockside duration times. It should be noted that the E&C data recorded the day the vessel arrived and the day the vessel departed. The daily periods were multiplied by 24 hours to get hourly values. If a vessel arrived and departed in the same day it was assumed that the dockside duration was 12 hours.

The EPA provided hourly containership dockside data for 15 ports (US EPA 2015a). For the 2014 NEI, these containership data replaced containership E&C data for the following ports:

- Ports of Los Angeles and Long Beach
- Ports of New York and New Jersey
- Port of Seattle
- Port of Houston
- Port of Baltimore
- Port of Savannah
- Port of Norfolk
- Port of Charleston
- Port of New Orleans
- Port of Mobile
- Port of Miami
- Port of Philadelphia
- Port of Tampa
- Port of San Juan
- Port of Portland

Additionally, dockside duration data were identified for ports that developed their own inventories. These data were assumed to be the highest quality and replaced E&C and EPA containership data. 2014 Detailed port data were obtained from the following ports:

- Port of Los Angeles
- Ports of New York and New Jersey
- Port of San Francisco
- Port of San Diego

**Activity data for waterborne commerce**

As with the E&C data, the Army Corps of Engineers Waterborne Commerce Data (WCD) provides vessel trips for individual vessels operating over a specified route. The WCD also includes vessel power ratings and distance of each route. The distance data were evaluated using typical vessel speeds to calculate hours of operation to transit a specified route. Note, hours of operation were adjusted for slower speeds transiting RSZs. The cruising speeds for each vessel type were compiled from a variety of sources. The primary data source was the IHS data; vessels equipped with Category 1 and 2 propulsion engines were identified and grouped by vessel type and averages of the vessel's maximum speed were developed for each grouping. These values are shown in Table 4-9. The cruising speed was assumed to be 94% of the average maximum speed.

**Table 4-9:** Category 1 and 2 Average Maximum Speed by Vessel Type

| Vessel Type | Vessel Count | Average Maximum Speed (knots) |
|---|---|---|
| Bulk Carrier | 376.00 | 10.09 |
| Bulk Carrier, Laker | 27.00 | 13.74 |
| Buoy Tender | 197.00 | 6.90 |
| Container | 111.00 | 8.48 |

**Table 4-9:** Category 1 and 2 Average Maximum Speed by Vessel Type

| Vessel Type | Vessel Count | Average Maximum Speed (knots) |
|---|---|---|
| Crude Oil Tanker | 44.00 | 6.97 |
| Drilling | 39.00 | 11.74 |
| Fishing | 13,652.00 | 5.67 |
| Floating Production and Storage Offloading | 10.00 | 4.90 |
| General Cargo | 7,179.00 | 8.09 |
| Icebreaker | 27.00 | 10.52 |
| Jackup | 173.00 | 4.25 |
| LNG Tanker | 3.00 | 9.33 |
| LPG Tanker | 183 | 10.83 |
| Miscellaneous | 2,014 | 6.83 |
| Passenger | 3,017 | 15.67 |
| Pipelaying | 280 | 6.39 |
| Reefer | 183 | 9.62 |
| Research | 951 | 9.79 |
| RORO | 1,997 | 11.28 |
| Supply | 3,409 | 12.98 |
| Support | 1,036 | 10.42 |
| Tanker | 2,880 | 8.28 |
| Tug | 15,660 | 8.54 |
| Vehicle Carrier | 20 | 14.42 |
| Well Stimulation | 30 | 8.63 |

Because the WCD contain confidential business information not available to the general public, the activity data were aggregated to develop national total activities and reapportioned to appropriate NEI underway shapes. This approach provided reasonable national estimates while protecting the confidential business aspects of the WCD. The spatial allocation was developed in GIS using an approach similar to that used for the E&C data. The WCD were evaluated to identify consolidated routes using both the port and location names for the origins and destinations. For example, routes to and from “St. Thomas, VI” were combined with routes to and from “St. Thomas Harbor Virgin Islands.” We also removed routes where the origin and destination were the same, because these records were considered to be inter-terminal maneuvering and are likely to be included in the maneuvering assumptions. This consolidation process reduced the number of unique routes from 40,775 to 27,991. The remaining routes were mapped in GIS using a shortest-distance based network analysis, and the routes were again intersected with NEI shapes to identify which routes passed through each shape. This intersection process identified portions of some routes that passed outside of US waters, for example, from Miami to Puerto Rico. For each route, the total length within US waters was divided by the total length of the route to obtain the percentage of the route activity that occurs in US waters. The activity data were adjusted accordingly to remove kilowatt hours that occurred in international waters.

Next, for each shipping lane segment shape, the number of vessel trips that passed through were totaled.

$$T_a = R_1+R_2$$

Where:

| | | |
|---|---|---|
| $T_a$ | = | Total number of trips on segment a |
| $R_1$ | = | Number of trips on route 1 |
| $R_2$ | = | Number of trips on route 2 |

The length of the waterway through each shape was calculated and multiplied by the number of trips that occur along the shape. This value was divided by the national total for trips multiplied by the length to determine the percentage of the national total activity to allocate to each shape.

$$P = (T * L)/(NT * NL)$$

Where:

| | | |
|---|---|---|
| P | = | Percentage of national activity |
| T | = | Total trips for the NEI underway shape |
| L | = | Waterway segment length within underway shape |
| NT | = | National trip total |
| LN | = | National waterway network length total |

### Updating the Category 1 and 2 Vessel Census activity data

Since E&C includes only larger internationally-travelling vessels, additional data sources were needed to fill data gaps, particularly for smaller C1 and C2 vessel population involved in domestic traffic.

#### Dredging:

As part of the effort to update the EPA's C1 and C2 vessel data, dredging data were compiled as a new vessel category. To estimate dredging activities for different types of dredging vessels, operating days were obtained from the U.S. Army Corps of Engineers database of dredging contracts for the entire country (U.S. Army Corps of Engineers 2014). This database included contracts from 2012 to 2014. For contracts active since 2012, only the portion of the contracts that were active during 2014 were used in this inventory. The 2014 dredging activities are presented in Appendix C by job name, dredging equipment, and actual operating days.

Operating hours were calculated from the number of days active in 2014, assuming a utilization rate documented in the Category 1/2 Vessel Census of 90% time spent dredging, excluding equipment positioning, maintenance, and refueling times. The U.S. Army Corps of Engineers data did not include horsepower or kW ratings for the engines on the dredging vessels but did include a dredging vessel type. A literature search of the dredging vessel types provided a kW rating for a typical vessel in each category, as summarized in Table 4-10.

**Table 4-10:** Power Rating by Dredging Type

| Type | Contract Code | kW | Source |
|---|---|---|---|
| Bucket or mechanical | B | 1,600 | Anderson 2008 |
| Hopper | H | 7,272 | TCEQ 2012 |
| Non-conventional (Specialty) Type | N | 2,093 | Van Oord 2015 |
| Pipeline (Cutterhead) | P | 7,161 | TCEQ 2012 |
| Pipeline and Hopper Combination | Y | 4080 | Robinson et al. 2011 |
| Undefined | U | 5028 | Average of compiled dredging data. |

The typical kW ratings in Table 4-10 were matched by dredge type to each contracted vessel noted in Appendix C. The matched power rating was multiplied by the utilization rate and dredging duration to estimate kW-hrs which are summarized in Table 4-11.

**Table 4-11:** Summary of National Kilowatt Hours by Dredging Vessel Type

| Type | Total kW-hr |
|---|---|
| Bucket or mechanical | 63,659,520 |
| Hopper | 302,526,835 |
| Non-conventional (specialty) type | 15,280,574 |
| Pipeline (cutterhead) | 654,286,248 |
| Undefined | 5,973,264 |

Dredging activities were spatially apportioned to ship channels based on the job name. The job names indicated general location, such as a bay area or a waterway portion; however, they did not provide sufficient information to precisely locate the dredging activities or even geographic extent of the project. Best effort was given to identify the waterway segments in EPA's GIS shape files that most closely match the limited location information. It should be noted that these activities have been increasing over the past several years to accommodate larger vessels that will be able to transit the new Panama Canal.

**Research Vessels:**

A list of current US research vessels was obtained from the University of Delaware's International Research Ship Information and Schedule database (University of Delaware 2015). In the 2007 vessel census study (US EPA 2007), only 31 research vessels were included. Using the University of Delaware's research vessels website for this inventory, 251 vessels were identified. This gave a more accurate representation of C1 research vessels, which were undercounted in the original C1 and C2 census. Twenty-three of these vessels had detailed trip schedules for 2014, and activity in days was determined for these vessels. The list did not have vessel identification numbers or codes, so an online search was implemented to find vessel identification codes for the remaining vessels. Where identification codes could be found, the vessels were linked to research vessels in the IHS database, providing details on the engine power ratings and engine category. However, not all vessels were matched and another online search was implemented to obtain engine power ratings for the unmatched vessels. During this process, 35 vessels were removed from this analysis because information was found that indicated that the vessel was not in service in 2014 or not powered by a diesel combustion engine (e.g. electric powered remotely operated vehicle (ROV)). Detailed results are presented in Appendix D. Summary of research vessel matching activities are provided in Table 4-12.

**Table 4-12:** Research Vessel Characteristics Matching by Reference

| Research Vessels Matching | |
|---|---|
| Original | 251 |
| IHS match | 77 |
| Online search | 109 |
| Annual schedule | 23 |
| Removed | 35 |

For research vessels without engine power ratings, the matched vessel data were averaged to provide a default of 732 kW which was used to gap fill missing research vessel power data.

For the 2014 inventory, the duration of each research mission was used when available. For the vessels with no activity data, an average value (220 days converted to 5,280 hours) was obtained from the previous Category 1 and 2 Census report. This default duration data was used to when vessel schedule data were not available. The vessel power data were applied to the duration data to calculate kW-hrs for the research vessels.

**Coast Guard:**

A roster of U.S. Coast Guard vessels was provided by the US Coast Guard's (USCG) External Coordination Division (U.S. Coast Guard 2015a). Among the data given were vessel name, horsepower, and annual underway hours for 246 USCG cutters (Appendix E) and over 1,600 smaller boats. Fifty-eight percent of the smaller vessels were gas powered and excluded from this analysis. Also boats which were flagged as retired were also excluded from this analysis. This reduced the Coast Guard Boat list to 652 vessels.

All vessel power ratings were converted from horsepower to kW using the conversion factor 1 HP = 0.7457 kW. The vessel power ratings were multiplied by underway hours also provided by the U.S. Coast Guard to estimate kW-hrs per vessel. As Table 4-13 indicates, approximately 95 percent of activity is related to cutter operations and 5 percent is associated with the smaller boats. The Coast Guard data also included general information about where the vessels operated; for the 2014 NEI inventory, each vessel's kW-hrs were associated with the area of operation and summarized in Table 4-14.

**Table 4-13:** Summary of Coast Guard Underway Activity

| Vessel Type | Number of Vessels | Total kW-hrs |
|---|---|---|
| Cutter | 267 | 2,125,794,310 |
| Boats | 652 | 117,895,003 |
| **Total** | **384** | **2,243,689,313** |

**Table 4-14:** General Location of Coast Guard Underway Activities

| Area | Total kW-hrs |
|---|---|
| Arkansas River | 1,025,173 |
| Atlantic | 643,954,356 |
| Elizabeth River | 92,689,163 |
| Great Lakes | 53,675,432 |
| Gulf | 129,482,530 |
| Illinois River | 343,721 |
| Lower Atchafalaya River | 625,932 |

**Table 4-14:** General Location of Coast Guard Underway Activities

| Area | Total kW-hrs |
|---|---|
| Mississippi River | 3,349,678 |
| Ohio River | 1,276,438 |
| Pacific | 1,311,967,588 |
| Puget Sound | 3,793,450 |
| Tennessee River | 1,115,487 |
| Willamette River | 354,849 |
| Lake Champlain | 35,515 |
| **Total** | **2,243,689,312** |

As the vessel fleet roster quantified at sea hours of operation, an inquiry was sent to the Coast Guard to ask specifically about in-port activities for the cutters. The Coast Guard staff indicated that cutters generally use shore power whenever it is available. There are some instances where maintenance, testing, or training could necessitate the need to run on ship's power. Because of these exceptions, it is estimated that the time on ship's power is no more than 10 hours per 30 days of in-port time. This means that while in-port, a Coast Guard cutter is estimated to be on shore power "99% of the time" (U.S. Coast Guard 2015b). As this response indicates, in-port ship activity is relatively small, so it was not included in this version of the NEI.

Note, currently the NEI does not include emission estimates from U.S. Naval exercises in U.S. waters. It is anticipated that data may be available in 2016 that will allow inclusion of these vessels.

**Commercial Fishing:**

To obtain the most accurate survey of commercial fishing vessels operating in the United States, regional offices of the National Oceanic and Atmosphere Administration (NOAA) were contacted. Of the offices contacted, only Northeast, Southeast (including the Gulf of Mexico), West Coast, and Alaska provided data. Data for the Great Lakes, Puerto Rico, and the U.S. Virgin Islands were not obtained. Upon further research, it was found that fishing vessels in Puerto Rico and the Virgin Islands are almost all powered by small single engines, diesels too small to be considered C1 vessels or gasoline powered vessels not included in this inventory effort.

Due to confidentiality concerns, the responding NOAA regions were not able to provide specific vessel information. The Northeast (NOAA 2015b) and Southeast (NOAA 2015d) region provided the data on annual number of trips, vessel count, and days absent by port or county, which were used to estimate and spatially allocate annual hours of operation.

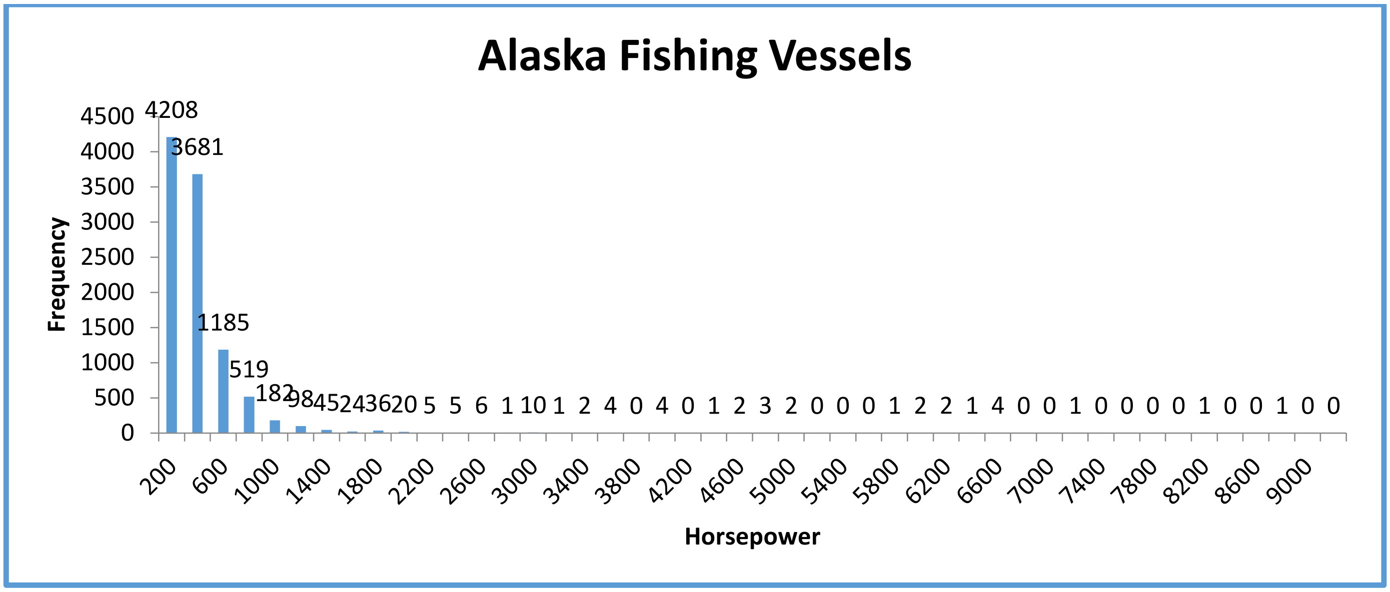
Data obtained from the West Coast regional office (NOAA 2015c) were not used in this inventory because the data provided only quantified the number of vessels operating and amount of fish caught by port. Data to quantify hours of operation were not provided. To gap fill the West Coast and the Great Lakes hours of operation, the NOAA website's commercial fishery landings by state (NOAA 2015a) were used to calculate a percent change between 2006 and 2013 commercial fish landings in pounds. It should be noted that data for 2014 was not available at the time, so 2013 data were used. Fishing vessel activity values in terms of kW-hrs developed in the original Category 1 and 2 Census Study (US EPA 2007) for the West Coast and Great Lakes were extrapolated using the percent change summarized in Table 4-15.

**Table 4-15:** State Fish Landing Data for Great Lakes and Pacific States

| | Great Lakes | | | | | Pacific | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Year** | **Michigan** | **Minnesota** | **Ohio** | **Wisconsin** | **Total** | **California** | **Hawaii** | **Oregon** | **Washington** | **Total** |
| 2006 Pounds | 9,350,764 | 308,409 | 4,241,973 | 4,449,476 | 18,350,622 | 341,660,769 | 26,020,904 | 282,846,344 | 241,606,439 | 892,134,456 |
| 2013 Pounds | 9,487,700 | 457,374 | 4,812,541 | 3,850,262 | 18,607,877 | 363,798,075 | 32,447,284 | 339,589,404 | 273,796,328 | 1,009,631,091 |
| Percent Change | 1.5% | 48.3% | 13.5% | -13.5% | 1.4% | 6.5% | 24.7% | 20.1% | 13.3% | 13.2% |

It is expected that the Alaska fishing vessel activity data would be significant as it represents about half of the U.S. fish landings. But the NOAA data (NOAA 2015e) obtained from the Alaska region was problematic as it documented the fleet size to be 2,267 vessels, noting the average duration at-sea per trip was 3 days, but could not provide an estimate of the number of trips these vessels made. Data from the Alaska Commercial Fisheries Entry Commission (CFEC) website which tracked Alaskan fishing vessels for the year 2014 (State of Alaska 2015) was used to evaluate the state's fishing fleet. The database included build date, horsepower rating, and duration at sea for 10,058 individual vessels. Assessing the horsepower of the vessels included in the database revealed that many of the vessels had very small or had no kW ratings (Figure 4-5). It was uncertain whether these smaller vessels were powered by recreational gasoline marine engines.

**Figure 4-5:** Horsepower for Alaskan Fishing Vessels




For this version of the NEI, vessels in the CFEC with a rating of 400 horsepower or less were omitted, leaving 2,169 vessels with horsepower ratings between 402 and 8,800. A study of active commercial Alaskan fishing vessels implemented by the North Pacific Fishery Management Council estimated the commercial fishing vessel fleet operating in state and federal waters around Alaska to be 1,646 unique vessels (North Pacific Fishery Management Council 2012). Unfortunately vessel characteristics of the fleet were not included in the report. Therefore the 2,169 larger vessels identified in the CFEC database were evaluated selecting the largest 1,646 vessels for inclusion into the 2014 NEI.

The days of operation for the vessels in the CFEC database seemed inflated and may indicate potential periods for operation, but not actual periods of operation. For example, many vessels were shown to operate year round, while most of the regulated fishing seasons in Alaska are restricted to the period from May to September (Alaska Department of Fish and Game 2014), which is about 150 days. The value of 3,600 hours per year (150 days/year x 24 hours = 3,600 hours) was used for Alaska vessels, which may over estimate emissions as it is assumed to be a maximum value for the fishing season. Future versions of the NEI marine vessel inventory should review available AIS data to better quantify Alaskan fishing vessel operations.

For the Northeast and Southeast regions where vessel power was not provided, an average fishing vessel kW power rating (1,000 kW) was obtained from the Category 1 and Category 2 Census (US EPA 2007) to estimate kW-hrs.

For the Alaska regions, horsepower ratings were converted to kW ratings, and applied to the hours of operation to estimate kW-hrs.

Where fishing vessel in-port and underway activities were not distinguished, activity was split to 95% underway and 5% in-port based on the Category 1 and Category 2 Census (US EPA 2007). Underway activity was also divided between state and federal waters using percentages derived from data on commercial landings of fish and shellfish in the Pacific Ocean for 2013 (NOAA 2015a); landings less than 3 miles from the coast were assumed to be in state waters and landings greater than 3 miles were assumed to be in federal waters. This approach will underestimate some states' activities such as Texas, Florida's Gulf coast, and Puerto Rico where the federal/state water boundary is 9 nautical miles.

It should be noted that additional study of fishing vessel activities is necessary to get a more accurate estimate of the fleet and its vessel characteristics and activity levels in Alaska, Pacific, and Great Lake Areas.

**Ferries:**

The U.S. Department of Transportation's Bureau of Transportation Statistics maintains a database of ferry vessels and activity (U.S. Department of Transportation 2014). This database includes ferry vessels characteristics by operator, trip segment, and terminal information. Individual vessels were linked to operators to develop operator fleet profiles which could be matched to trip segments. The operator fleet profiles included average vessel power and speed. The trip segments did not include travel distance or time information, so GIS tools were used to determine the distance between originating and destination terminals for each segment. During the process, duplicate trip segments were consolidated. Segment travel time was calculated using the segment distances and typical vessel speeds. Each segment had a season start date, as well as a count of trips. Total kW-hrs for each segment that an operator used were calculated using the following equation.

$$\text{kW-hrs} = (D_S / S_V) \times (SL \times [WT_V / 7]) \times kW_V$$

Where:

$D_S$ = distance of segment S in nautical miles between the start and end ports
$S_V$ = typical speed of vessel V in knots
$SL$ = length of the ferry season in days
$WT_V$ = number of trips made in a week for vessel V
$kW_V$ = kW rating of main engines for vessel V

**Offshore oil and gas support vessels:**

For the purpose of this inventory, 2011 estimates for the offshore oil and gas support vessels operating in the Gulf of Mexico were obtained from the Bureau of Ocean Energy Management (BOEM 2013). These vessels include:

- Seismic survey vessels
- Crew boats
- Supply boats
- Drilling rigs
- Anchor handling tugs
- Offshore tugs
- Pipelaying vessels

The 2011 estimates were adjusted to 2014 based on changes in the Gulf of Mexico's annual crude oil production. BOEM anticipates that the 2014 Gulf of Mexico emission inventory will be available in later 2016.

#### 4.3.4.2 *Engine Operating Loads*

Because the activity data used to develop the 2014 NEI did not include engine operating load data or actual vessel speeds, typical operating loads were compiled for each vessel type based on published reports. Initially engine operating load assumptions were taken from the EPA's Current Methodologies in Preparing Port Emission Inventories (US EPA 2009). This guidance document provided a typical cruising load factor of 0.83. Engine load data from the most recent IMO GHG study (IMO 2014) were also evaluated. The data in the IMO study included an assessment of bulk carriers, containerships, and tanker speed and engine loads, which accounted for the practice of slow steaming. The IMO data were weighed based on the fleet composition of the E&C data linked up to the IHS vessel characteristics, as provided in Table 4-16.

**Table 4-16:** IMO Underway Cruising Vessel Speed and Engine Load Factors for Bulk Carriers, Containerships, and Tankers

| Ship Type | Size Category | Size Units | Average at-sea Main Engine Load Factor (% MCR) | Percent of Total Pop. | Engine Load Weight Fraction | Weighted Load Factor |
|---|---|---|---|---|---|---|
| Bulk Carrier | 0-9999 | dwt | 70% | 0.9% | 0.0062 | 0.5893 |
| | 10000-34999 | | 59% | 25.1% | 0.1480 | |
| | 35000-59999 | | 58% | 36.0% | 0.2089 | |
| | 60000-99999 | | 60% | 31.7% | 0.1902 | |
| | 100000-199999 | | 57% | 6.2% | 0.0353 | |
| | 200000+ | | 62% | 0.1% | 0.0008 | |
| Container | 0-999 | TEU | 52% | 4.9% | 0.0257 | 0.3672 |
| | 1000-1999 | | 45% | 11.8% | 0.0531 | |
| | 2000-2999 | | 39% | 12.5% | 0.0489 | |
| | 3000-4999 | | 36% | 32.8% | 0.1181 | |
| | 5000-7999 | | 32% | 28.6% | 0.0915 | |
| | 8000-11999 | | 32% | 9.0% | 0.0288 | |

**Table 4-16:** IMO Underway Cruising Vessel Speed and Engine Load Factors for Bulk Carriers, Containerships, and Tankers

| Ship Type | Size Category | Size Units | Average at-sea Main Engine Load Factor (% MCR) | Percent of Total Pop. | Engine Load Weight Fraction | Weighted Load Factor |
|---|---|---|---|---|---|---|
| | 12000-14500 | | 34% | 0.3% | 0.0011 | |
| | 14500+ | | 28% | 0.0% | 0.0000 | |
| Oil Tanker | 0-4999 | dwt | 67% | 0.1% | 0.0009 | 0.5158 |
| | 5000-9999 | | 49% | 0.3% | 0.0013 | |
| | 10000-19999 | | 49% | 0.0% | 0.0000 | |
| | 20000-59999 | | 55% | 3.6% | 0.0196 | |
| | 60000-79999 | | 57% | 15.6% | 0.0889 | |
| | 80000-11999 | | 51% | 43.4% | 0.2212 | |
| | 120000-199999 | | 49% | 32.6% | 0.1595 | |
| | 200000+ | | 54% | 4.5% | 0.0244 | |

dwt = dead weight tonnage; TEU = twenty foot equivalent units

Load factors for RSZ were developed based on vessel speed which was either the maximum speed of the RSZ or the cruising speed of the vessel, which ever value was the smaller. The vessel speed was used in conjunction with the vessel's maximum speed and the propeller rule to estimate the propulsion engine operating load while in the RSZ.

$$LF = (AS/MS)^3$$

Where:

LF = Load Factor (percent)
AS = Actual Speed (knots)
MS = Maximum Speed (knots)

Propulsion engine load factor for maneuvering was assumed to be 0.2, based on Entec's European emission inventory (Entec 2002). It is recommended that future versions of this inventory consider reviewing AIS in port data to more accurately quantify maneuvering loads. It was also assumed that the auxiliary engines would be operating during maneuvering based on EPA port guidance (US EPA 2009) as summarized in Table 4-17.

**Table 4-17:** Auxiliary Operating Loads

| Vessel Types | Maneuver | Hotel |
|---|---|---|
| Bulk Carrier | 0.45 | 0.1 |
| Bulk Carrier, Laker | 0.45 | 0.1 |
| Buoy Tender | 0.45 | 0.22 |
| Container | 0.48 | 0.19 |
| Crude Oil Tanker | 0.33 | 0.26 |
| Drilling | 0.45 | 0.22 |
| Fishing | 0.45 | 0.22 |
| FPSO | 0.45 | 0.22 |

**Table 4-17:** Auxiliary Operating Loads

| Vessel Types | Maneuver | Hotel |
|---|---|---|
| General Cargo | 0.45 | 0.22 |
| Icebreaker | 0.45 | 0.22 |
| Jackup | 0.45 | 0.22 |
| LNG Tanker | 0.33 | 0.26 |
| LPG Tanker | 0.33 | 0.26 |
| Misc. | 0.45 | 0.22 |
| Passenger | 0.8 | 0.64 |
| Pipelaying | 0.45 | 0.22 |
| Reefer | 0.67 | 0.32 |
| Research | 0.45 | 0.22 |
| RORO | 0.45 | 0.26 |
| Supply | 0.45 | 0.22 |
| Support | 0.45 | 0.22 |
| Tanker | 0.33 | 0.26 |
| Tug | 0.45 | 0.22 |
| Vehicle Carrier | 0.45 | 0.22 |
| Well Stimulation | 0.45 | 0.22 |

While the vessel is dockside, it was assumed that propulsion engines would not be operating and the auxiliary engines were operating at the loads noted in Table 4-17. For vessels equipped with C 1 and C2 propulsion engines it was assumed that neither the propulsion nor the auxiliary engines would be operating while dockside to conserve fuel. This version of the NEI also did not include activity or emissions associated with boilers used to generate steam or to run cargo handling equipment and pumps.

#### 4.3.4.3 *Emission Factors/ HAP Speciation Profiles*

**Vessels equipped with Category 3 propulsion engines**

As the dominant propulsion engine configuration for large Category 3 vessels is the slow speed diesel (SSD) engine, the following SSD emission factors were used for Category 3 propulsion engines. Medium speed diesel (MSD) emission factors were used for auxiliary engines associated with these larger vessels. For the 2014 inventory, it was assumed that Emission Control Area (ECA) compliant fuels were used while transiting U.S. waters. Emission factors for vessels equipped with Category 3 propulsion engines are presented in Table 4-18.

**Table 4-18:** Category 3 Emission Factors (g/kW-hrs)

| Type | Engine | Fuel | $NO_X$ | $VOC_a$ | HC | CO | $SO_2$ | $CO_2$ | $PM_{10}$ | $PM_{2.5\ b}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| SSD | Main | 1% Sulfur | 14.7 | 0.6318 | 0.6 | 1.4 | 3.62 | 588.86 | 0.45 | 0.42 |
| MSD | Aux | 1% Sulfur | 12.1 | 0.4212 | 0.4 | 1.1 | 3.91 | 636.6 | 0.47 | 0.43 |

From: U.S. EPA/OTAQ, Regulatory Impact Analysis: Control of Emissions of Air Pollution from Locomotive Engines and Marine Compression Ignition Engines Less than 30 Liters Per Cylinder, March 2008.

[a] Hydrocarbon (HC) was converted to VOC using a conversion factor of 1.053 as provided in the above reference

[b] $PM_{2.5}$ was assumed to be 97 percent of $PM_{10}$ using the above reference

Note that this approach assumes that all large vessels will implement fuel switching before 2014 to comply with the 1% fuel sulfur standard, and use of controls such as scrubbing of high sulfur fuels, which is also an option to meet regulations, will be minimal.

If an engine load factor is less than 20 percent of the engine operating load, the emission factors were adjusted to account for operations outside the engines typical optimal load. For this 2014 inventory, these low load periods tend to occur during vessel movements in the RSZ. The low load adjustment factors used in this inventory were obtained from the EPA port guidance (US EPA 2009) and are provided in Table 4-19.

**Table 4-19:** Calculated Low Load Multiplicative Adjustment Factors

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

### Vessels equipped with Category 1 / Category 2 propulsion engine

Activity data for smaller vessels equipped with C1 and C2 engines are aggregated together, therefore Category 2 emission factors (Table 4-20) were used for these vessels as these factors tended to provide more conservative emission estimates.

**Table 4-20:** Tier Emission Factors for Vessels Equipped With Category 2 Propulsion Engines (g/kW-hrs)

| Tier | $PM_{10}$ | $NO_x$ | HC | CO | VOC [a] | $PM_{25}$ [b] | $SO_2$ | $CO_2$ |
|---|---|---|---|---|---|---|---|---|
| 0 | 0.32 | 13.36 | 0.134 | 2.48 | 0.141102 | 0.3104 | 0.006 | 648.16 |
| 1 | 0.32 | 10.55 | 0.134 | 2.48 | 0.141102 | 0.3104 | 0.006 | 648.16 |
| 2 | 0.32 | 8.33 | 0.134 | 2.00 | 0.141102 | 0.3104 | 0.006 | 648.16 |
| 3 | 0.11 | 5.97 | 0.07 | 2.00 | 0.073710 | 0.1067 | 0.006 | 648.16 |

From: U.S. EPA/OTAQ, Regulatory Impact Analysis: Control of Emissions of Air Pollution from Locomotive Engines and Marine Compression Ignition Engines Less than 30 Liters per Cylinder, March 2008.

[a] HC was converted to VOC using a conversion factor of 1.053 as provided in the above reference.

[b] $PM_{2.5}$ was assumed to be 97 percent of $PM_{10}$ using the above reference.

The Tier emission factors noted in Table 4-20 were weighted relative to the vessel type based on the year the vessel was manufactured. Table 4-21 shows the vessel age distribution by Tier.

**Table 4-21:** Vessel Tier Population By Type For Vessels Equipped With C1 or C2 Propulsion Engines

| Trip Count | Vessel Count | Vessel Type | Total* | Tier Level | | | | Percent Tier | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 0 | 1 | 2 | 3 | 0 | 1 | 2 | 3 |
| 5330 | 51 | Bulk Carrier | 51 | 46 | | 5 | | 90.2% | 0.0% | 9.8% | 0.0% |
| 932 | 23 | Bulk Carrier, Laker | 23 | 23 | | | | 100.0% | 0.0% | 0.0% | 0.0% |
| 5 | 3 | Buoy Tender | 3 | 3 | | | | 100.0% | 0.0% | 0.0% | 0.0% |
| 200 | 2 | Container | 2 | 2 | | | | 100.0% | 0.0% | 0.0% | 0.0% |
| 2421 | 25 | Containership | 25 | 22 | 3 | | | 88.0% | 12.0% | 0.0% | 0.0% |
| 140767 | 426 | Crewboat / Supply / Utility Vessel | 425 | 298 | 37 | 87 | 3 | 70.1% | 8.7% | 20.5% | 0.7% |
| 7 | 5 | Drilling | 5 | 2 | | 3 | | 40.0% | 0.0% | 60.0% | 0.0% |
| 19026 | 13 | Excursion / Sightseeing Vessel | 13 | 12 | | 1 | | 92.3% | 0.0% | 7.7% | 0.0% |
| 276 | 45 | Fishing | 45 | 43 | 2 | | | 95.6% | 4.4% | 0.0% | 0.0% |
| 29660 | 153 | General Cargo | 152 | 93 | 11 | 48 | | 61.2% | 7.2% | 31.6% | 0.0% |
| 8 | 2 | Icebreaker | 2 | 2 | | | | 100.0% | 0.0% | 0.0% | 0.0% |
| 10 | 3 | Jackup | 3 | 2 | | 1 | | 66.7% | 0.0% | 33.3% | 0.0% |
| 8 | 2 | LPG Tanker | 2 | | | 2 | | 0.0% | 0.0% | 100.0% | 0.0% |
| 247369 | 35 | Misc. | 33 | 28 | 2 | 3 | | 84.8% | 6.1% | 9.1% | 0.0% |
| 749 | 26 | Passenger | 26 | 24 | 1 | 1 | | 92.3% | 3.8% | 3.8% | 0.0% |
| 4666 | 18 | Passenger Carrier | 18 | 15 | 3 | | | 83.3% | 16.7% | 0.0% | 0.0% |
| 61 | 10 | Pipelaying | 10 | 10 | | | | 100.0% | 0.0% | 0.0% | 0.0% |
| 344540 | 1626 | Pushboat | 1,625 | 1,348 | 43 | 214 | 20 | 83.0% | 2.6% | 13.2% | 1.2% |
| 63 | 12 | Reefer | 12 | 12 | | | | 100.0% | 0.0% | 0.0% | 0.0% |
| 346 | 42 | Research | 42 | 35 | 1 | 6 | | 83.3% | 2.4% | 14.3% | 0.0% |
| 1771 | 19 | RORO | 19 | 17 | 1 | 1 | | 89.5% | 5.3% | 5.3% | 0.0% |
| 230 | 3 | RO-RO Vessel | 3 | 3 | | | | 100.0% | 0.0% | 0.0% | 0.0% |
| 4778 | 243 | Supply | 243 | 126 | 31 | 86 | | 51.9% | 12.8% | 35.4% | 0.0% |
| 808 | 66 | Support | 66 | 28 | 7 | 31 | | 42.4% | 10.6% | 47.0% | 0.0% |

**Table 4-21:** Vessel Tier Population By Type For Vessels Equipped With C1 or C2 Propulsion Engines

| Trip Count | Vessel Count | Vessel Type | Total* | Tier Level | | | | Percent Tier | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 0 | 1 | 2 | 3 | 0 | 1 | 2 | 3 |
| 5553 | 102 | Tanker | 101 | 47 | 11 | 43 | | 46.5% | 10.9% | 42.6% | 0.0% |
| 3962 | 336 | Tug | 336 | 286 | 13 | 35 | 2 | 85.1% | 3.9% | 10.4% | 0.6% |
| 142519 | 867 | Tugboat | 867 | 630 | 48 | 172 | 17 | 72.7% | 5.5% | 19.8% | 2.0% |
| 2 | 1 | Well Stimulation | 1 | 1 | | | | 100.0% | 0.0% | 0.0% | 0.0% |
| 956067 | 4159 | Total / Average Percent Tier | 4,153 | 3158 | 214 | 739 | 42 | 76.0% | 5.2% | 17.8% | 1.0% |

Note this approach does not account for early introduction of controls by vessel operators, compliance with more stringent local standards, or participation in voluntary emission reduction programs such as California's Carl Moyer Program or the Texas Emission Reduction Plan (TERP).

Hazardous air pollutant emissions were estimated by applying speciation profiles (Appendix F) to the VOC estimates for organic HAPs and PM estimates for metal HAPs using the following equation:

$$E = A \times SF$$

Where:

E = Annual emissions for HAP (tons)
A = Annual emissions for speciation base (tons)
SF = Speciation factor (unit less fraction)

### Emission Summaries

Based on the approach documented above, Table 4-22 summarizes activity and emissions by vessel propulsion engine category and mode.

**Table 4-22:** 2014 Vessel Activity (kW-hrs) and Emissions (tons) by Propulsion Engine and Mode

| Category | Source | SCC | Mode | Total Activity (kW-hr) | CO | $CO_2$ | $NO_X$ | $PM_{10}$-PRI | $PM_{25}$-PRI | $SO_2$ | VOC |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Cat1/2 | E&C | 2280002100 | Maneuvering | 742,228,543 | 125 | 61,923 | 1,179 | 44 | 40 | 333 | 39 |
| Cat1/2 | E&C | 2280002200 | Cruising | 945,222,365 | 1,896 | 516,687 | 9,648 | 255 | 247 | 5 | 113 |
| Cat1/2 | Misc-C1/C2 | 2280002100 | Maneuvering | 4,086,763,051 | 2,178 | 583,975 | 11,316 | 285 | 276 | 5 | 126 |
| Cat1/2 | Misc-C1/C2 | 2280002200 | Cruising | 13,348,660,561 | 66,114 | 21,066,882 | 336,909 | 10,409 | 10,097 | 2,258 | 5,785 |
| Cat1/2 | WBD | 2280002100 | Maneuvering | 2,090,680,129 | 1,112 | 298,746 | 5,754 | 147 | 143 | 3 | 65 |
| Cat1/2 | WBD | 2280002200 | Cruising | 19,795,947,087 | 38,038 | 10,250,302 | 196,657 | 5,049 | 4,898 | 94 | 2,228 |

**Table 4-22:** 2014 Vessel Activity (kW-hrs) and Emissions (tons) by Propulsion Engine and Mode

| Category | Source | SCC | Mode | Total Activity (kW-hr) | CO | $CO_2$ | $NO_X$ | $PM_{10}$-PRI | $PM_{25}$-PRI | $SO_2$ | VOC |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Cat3 | E&C | 2280003100 | Dock | 27,735,673,393 | 3,775 | 2,060,823 | 39,098 | 1,540 | 1,409 | 12,665 | 1,503 |
| Cat3 | E&C | 2280003100 | Maneuvering | 7,217,499,394 | 618 | 286,003 | 6,568 | 216 | 200 | 1,758 | 267 |
| Cat3 | E&C | 2280003200 | Cruising | 64,474,040,733 | 55,862 | 23,496,513 | 586,555 | 17,956 | 16,759 | 144,444 | 25,210 |
| Cat3 | E&C | 2280003200 | Reduced Speed Zone | 7,055,981,077 | 2,629 | 891,303 | 22,034 | 713 | 666 | 5,492 | 1,319 |
| Total | | | | 147,492,696,332 | 172,348 | 59,513,157 | 1,215,718 | 36,614 | 34,735 | 167,058 | 36,654 |

Note: Misc C1/C2 includes: Coast Guard, dredging, ferries, fishing, offshore oil & gas support, and research.

Table 4-23 also summaries emissions by vessel type.

**Table 4-23**: 2014 Vessel Activity (kW-hrs) and Emissions (tons) by Vessel Type

| Vessel Type | Total Activity (kW-hr) | CO | $CO_2$ | $NO_X$ | $PM_{10}$-PRI | $PM_{25}$-PRI | $SO_2$ | VOC |
|---|---|---|---|---|---|---|---|---|
| Bulk Carrier | 16,502,188,704 | 11,855 | 4,539,374 | 108,528 | 3,278 | 3,070 | 23,396 | 4,264 |
| Bulk Carrier, Laker | 591,085,436 | 502 | 183,897 | 4,349 | 129 | 121 | 865 | 161 |
| Buoy Tender | 2,647,731 | 6 | 1,548 | 32 | 1 | 1 | 0 | 0 |
| Coast Guard | 2,150,964,635 | 4,881 | 1,275,547 | 26,292 | 630 | 611 | 12 | 278 |
| Containership | 53,193,329,151 | 23,199 | 9,236,172 | 220,943 | 6,808 | 6,359 | 50,912 | 9,048 |
| Dredging | 1,041,726,442 | 2,278 | 595,427 | 12,273 | 294 | 285 | 5 | 130 |
| Excursion / Sightseeing Vessel | 4,319,972 | 10 | 2,562 | 50 | 1 | 1 | 0 | 1 |
| Ferries | 5,641,357,376 | 6,307 | 1,694,863 | 32,678 | 825 | 800 | 16 | 365 |
| Fishing | 6,585,566,278 | 14,354 | 3,751,598 | 76,606 | 1,852 | 1,797 | 34 | 817 |
| General Cargo | 4,462,901,347 | 3,729 | 1,527,286 | 36,436 | 1,126 | 1,052 | 8,522 | 1,472 |
| Misc | 1,101,196,066 | 794 | 214,600 | 4,247 | 108 | 105 | 53 | 53 |
| Offshore Oil & Gas* | 669,380,168 | 37,117 | 13,443,080 | 182,540 | 6,653 | 6,454 | 2,188 | 4,128 |
| Passenger | 11,886,827,285 | 11,964 | 5,053,464 | 123,561 | 3,835 | 3,576 | 30,586 | 5,254 |
| Reefer | 1,082,375,467 | 930 | 400,149 | 9,645 | 303 | 282 | 2,425 | 406 |
| Research | 2,015,808,882 | 4,316 | 1,160,121 | 22,507 | 573 | 556 | 11 | 253 |
| RO-RO | 2,369,916,464 | 3,245 | 987,219 | 20,995 | 574 | 547 | 1,998 | 469 |
| Tanker, Crude Oil | 7,192,697,038 | 4,061 | 1,742,324 | 42,670 | 1,329 | 1,238 | 10,710 | 1,819 |
| Tanker, LNG/LPG | 1,461,972,434 | 1,268 | 540,689 | 13,291 | 412 | 384 | 3,314 | 567 |
| Tanker, Misc | 14,088,889,926 | 15,197 | 5,558,738 | 121,580 | 3,725 | 3,508 | 22,470 | 4,221 |
| Tug | 11,197,514,271 | 22,763 | 6,093,037 | 119,306 | 3,005 | 2,913 | 250 | 1,343 |
| Vehicle Carrier | 4,250,031,261 | 3,571 | 1,511,461 | 37,187 | 1,154 | 1,076 | 9,291 | 1,608 |
| Total | 147,492,696,332 | 172,348 | 59,513,157 | 1,215,718 | 36,614 | 34,735 | 167,058 | 36,654 |

* Note: Some Offshore Oil & Gas emissions were derived from the BOEM Emission Inventory which did not include activity data.

#### 4.3.4.4 *Allocation of Port and Underway Emissions*

Ports and underway activity and emissions are summarized in Table 4-24. Note that in this version of the marine vessel component of the NEI, auxiliary emissions for underway operations were considered less significant than other modes and were not included in this version of the NEI marine vessel inventory, such that actual underway emissions may be slightly higher than the values presented in Table 4-24.

**Table 4-24:** 2014 Vessel Activity (kW-hrs) and Emissions (tons) by Propulsion Engine and in Port and Underway Modes

| SCC Description | SCC | Total Activity (kW-hr) | CO | $CO_2$ | $NO_X$ | $PM_{10}$-PRI | $PM_{25}$-PRI | $SO_2$ | VOC |
|---|---|---|---|---|---|---|---|---|---|
| Diesel Port Emissions | 2280002100 | 6,919,671,722 | 3,416 | 944,645 | 18,250 | 476 | 459 | 341 | 230 |
| Diesel Underway Emissions | 2280002200 | 34,089,830,013 | 106,048 | 31,833,871 | 543,214 | 15,713 | 15,242 | 2,357 | 8,125 |
| Residual Port Emissions | 2280003100 | 34,953,172,787 | 4,393 | 2,346,825 | 45,666 | 1,756 | 1,609 | 14,423 | 1,770 |
| Residual Underway Emissions | 2280003200 | 71,530,021,810 | 58,491 | 24,387,816 | 608,589 | 18,669 | 17,425 | 149,936 | 26,529 |
| Total | | 147,492,696,332 | 172,348 | 59,513,157 | 1,215,718 | 36,614 | 34,735 | 167,058 | 36,654 |

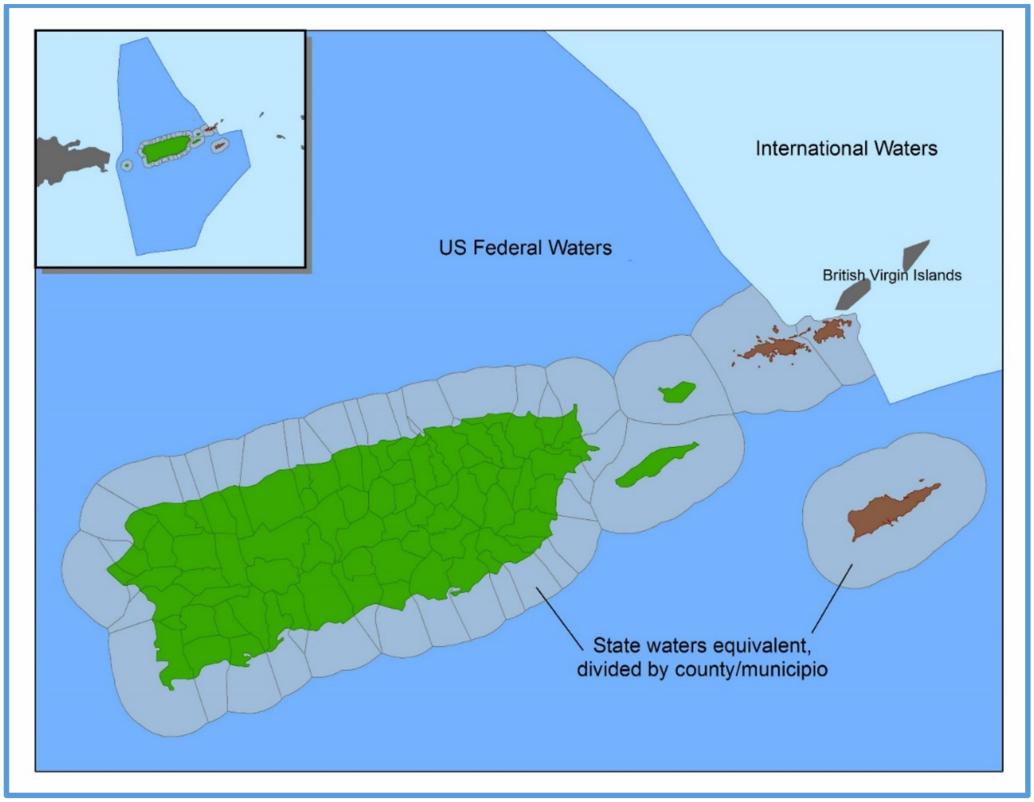
EPA has continued to develop and improve port shapes using a variety of resources. First, GIS data or maps provided directly from the ports were used to delineate port boundaries. Next, maps or port descriptions from local port authorities and port districts were used in combination with existing GIS data to identify port boundaries. Finally, satellite imagery from tools such as Google Earth and street layers from StreetMap USA were used to delineate port areas. Originally, primary emphasis was placed on mapping the 117 ports with C3 vessel activity using available shapefiles of the port area. As the availability of C1 and C2 activity improved, additional port shapes were required to represent their emissions. The NEI port shapefiles were revised to include 114 additional ports from the 2014 inventory. Further revisions over the years have increased the count of the current 5,649 port shapes for the 2014 inventory.

In all cases, port shapes were split by county boundary, such that no shape crosses county lines, to facilitate totaling of emissions to the state or county level. Each port shape was identified by the port name and state and county FIPS in addition to a unique Shape ID. In most cases, port shapes were created on land bordering waterways and coastal areas. However, the additional port shapes created in this effort were generated as small circles with a radius of 0.25 miles that cover both land and water. Additionally, activity data such as Automatic Identification System (AIS) indicated that vessels frequently have maneuvering/hoteling activities further offshore than previously anticipated. As such, the underway shapes were duplicated, given new

IDs, and added to the port shapefile to provide a place to put these activities if state or local agencies wish to include them.

Underway shapes remain unchanged with the exception of new shapes added to represent state and federal waters around Puerto Rico and the U.S. Virgin Islands as shown in Figure 4-6.

**Figure 4-6:** New Underway Shapes for Puerto Rico and the U.S. Virgin Islands




Spatial allocation of the activity data varied by data source. Port activity was allocated to the origin and destination port shapes. E&C data and the WCD were routed along a waterway network, then the routes were intersected with EPA's shapefiles shipping lanes for NEI. For the E&C data, underway activity for each vessel trip was divided among the NEI shapes based on the portion of the route that passed through each shape. The length of the waterway segment passing through each shape was divided by the total trip length to calculate the percentage of the trip's activity to assign to each shape.

$$V = (L/T)* A$$

Where:

- V = Activity for shape V
- L = Length of waterway segment within shape V
- T = Total trip length

A = Total trip activity

For WCD, hoteling and maneuvering activity was allocated to the nearest water-based port shapes for each origin and destination. For underway activity, the length of the waterway through each shape was calculated and multiplied by the number of trips in that shape. This value was divided by the national total for trips multiplied by length to determine the percentage of the national total activity to allocate to each shape.

$$P = (T * L)/(NT*NL)$$

Where:

P = Percentage of national activity
T = Total trips for the NEI underway shape
L = Waterway segment length within underway shape
NT = National trip total
LN = National waterway network length total

Offshore oil and gas support vessel data derived from AIS data used by BOEM was limited to federal waters and was assigned to the associated shape, though the more refined activity can be seen in Figure 4-7. Research vessel activity was allocated to shapes based on the spatial allocation from the Category 1 and Category 2 Census (US EPA 2007). Dredging activities were spatially apportioned to ship channels based on the job name. The job names indicated general location, such as a bay area or a waterway portion; however, they did not provide sufficient information to precisely locate the dredging activities or even extent of the project. Best effort was given to identify the waterway segments in GIS that most closely match the limited location information. Ferry activity was split to 65% port and 35% underway, and all terminals were mapped using the coordinates available in the National Census of Ferry Operators (DOT 2014). Activity was then allocated to the port or underway shape nearest each ferry terminal. The underway spatial allocation can be seen in Figure 4-8. U.S. Coast Guard activity was provided by region, NEI shapes in each region were identified, and underway activity was allocated to individual shapes as a fraction of the total region's area as shown in Figure 4-9.

**Figure 4-7:** Spatial Allocation of 2014 Support Vessel Activity

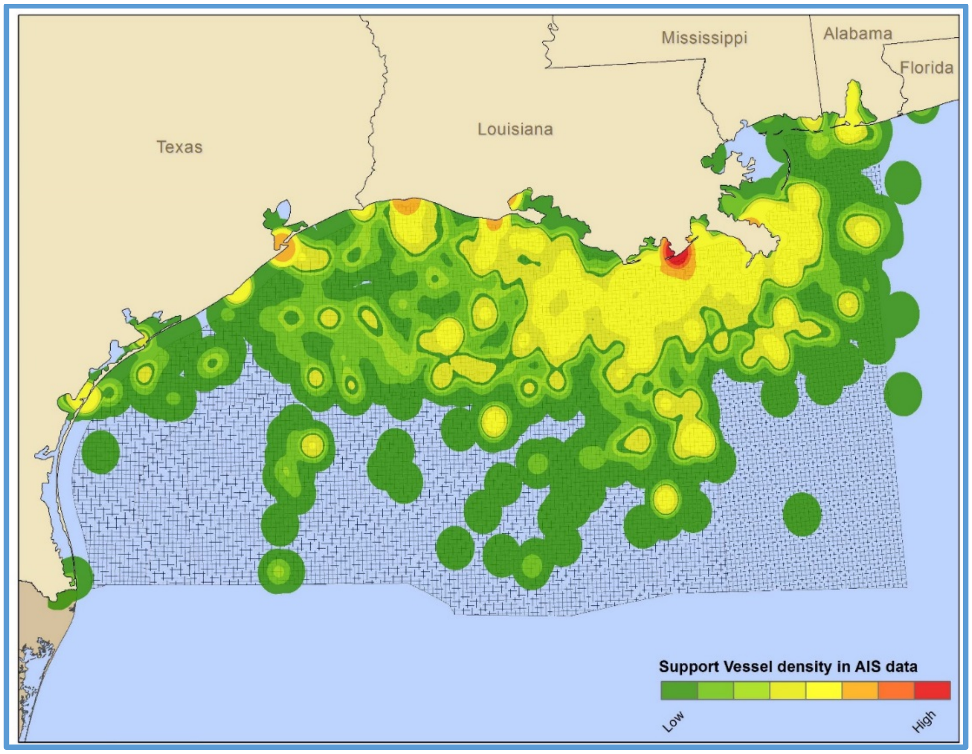



**Figure 4-8:** Spatial Allocation of 2014 Ferry Activity

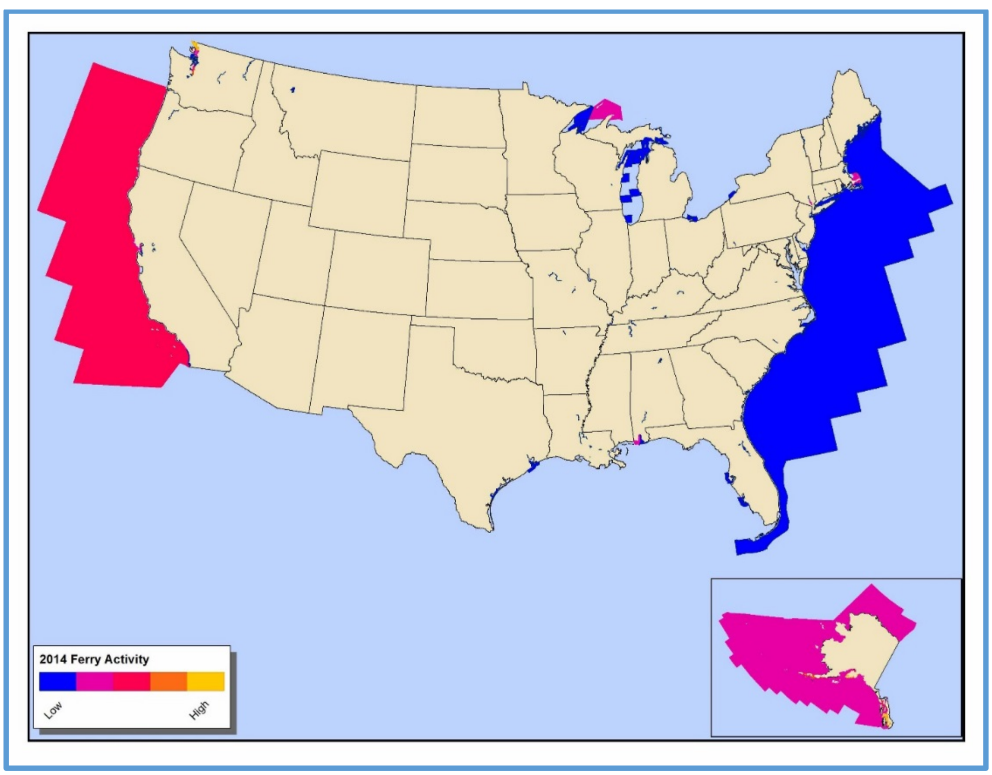
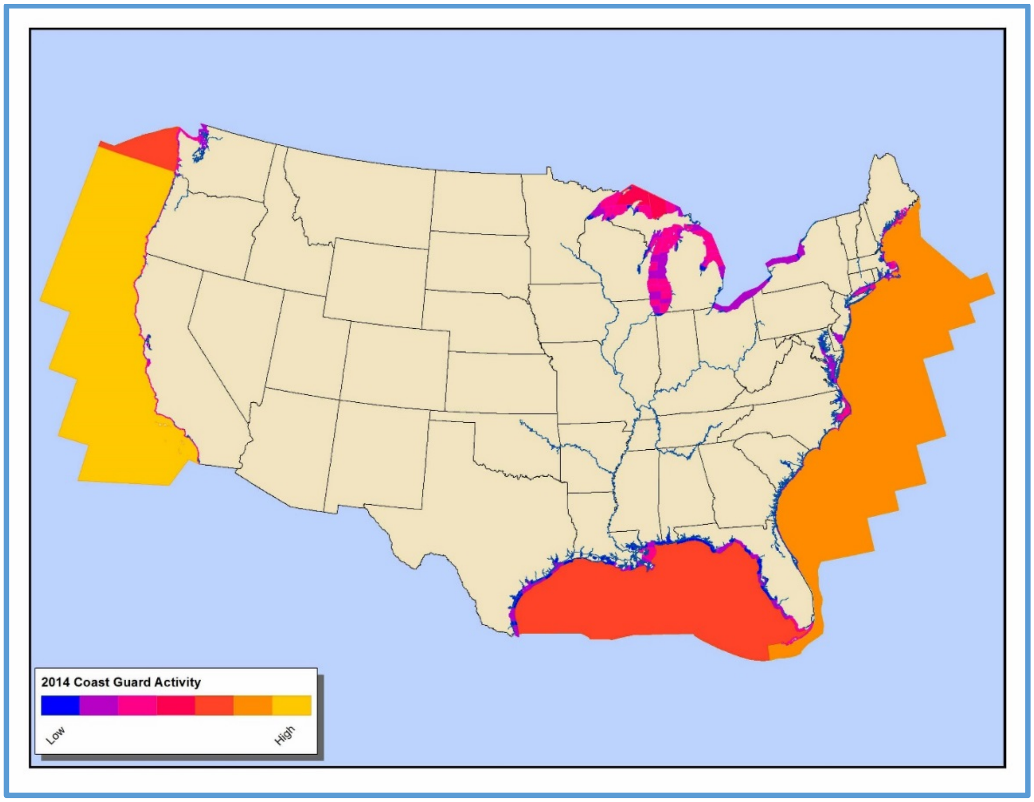


**Figure 4-9:** Spatial Allocation of 2014 Coast Guard Activity



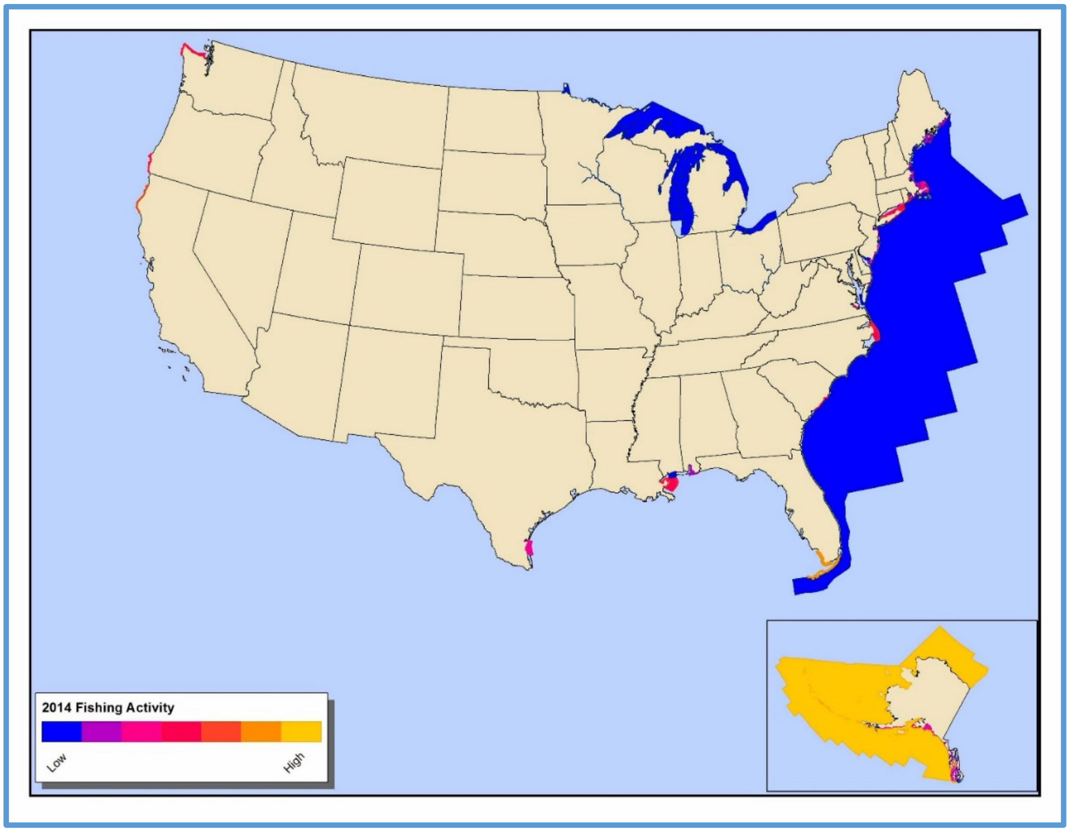

Fishing vessel activity was spatially allocated using different methods based on available regional data. Alaska fishing activity was spatially apportioned based on NOAA data that listed the number of catcher vessels by region for the Aleutian Islands, Western Alaska, Central Gulf of Alaska, and Eastern Gulf of Alaska as shown in Table 4-25. The NEI shapes were assigned to these regions in GIS, and then emissions were spatially allocated by region based on shape area.

**Table 4-25:** Alaska Commercial Fishing Catcher Vessel Count

| Area | Catcher Vessels | Percent |
|---|---|---|
| Aleutian Islands | 494 | 0.23 |
| Western Alaska | 64 | 0.03 |
| Central Gulf of Alaska | 728 | 0.34 |
| Eastern Gulf of Alaska | 854 | 0.40 |

The Northeast NOAA data provided fishing activity by city or by state (NOAA 2015b). Cities were mapped, and activity values were assigned to the nearest port and underway shape ID. In some cases, the city name was unknown, so the activity was divided between other known ports within that state proportionate to their activity values. For the southeast and the west coast, total activity was provided by state. Statewide activity was divided as 95% underway and 5% in-port and then allocated to shapes based on the previous fishing allocation in the Category 1 and Category 2 Census (US EPA 2007). The final fishing allocation can be seen in Figure 4-10.

**Figure 4-10:** Spatial Allocation of 2014 Commercial Fishing Activity




### 4.3.5 Summary of quality assurance methods

- While developing the EPA 2014 marine vessel inventory, data quality checks were implemented at critical points; this included comparison with earlier data sets used to develop the C1 and C2 inventory, published emission factors, and previous NEI emission estimates for all engine categories.
- All calculations were checked by experience staff members of the team.
- During data transfers into the project database, quality assurance checks were implemented and data summary tables generated to ensure that no corrupted data were transferred and the record count was consistent with the transfer.
- All assumptions were documented and discussed with team members to ensure that the assumptions were reasonable and consistent with other known data points.

- Microsoft Access data queries were documented and reviewed by experience staff who were not directly involved in developing the current databases.
- GIS imagery were reviewed to identify any spatial anomalies in the data.
- Where anomalies were found during these checks, additional research was implemented to determine whether the identified issue was correct or whether there was an error in developing the estimate.

EPA compared shape-, state-, and county-level sums in (1) EPA default data, (2) state/local/tribal (S/L/T) agency submittals, and (3) the resultant 2011 NEI selection by:

- Pollutants, SCCs, and SCC-emission types
- Emissions summed to agency and SCC level.

#### 4.3.6 References for commercial marine vessels

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**Appendix A. Detailed Equations**

As mentioned in the text the general equation for estimating emissions is noted in the following equation:

$$\text{EF}\left(\frac{\text{g}}{\text{kWh}}\right) \times \frac{\text{D (NM)}}{\text{Vs}\,\frac{\text{NM}}{\text{hr}}} \times \text{LF} \times \text{Vp (kW)} = \text{Emissions}$$

Where:

D = Distance along Segment, NM / C or RSZ Knots

Vs = 0.94 x maximum vessel speed = cruising speed or RSZ speed.

If vessel speed is unknown used typical speed by vessel type.

(D/Vs is used to estimate operating hours for E&C data and WC data – for C1/C2 study typical operating hours are used instead)

LF = Load Factor (fraction less than 1)

Vp = Vessel Power

Below are more detailed equations based on the actual data and their field names for the various transportation modes (cruising, RSZ, maneuvering, and hoteling).

**Entrance and Clearance Emission Estimation:**

Routes in the E&C were subdivided into cruising portions and RSZ portions. The data fields for cruising and RSZ are the same and the field names and descriptions are listed below in Table A-1.

**Table A-1:** Data Fields in Entrance and Clearance Data

| Data Field | Description |
|---|---|
| RecordIDRaw | Internal tracking number |
| ECDATE | E&C dates |
| WHERE_IND | "D" or "F" for Domestic or Foreign trips |
| ERGVesselID | Internal vessel tracking number |
| ShipType | Standardized Vessel Type to link to Emission Factors |
| FromPortv2 | Standardized Origin Port Name (Domestic) or Country (Foreign) |
| ToPortv2 | Standardized Destination Port Name (Domestic) or Country (Foreign) |
| MainkW | Total kW for main engines |
| AuxkW | Total kW for auxiliary engines |
| CruiseSpeed(94%Max)Revised | Cruising Speed (knots), 94% of the max rated speed.* |
| CatLookup | Vessel Category to link to Emission Factors |

**Table A-1:** Data Fields in Entrance and Clearance Data

| Data Field | Description |
|---|---|
| RSZName | Reduced Speed Zone Name or "Cruising" if not in a RSZ |
| RSZ_Speed_kn | RSZ limit |
| SumOfLength_nm | Distance of route within U.S. water (nautical miles) |

* Note: Cruise speed (CruiseSpeed(94%Max)Revised) was further adjusted for slow steaming (Bulk Carrier, Container, and Tankers). This information is listed below.

Bulk Carriers, containerships, and tankers slow steam (travel at slower speeds) to be more efficient. Therefore the cruising speed, which is 94% of the rated max speed) is further reduced multiplying the speed by the reduction factors in Appendix B.

The emission factor data field names and descriptions are summarized in Table A-2 below.

**Table A-2:** Emission Factor Data Fields

| EF Data Field | Description |
|---|---|
| ShipType | Standardized Vessel Type to link to E&C data |
| RSZ_Speed_nm | Links to E&C data |
| Engine Type | Main or Auxiliary |
| Mode | RSZ or Cruising |
| CatLookup | Vessel Category to link to E&C data |
| Pollutant | Pollutant name |
| EF-g/kwhr | Emission Factor in g/kW-hr |

**Entrance and Clearance Cruising:**

Emissions are calculated for main engines only for cruising. Using the detailed equation and the data field names from the E&C data and the emission factor table, the following criteria and equation are used.

Cruising Criteria

- E&C RSZName = "Cruising"
- EF Mode = “RSZ”
- EF Engine Type = “Main”

Cruising Linkage

- ShipType
- CatLookup
- RSZ_Speed_nm

Cruising Emission Equation

EM = SumofLength_nm / CruiseSpeed(94%Max)Revised * MainkW * EF-g/kWhr

**Entrance and Clearance RSZ:**

Emissions are calculated for main engines only for RSZ. Using the detailed equation and the data field names from the E&C data and the emission factor table, the following criteria, linkages, and equation are used. It should be noted that there is an IF statement for the speed based on the fact that if the vessel's cruising speed is already lower than the RSZ speed limit the vessel would not accelerate to the speed limit but stay at the already lower speed.

RSZ Criteria

- E&C RSZName <> "Cruising"
- EF Mode = "Cruising"
- EF Engine Type = "Main"
- IF (CruiseSpeed(94%Max)Revised < RSZ_Speed_kn,
    - then CruiseSpeed(94%Max)Revised
    - otherwise RSZ_Speed_kn

RSZ Linkage

- ShipType
- CatLookup
- RSZ

RSZ Emission Equation

EM = SumofLength_nm / IF(CruiseSpeed(94%Max)Revised < RSZ_Speed_kn, then CruiseSpeed(94%Max)Revised, otherwise RSZ_Speed_kn)* MainkW * EF-g/kWhr

**Entrance and Clearance Maneuvering:**

Emissions are calculated for both main and auxiliary engines for maneuvering. Using the detailed equation and the data field names from the Port E&C data and the emission factor table, the following criteria, linkages, and equation are used. The data fields in the Port E&C for maneuvering are summarized in Table A-3.

**Table A-3:** Port Entrance and Clearance Data Fields for Maneuvering

| Port E and C Data Field | Description |
|---|---|
| Port | Standardized US Ports |
| ERGVesselType | Standardized Vessel Type to link to Emission Factors |

**Table A-3:** Port Entrance and Clearance Data Fields for Maneuvering

| Port E and C Data Field | Description |
|---|---|
| Count | Trip Count to Port |
| ERGVesselID | Internal vessel tracking number |
| MainkW | Total kW for main engines |
| AuxkW | Total kW for auxiliary engines |
| CatLookup | Vessel Category to link to Emission Factors |
| Maneuvering Time (hours) | Maneuvering Time by Port and Type Divided by 2 to correct for the change from routes (lines) to ports (points) |
| TotalMainkW-hrs | Main kW * maneuvering time * Count |
| TotalAuxkW-hrs | AuxkW*maneuvering time * Count |

Maneuvering Criteria

- EF Mode = “Man”
- EF Engine Type = IF(Engine Type = “Main”
  - Then, kW-hrs = MainkW* Maneuvering Time,
  - Otherwise, kW-hrs = AuxKW*Maneuvering Time (where Engine Type = “Aux”)

Maneuvering Linkage

- ShipType
- CatLookup
- Engine Type

Maneuvering Emission Equation

EM = If Engine Type = “Main”

- Then, MainkW-hrs* EF-g/kWhr,
- Otherwise AuxkW-hrs * EF-g/kWhr (where Engine Tytpe = “Aux”)

**Entrance and Clearance Hoteling:**

Emissions are calculated for auxiliary engines only for maneuvering and Hoteling, which is when their operations are assumed to be the most significant. Using the detailed equation and the data field names from the Port E&C data and the emission factor table, the following criteria, linkages, and equation are used. The data fields in the Port E&C for hoteling are summarized in Table A-4.

**Table A-4:** Port Entrance and Clearance Data Fields for Hoteling

| Port E and C Data Field | Description |
|---|---|
| Port | Standardized US Ports |
| ERGVesselType | Standardized Vessel Type to link to Emission Factors |
| Count | Trip Count to Port |
| ERGVesselID | Internal vessel tracking number |
| AuxkW | Total kW for auxiliary engines |
| CatLookup | Vessel Category to link to Emission Factors |
| Hours Time (hours) | Hoteling Time by Port and Type Divided by 2 to correct for the change from routes (lines) to ports (points) |
| TotalAuxkW-hrs | AuxkW*maneuvering time * Count |

Hoteling Criteria

- EF Mode = "Man"
- EF Engine Type = "Aux"

Hoteling Linkage

- ShipType
- CatLookup
- Engine Type

Hoteling Emission Equation

EM = AuxkW-hrs * EF-g/kWwhr

**Waterborne Commerce Cruising:**

Emissions are calculated for main engines only for cruising. Using the detailed equation and the data field names from the E&C data and the emission factor table, the following criteria and equation are used. The data fields in the U.S. WCD for cruising are summarized in Table A-5.

**Table A-5:** U.S. WCD for Cruising Data Fields

| U.S. ACE Data Field | Description |
|---|---|
| VESSEL | Internal tracking number |
| ERGVesselType | Pushboat |
| StandardVesselType | Standardized Vessel Type to link to Emission Factors |
| HORSEPOWER | Main Horsepower |
| UniqueRouteID | Internal Route ID for tracking purposes |
| Origin | Standardized Origin Port |

**Table A-5:** U.S. WCD for Cruising Data Fields

| U.S. ACE Data Field | Description |
|---|---|
| Destination | Standardized Destination Port |
| TRIP_MILES | Total Distance of Trip (nm) |
| SumOfTRIPS | Total Sum of Trip Counts |
| Speed(knots) | 94% of Average Max speed (knots) |
| Time(hr) | Total time (TRIP_MILES/ Speed(knots)) |
| Percent | Percent of distance in US Waters |

Cruising Criteria

- EF Mode = “Cruising”
- EF Category = “Cat1/2”

Cruising Linkage

- StandardVesselType

Cruising Emission Equation

EM = TRIP_MILES/ Speed(knots)* SUMorTRIPS* Percent* HORSEPOWER* HP to kW conversion factor * EF-g/kWhr

**Waterborne Commerce Maneuvering:**

Emissions are calculated for main engines only for cruising. Using the detailed equation and the data field names from the E&C data and the emission factor table, the following criteria and equation are used. The data fields in the WCD for cruising are summarized in Table A-6.

**Table A-6:** U.S. WCD for Maneuvering Data Fields

| WCD Data Field | Description |
|---|---|
| VESSEL | Internal tracking number |
| ERGVesselType | Pushboat |
| StandardVesselType | Standardized Vessel Type to link to Emission Factors |
| HORSEPOWER | Main Horsepower |
| MaxOfUniqueRouteID | Internal Route ID for tracking purposes |
| Port | Standardized Port Name |
| Source | “Origin” or “Destination” Port |
| SumOfTRIPS | Total Sum of Trip Counts |
| Time(hr) | 0.5 default for maneuvering |

Maneuvering Criteria

- EF Mode = “Man”
- EF Category = “Cat1/2”

Maneuvering Linkage

- StandardVesselType

Maneuvering Emission Equation

EM = 0.5 hours * SumofTRIPS* HORSEPOWER* HP to kW conversion factor * EF-g/kWhr

**Misc. C1 and C2 Vessels:**

For all other C1 and C2 vessels not included in the E&C data or the Waterborne Commerce were calculated together. Vessel data were aggregated by type. The kW-hrs were summed together and the emission factors were applied to the kW-hrs. Emission factors were linked by vessel category and StandardVesselType.

EM = kW-hrs * EF (g/kW-hrs)

**Appendix B. Reduced Speed Zone**

**Table B-1:** Segments and RSZs Based on Summary of EPA Regulatory Impact Assessment for Category 3 Vessels

| Port Name | RSZ Distance (NM) | RSZ Speed (knots) |
|---|---|---|
| Palm Beach, FL | 3.1 | 3 |
| Lake Charles, LA | 38 | 6 |
| Coos Bay, OR | 13 | 6.5 |
| Beaumont, TX | 53.5 | 7 |
| Port Arthur, TX | 21 | 7 |
| Matagorda Ship | 24 | 7.3 |
| Everglades, FL | 2.1 | 7.5 |
| Brownsville, TX | 18.7 | 8.8 |
| Manatee, FL | 27.4 | 9 |
| Tampa, FL | 30 | 9 |
| Fall River, MA | 22.7 | 9 |
| Providence, RI | 24.9 | 9 |
| Searsport, ME | 22.2 | 9 |
| New Bedford/Fairhaven, MA | 22.4 | 9 |
| Kalama, WA | 68.2 | 9.25 |
| Longview, WA | 67.3 | 9.25 |
| Vancouver, WA | 95.7 | 9.25 |
| Portland, OR | 105.1 | 9.25 |
| Barbers Point, HI | 5.1 | 10 |
| Honolulu, HI | 10 | 10 |
| Valdez, AK | 27.2 | 10 |
| Hilo, HI | 7.1 | 10 |
| Kahului, HI | 7.5 | 10 |
| Nawiliwili, HI | 7.3 | 10 |
| Gulfport, MS | 17.4 | 10 |
| Panama City, FL | 10 | 10 |
| Pascagoula, MS | 17.5 | 10 |
| New Orleans, LA | 104.2 | 10 |
| Baton Rouge, LA | 219.8 | 10 |
| South Louisiana, LA | 142.8 | 10 |
| Plaquemines, LA | 52.4 | 10 |
| Portland, ME | 11.4 | 10 |
| Hopewell, VA | 91.8 | 10 |
| Morehead City, NC | 2.2 | 10 |

**Table B-1:** Segments and RSZs Based on Summary of EPA Regulatory Impact Assessment for Category 3 Vessels

| Port Name | RSZ Distance (NM) | RSZ Speed (knots) |
|---|---|---|
| Canaveral, FL | 4.4 | 10 |
| New Haven, CT | 2.1 | 10 |
| Bridgeport, CT | 2 | 10 |
| Wilmington, NC | 27.6 | 10 |
| Richmond, VA | 106.4 | 10 |
| Jacksonville, FL | 18.6 | 10 |
| Boston, MA | 14.3 | 10 |
| Mobile, AL | 36.1 | 11 |
| Pensacola, FL | 12.7 | 12 |
| Georgetown, SC | 17.6 | 12 |
| Charleston, SC | 17.3 | 12 |
| Miami, FL | 3.8 | 12 |
| Catalina, CA | 11.9 | 12 |
| Carquinez, CA | 39 | 12 |
| El Segundo, CA | 23.3 | 12 |
| Eureka, CA | 9 | 12 |
| Hueneme, CA | 2.8 | 12 |
| Long Beach, CA | 18.1 | 12 |
| Los Angeles, CA | 20.6 | 12 |
| Oakland, CA | 18.4 | 12 |
| Redwood City, CA | 36 | 12 |
| Richmond, CA | 22.6 | 12 |
| Sacramento, CA | 90.5 | 12 |
| San Diego, CA | 11.7 | 12 |
| San Francisco, CA | 14.4 | 12 |
| Stockton, CA | 86.9 | 12 |
| Brunswick, GA | 38.8 | 13 |
| Savannah, GA | 45.5 | 13 |
| Newport News, VA | 24.3 | 14 |
| Anchorage, AK | 143.6 | 14.5 |
| Nikishka, AK | 90.7 | 14.5 |
| Anacortes, WA | 108.3 | unknown |
| Everett, WA | 123.3 | unknown |
| Grays Harbor, WA | 4.9 | unknown |
| Olympia, WA | 185.9 | unknown |
| Port Angeles, WA | 65 | unknown |
| Seattle, WA | 133.3 | unknown |

**Table B-1:** Segments and RSZs Based on Summary of EPA Regulatory Impact Assessment for Category 3 Vessels

| Port Name | RSZ Distance (NM) | RSZ Speed (knots) |
|---|---|---|
| Tacoma, WA | 150.5 | unknown |
| Other Puget Sound | 106 | unknown |
| Freeport, TX | 2.6 | unknown |
| Galveston, TX | 9.3 | unknown |
| Houston, TX | 49.6 | unknown |
| Texas City, TX | 15.1 | unknown |
| Albany, NY | 142.5 | unknown |
| New York/New Jersey | 15.7 | unknown |
| Marcus Hook, PA | 94.7 | unknown |
| Paulsboro, NJ | 83.5 | unknown |
| Chester, PA | 78.2 | unknown |
| New Castle, DE | 60.5 | unknown |
| Penn Manor, PA | 114.5 | unknown |
| Camden, NJ | 94 | unknown |
| Philadelphia, PA | 88.1 | unknown |
| Wilmington, DE | 65.3 | unknown |
| Baltimore, MD | 157.1 | unknown |
| Corpus Christi, TX | 30.1 | unknown |

## Appendix C. Dredging Activities

**Table C-1:** 2014 Dredging Activities

| Job Name | Dredge Type | Operating Days |
|---|---|---|
| La Pointe, WI | bucket or mechanical | 13 |
| Raritan River-Arthur Kill | bucket or mechanical | 39 |
| Raritan River, NJ | bucket or mechanical | 55 |
| NYNJ Chan-Perth Amboy | bucket or mechanical | 70 |
| Matoc Ybor Channel/Sparkman | bucket or mechanical | 61 |
| Great Kills Harbor, NY | bucket or mechanical | 94 |
| Bayridge & Redhook Channel | bucket or mechanical | 89 |
| Baltimore Harbor and Channel | bucket or mechanical | 87 |
| MOTSU/WH/Mid-river | bucket or mechanical | 33 |
| S-SR-2 | bucket or mechanical | 245 |
| Wethersfield Cove | bucket or mechanical | 59 |
| Buttermilk Bay, MA | bucket or mechanical | 31 |
| Manitowoc, WI (W/ Kewaunee) | bucket or mechanical | 36 |
| WIN / RCB Lower Approaches | bucket or mechanical | 9 |
| Big Sandy Harbor | bucket or mechanical | 55 |
| St Lucie Inlet O&M | bucket or mechanical | 51 |
| Kewaunee, WI (w/ Manitowoc) | bucket or mechanical | 36 |
| The Dalles Shoal Removal | bucket or mechanical | 2 |
| Oakland Harbor (Inner & Outer) | bucket or mechanical | 9 |
| FY14 Swinomish Channel | bucket or mechanical | 35 |
| Lower Col River Clamshell | bucket or mechanical | 97 |
| Seattle Harbor | bucket or mechanical | 32 |
| South Coast Clamshell Maint. | bucket or mechanical | 81 |
| Waukegan Harbor | bucket or mechanical | 263 |
| Point Lookout, MI - SOM | bucket or mechanical | 107 |
| Oakland Harbor (Inner & Outer) | bucket or mechanical | 153 |
| Matoc Kings Bay EC O&M | hopper | 20 |
| Calcasieu Bar HDR 1-13 | hopper | 255 |
| Wilm Hbr Outer Ocean Bar | hopper | 37 |
| SNWW Outer Bar and Bank | hopper | 69 |
| Anchorage 2012-2014 | hopper | 184 |
| Hudson River, NY (Germantown) | hopper | 324 |
| Asbury Park-Avon, NJ (3b) | hopper | 97 |
| Matoc Ft Pierce O&M TO ODMDS | hopper | 20 |
| Brevard CO SPP | hopper | 112 |
| BIH-Jetty Ch (Rapid Response) | hopper | 19 |
| FY14 Chas Entrance Channel | hopper | 43 |

**Table C-1:** 2014 Dredging Activities

| Job Name | Dredge Type | Operating Days |
|---|---|---|
| Galveston Hrbr-Ent Ch/Redfish | hopper | 248 |
| Miss Riv SWP HDR 1-14 | hopper | 92 |
| Dade Co. BEC, Contract G | hopper | 41 |
| Hudson River (NYC-Albany) | hopper | 51 |
| West Coast Regional Hopper | hopper | 166 |
| SH & BH Entr Channel | hopper | 148 |
| Port Orford Hoist | non-conventional (specialty) type | 135 |
| Manasquan Inlet, NJ | non-conventional (specialty) type | 203 |
| West of Shinnecock Inl | pipeline (cutterhead) | 12 |
| Rockaway, NY (1B) | pipeline (cutterhead) | 175 |
| Jones Inlet, NY | pipeline (cutterhead) | 43 |
| Sav & Bruns Inner Harbor | pipeline (cutterhead) | 55 |
| AIWW Inlet Crossing | pipeline (cutterhead) | 80 |
| Anna/Gasp/Manatee/Lee Co | pipeline (cutterhead) | 60 |
| Joint Base Chas. & TC Dock | pipeline (cutterhead) | 27 |
| Shem Creek & Anchorage Basin | pipeline (cutterhead) | 177 |
| Detroit River, MI | pipeline (cutterhead) | 113 |
| Lexington, MI - SOM | pipeline (cutterhead) | 30 |
| BIH-Brownsville Ship CH | pipeline (cutterhead) | 20 |
| Barbours Terminal Mn Ch & TB | pipeline (cutterhead) | 8 |
| Matoc KBIC AND USMC | pipeline (cutterhead) | 161 |
| SNWW-Neches River | pipeline (cutterhead) | 252 |
| Fire Isl to Jones Inl | pipeline (cutterhead) | 38 |
| FT Pierce Inlet O&M | pipeline (cutterhead) | 25 |
| IWW Jupit/Bakers O&M | pipeline (cutterhead) | 59 |
| Mayport Naval Base O&M | pipeline (cutterhead) | 30 |
| PB Boca/DelRay/OR | pipeline (cutterhead) | 105 |
| Pinellas Co Ti - Lk | pipeline (cutterhead) | 49 |
| Old River-Outflow Channels | pipeline (cutterhead) | 9 |
| GIWW-High Island to Bolivar | pipeline (cutterhead) | 42 |
| James R - Jordan PT TO#3 | pipeline (cutterhead) | 24 |
| CC Inner Basn-Viola-LaQuinta | pipeline (cutterhead) | 80 |
| Noh & Var Bsar Chann 3-14 | pipeline (cutterhead) | 52 |
| Noh Hou Laf Bap Cdr 2-14 | pipeline (cutterhead) | 240 |
| LI Intracoastal, NY | pipeline (cutterhead) | 350 |
| Mattituck Harbor, NY | pipeline (cutterhead) | 68 |
| Miss Riv Swp Cdr 1-2014 | pipeline (cutterhead) | 286 |

**Table C-1:** 2014 Dredging Activities

| Job Name | Dredge Type | Operating Days |
|---|---|---|
| James R - Dancing PT TO#3 | pipeline (cutterhead) | 39 |
| E & W Calumet Floodgates | pipeline (cutterhead) | 12 |
| Sav and Bruns Inner Harbor | pipeline (cutterhead) | 315 |
| Tybee Island Beach Renourish | pipeline (cutterhead) | 86 |
| Morehead City Harbor Rng A-B | pipeline (cutterhead) | 41 |
| NC Hwy Protection Project | pipeline (cutterhead) | 51 |
| Wilm Hbr Anchorage Basin | pipeline (cutterhead) | 35 |
| Wrig'sville B, OIB Coast SDR | pipeline (cutterhead) | 90 |
| Shrewsbury River, NJ | pipeline (cutterhead) | 22 |
| Chnl To Victoria Lower Reach | pipeline (cutterhead) | 71 |
| HOMER 2012-2016 | pipeline (cutterhead) | 9 |
| NINILCHIK 2012-2016 | pipeline (cutterhead) | 7 |
| Nome Harbor 2013-2017 | pipeline (cutterhead) | 37 |
| FY14 USCG Tradd Street Pier | pipeline (cutterhead) | 14 |
| Grand Haven (Outer) W/Hollan | pipeline (cutterhead) | 30 |
| Holland (Outer) W/Grand Hav | pipeline (cutterhead) | 21 |
| Miss Riv SWP CDR 2-14 | pipeline (cutterhead) | 49 |
| Leland, MI | pipeline (cutterhead) | 9 |
| Dillingham 2014-2016 | pipeline (cutterhead) | 22 |
| GIWW Corpus to Port Isabel | pipeline (cutterhead) | 98 |
| GIWW Turnstake to Live Oak | pipeline (cutterhead) | 123 |
| HSC Bayprt Flare-HSC Redfish | pipeline (cutterhead) | 146 |
| Bayou Coden 24 inch TO2 | pipeline (cutterhead) | 13 |
| Atch Riv & Bay Ch, BF, & BLK | pipeline (cutterhead) | 99 |
| Atch Riv Crew Boat Cy Cut | pipeline (cutterhead) | 20 |
| Calcasieu MI 5-17/Devl's EB | pipeline (cutterhead) | 101 |
| Westhampton Interim NY | undefined | 55 |

## Appendix D. Research Vessels

**Table D-1:** Research Vessel Engine Characteristics

| Ship Name | Main Engine kW | Online Source |
|---|---|---|
| A.E. Verril | 235 | http://tidings.disl.org/pastissues/vol15_no3_2004/ |
| Acadiana | 650 | http://lumconvessels.com/rv-acadiana |
| Agassiz | 200 | http://www.mtu.edu/greatlakes/fleet/agassiz/emergency/ |
| Alaska Region Research Vessel (ARRV) | 2,237 | http://www.marinettemarine.com/data%20sheets/ARRV_WebReady2011.pdf |
| Alguita | 56 | http://www.researchvessels.org/ship_info_display.asp?shipID=477#Engineering |
| Annika Marie | 455 | http://www.researchvessels.org/ship_info_display.asp?shipID=769#Engineering |
| Apalachee | 559 | https://www.deere.com/en_US/products/engines_and_drivetrain/marine/propulsion_certified/6135_Series/6135SFM85_A.page |
| Aquaonitor | 581 | http://www.researchvessels.org/ship_info_display.asp?shipID=987 |
| Aquarius (GLCBSC) | 1,069 | http://www.ship-technology.com/projects/aquarius-g-seismic-research-support-vessel/ |
| Aquarius (U) | 1,387 | http://www.researchvessels.org/ship_info_display.asp?shipID=215 |
| Arabella | 522 | http://marine.rutgers.edu/rumfs/MarineOps/MaropsArabella.htm |
| Barney Devine | 175 | http://dnr.wi.gov/topic/fishing/lakemichigan/BarneyDevine.html |
| Bellows | 400 | http://www.marine.usf.edu/geoweb/bell.html |
| Calanus | 180 | http://www.researchvessels.org/ship_info_display.asp?shipID=150 |
| Cape Fear | 403 | http://www.researchvessels.org/ship_info_display.asp?shipID=748#Engineering |
| Capricorn | 492 | http://marine.unh.edu/specifications-and-drawings |
| Centennial | 425 | http://depts.washington.edu/fhl/fac_RVCentennialSpecifics.html#vesSpecs |
| Challenger | 492 | http://marine.unh.edu/specifications-and-drawings |
| Channel Cat | 313 | http://www.researchvessels.org/ship_info_display.asp?shipID=805#Engineering |
| Chinook | 172 | http://michigan.gov/documents/dnr/RV-FactSheet_454641_7.pdf |
| Clifford A. Barnes | 298 | http://www.researchvessels.org/ship_info_display.asp?shipID=76#Engineering |
| Coastal Surveyor | 200 | http://ccom.unh.edu/facilities/research-vessels/rv-coastal-surveyor |
| Connecticut | 213 | http://www.researchvessels.org/ship_info_display.asp?shipID=515#Engineering |
| Coral Sea | 373 | http://www.researchvessels.org/ship_info_display.asp?shipID=925#Engineering |
| Corwith Craer | 373 | http://www.researchvessels.org/ship_info_display.asp?shipID=224#Engineering |
| D. J. Angus | 86 | http://www.gvsu.edu/wri/education/dj-angus-24.htm |
| David Starr Jordan | 1,068 | http://www.researchvessels.org/ship_info_display.asp?shipID=87#Engineering |
| Delphinus | 238 | http://www.researchvessels.org/ship_info_display.asp?shipID=68#Engineering |
| Derek M. Baylis | 100 | http://www.researchvessels.org/ship_info_display.asp?shipID=971#Engineering |
| Dolphin (USS) | 317 | http://www.researchvessels.org/ship_info_display.asp?shipID=704#Engineering |
| Donald W. Pritchard | 186 | http://www.researchvessels.org/ship_info_display.asp?shipID=707#Engineering |
| Elakha | 224 | http://www.researchvessels.org/ship_info_display.asp?shipID=503#Engineering |

**Table D-1:** Research Vessel Engine Characteristics

| Ship Name | Main Engine kW | Online Source |
|---|---|---|
| elosira | 2,144 | http://www.researchvessels.org/ship_info_display.asp?shipID=122#Engineering |
| Explorer U.S. | 168 | http://www.researchvessels.org/ship_info_display.asp?shipID=230#Engineering |
| Fauna | 138 | http://www.researchvessels.org/ship_info_display.asp?shipID=955#Engineering |
| Fay Slover | 522 | http://www.researchvessels.org/ship_info_display.asp?shipID=953#Engineering |
| Flip (FLoating Platform) | 300 | http://www.ship-technology.com/projects/flip-ship/ |
| Flora | 93 | http://www.researchvessels.org/ship_info_display.asp?shipID=956#Engineering |
| Forerunner | 242 | http://www.researchvessels.org/ship_info_display.asp?shipID=234#Engineering |
| GS-1 | 216 | http://www.researchvessels.org/ship_info_display.asp?shipID=817#Engineering |
| Gulf Challenger | 447 | http://www.researchvessels.org/ship_info_display.asp?shipID=700#Engineering |
| Hayes (USNS) | 2,699 | http://www.researchvessels.org/ship_info_display.asp?shipID=881#Engineering |
| Henry Stoel | 172 | http://www.researchvessels.org/ship_info_display.asp?shipID=744#Engineering |
| Independence | 895 | http://www.researchvessels.org/ship_info_display.asp?shipID=469#Engineering |
| Ira C | 380 | http://dmc.umaine.edu/facilities/research-vessels/ |
| J.E. Henderson | 82 | http://www.apl.washington.edu/about/vessels.php |
| J.H. Martin | 969 | http://www.researchvessels.org/ship_info_display.asp?shipID=791#Engineering |
| John M. Kingsbury | 109 | http://www.researchvessels.org/ship_info_display.asp?shipID=960#Engineering |
| John B. Heiser | 313 | http://www.researchvessels.org/ship_info_display.asp?shipID=961#Engineering |
| John H. Martin | 969 | https://marineops.mlml.calstate.edu/JM-Specs |
| John N. Cobb | 328 | http://www.oldtacomamarine.com/fairbanks/johnncobb.html |
| Kaho | 291 | http://www.researchvessels.org/ship_info_display.asp?shipID=828#Engineering |
| Karluk | 318 | http://walrus.wr.usgs.gov/infobank/programs/html/karluk/specs.html |
| Katy | 238 | https://utmsi.utexas.edu/research/research-vessels |
| Kerhin | 38 | http://mddnr.chesapeakebay.net/eyesonthebay/documents/KerhinFlyer.pdf |
| Kila | 544 | http://www.researchvessels.org/ship_info_display.asp?shipID=245#Engineering |
| Laidly | 485 | http://www.researchvessels.org/ship_info_display.asp?shipID=781#Engineering |
| Lake Explorer II | 317 | http://www.researchvessels.org/ship_info_display.asp?shipID=990#Engineering |
| Langley | 130 | http://www.researchvessels.org/ship_info_display.asp?shipID=788#Engineering |
| Laurentian | 254 | http://www.researchvessels.org/ship_info_display.asp?shipID=134 |
| NAVAIR Acoustic Pioneer | 895 | http://www.researchvessels.org/ship_info_display.asp?shipID=492#Engineering |
| NAVAIR-03 | 500 | http://www.researchvessels.org/ship_info_display.asp?shipID=493#Engineering |
| Neeskay | 254 | http://home.freshwater.uwm.edu/neeskay/specifications/ |
| Neil Armstrong | 3,952 | http://www.whoi.edu/main/ships/neil-armstrong/specifications |
| Noodin | 11 | http://www.d.umn.edu/~bann0036/LLO/facilities/noodin.html |
| Nucella | 149 | http://www.researchvessels.org/ship_info_display.asp?shipID=940#Engineering |
| Odyssey (WCI) | 163 | http://www.researchvessels.org/ship_info_display.asp?shipID=850#Engineering |
| Odyssey Explorer | 2,075 | http://www.researchvessels.org/ship_info_display.asp?shipID=714#Engineering |
| Osprey | 320 | http://www.mtu.edu/greatlakes/fleet/osprey/ |

**Table D-1:** Research Vessel Engine Characteristics

| Ship Name | Main Engine kW | Online Source |
|---|---|---|
| Outer Limits | 373 | http://www.researchvessels.org/ship_info_display.asp?shipID=978#Engineering |
| Palmetto | 373 | http://www.dnr.sc.gov/marine/mrri/vessels/palmetto.html |
| Parke Snavely | 231 | http://walrus.wr.usgs.gov/mapping/Snavely.html |
| Perca (WDNR) | 261 | http://www.researchvessels.org/ship_info_display.asp?shipID=845#Engineering |
| Peter W. Anderson | 1,081 | http://www.researchvessels.org/ship_info_display.asp?shipID=214#Engineering |
| Point Lobos | 895 | http://www.mbari.org/dmo/vessels_vehicles/Point_Lobos/ptlobos.html |
| Polar Star | 51,714 | http://www.uscg.mil/pacarea/cgcpolarstar/history.asp |
| Pride of Michigan | 1,014 | http://www.researchvessels.org/ship_info_display.asp?shipID=849#Engineering |
| Pugettia | 97 | http://www.researchvessels.org/ship_info_display.asp?shipID=950#Engineering |
| Rafeal | 298 | http://www.researchvessels.org/ship_info_display.asp?shipID=926#Engineering |
| Retriever | 20 | http://www.shanarae.com/retriever.html |
| Robert C Seamans | 339 | http://www.researchvessels.org/ship_info_display.asp?shipID=695#Engineering |
| Robert Gordon Sproul | 503 | https://scripps.ucsd.edu/ships/sproul/specifications |
| Sally Ride | 1,733 | http://shipsked.ucsd.edu/Ships/AGOR28/AGOR28-Specs.pdf |
| Sea World UCLA | 50 | http://www.msc.ucla.edu/Sea_World/sea_world_specifications.html |
| Seahawk | 168 | http://www.researchvessels.org/ship_info_display.asp?shipID=946#Engineering |
| Seawatch | 686 | http://www.researchvessels.org/ship_info_display.asp?shipID=83#Engineering |
| Seth Green | 175 | http://www.researchvessels.org/ship_info_display.asp?shipID=912#Engineering |
| Seward Johnson | 634 | http://www.researchvessels.org/ship_info_display.asp?shipID=13#Engineering |
| Seward Johnson II | 701 | http://www.researchvessels.org/ship_info_display.asp?shipID=460#Engineering |
| Shana Rae | 261 | http://www.researchvessels.org/ship_info_display.asp?shipID=22#Engineering |
| Sheila B. | 224 | https://marineops.mlml.calstate.edu/SB-Specs |
| Silversides | 101 | http://www.researchvessels.org/ship_info_display.asp?shipID=941#Engineering |
| State of Maine T.V. | 6,000 | http://www.researchvessels.org/ship_info_display.asp?shipID=189#Engineering |
| State of Michigan | 5,350 | https://www.nmc.edu/maritime/about/ts-state-mich-specifications.html |
| Stephan | 5,517 | http://www.researchvessels.org/ship_info_display.asp?shipID=934#Engineering |
| Suncoaster | 597 | http://www.researchvessels.org/ship_info_display.asp?shipID=24#Engineering |
| Susan Hudson | 522 | http://sites.duke.edu/dumlphotoarchive/files/2014/04/DUML_News_v9_no1_Spring1991.pdf |
| Tiglax | 634 | http://www.researchvessels.org/ship_info_display.asp?shipID=26#Engineering |
| Tioga | 1,119 | http://www.whoi.edu/main/tioga/specifications |
| Tom McIlwain | 13.5 | http://www.usm.edu/gcrl/research_vessels/tom.mcilwain.research.vessel.php |
| Musky II | 186 | http://www.researchvessels.org/ship_info_display.asp?shipID=837#Engineering |
| Mussel Point | 373 | http://www.researchvessels.org/ship_info_display.asp?shipID=853#Engineering |
| Vantuna | 686 | http://www.researchvessels.org/ship_info_display.asp?shipID=27#Engineering |
| Ventana (ROV) | 30 | http://www.mbari.org/dmo/vessels_vehicles/ventana/specifications.html |
| W. G. Jackson | 410 | http://www.gvsu.edu/wri/education/wg-jackson-25.htm |
| Weatherbird | 447 | http://www.researchvessels.org/ship_info_display.asp?shipID=268#Engineering |

**Table D-1:** Research Vessel Engine Characteristics

| Ship Name | Main Engine kW | Online Source |
|---|---|---|
| William Scandling | 200 | http://www.hws.edu/fli/sos_scandling.aspx |
| Mysis | 340 | http://www.atlanticpowercleaning.com/mysis/ |

## Appendix E. Coast Guard Cutter Fleet

**Table E-1:** Compilation of Coast Guard Cutter Data

| Vessel Name | Vessel ID | Annual Underway Hours per Vessel (2014) | HP | Engine Power (kW) | kW-hrs |
|---|---|---|---|---|---|
| Abbie Burgess | WLM 553 | 1093.6 | 3,400 | 2,535 | 2,772,691 |
| Active | WMEC 618 | 2889.4 | 5,000 | 3,728 | 10,773,126 |
| Adak | WPB 1333 | 1956.5 | 5,760 | 4,295 | 8,403,620 |
| Adelie | WPB 87333 | 1592.3 | 3,000 | 2,237 | 3,562,134 |
| AHI | WPB 87364 | 1376 | 3,000 | 2,237 | 3,078,249 |
| Albacore | WPB 87309 | 1558.1 | 3,000 | 2,237 | 3,485,625 |
| Alder | WLB 216 | 1806.5 | 6,200 | 4,623 | 8,352,062 |
| Alert | WMEC 630 | 2935.9 | 5,000 | 3,728 | 10,946,501 |
| Alex Haley | WMEC 39 | 2366.7 | 6,800 | 5,071 | 12,000,966 |
| Alligator | WPB 87369 | 1500.1 | 3,000 | 2,237 | 3,355,873 |
| Amberjack | WPB 87315 | 1288.6 | 3,000 | 2,237 | 2,882,727 |
| Anacapa | WPB 1335 | 1810.5 | 5,760 | 4,295 | 7,776,516 |
| Anthony Petit | WLM 558 | 1422.6 | 3,400 | 2,535 | 3,606,831 |
| Anvil | WLIC 75301 | 437.4 | 673 | 502 | 219,512 |
| Aspen | WLB 208 | 1500.1 | 6,200 | 4,623 | 6,935,471 |
| Assateague | WPB 1337 | 1361.5 | 5,760 | 4,295 | 5,847,957 |
| Axe | WLIC 75310 | 635.9 | 1,320 | 984 | 625,932 |
| Bainbridge Island | WPB 1343 | 545.6 | 5,760 | 4,295 | 2,343,478 |
| Baranof | WPB 1318 | 3039.6 | 5,760 | 4,295 | 13,055,785 |
| Barbara Mabrity | WLM 559 | 994.1 | 3,400 | 2,535 | 2,520,421 |
| Barracuda | WPB 87301 | 1303.2 | 3,000 | 2,237 | 2,915,388 |
| Bayberry | WLI 65400 | 212.1 | 673 | 502 | 106,444 |
| Bear | WMEC 901 | 3280.5 | 7,300 | 5,444 | 17,857,760 |
| Beluga | WPB 87325 | 1635.7 | 3,000 | 2,237 | 3,659,224 |
| Bernard C. Webber | WPC 1101 | 2474.9 | 5,800 | 4,325 | 10,704,089 |
| Bertholf | WMSL 750 | 2456.1 | 49,875 | 37,192 | 91,346,734 |
| Biscayne Bay | WTGB 104 | 1839 | 2,500 | 1,864 | 3,428,355 |
| Blackfin | WPB 87317 | 1721.4 | 3,000 | 2,237 | 3,850,943 |
| Blacktip | WPB 87326 | 1810.6 | 3,000 | 2,237 | 4,050,493 |
| Block Island | WPB 1344 | 649.5 | 5,760 | 4,295 | 2,789,753 |
| Blue Shark | WPB 87360 | 1695.7 | 3,000 | 2,237 | 3,793,450 |
| Bluebell | WLI 313 | 721 | 660 | 492 | 354,849 |
| Bluefin | WPB 87318 | 1474.1 | 3,000 | 2,237 | 3,297,709 |

**Table E-1:** Compilation of Coast Guard Cutter Data

| Vessel Name | Vessel ID | Annual Underway Hours per Vessel (2014) | HP | Engine Power (kW) | kW-hrs |
|---|---|---|---|---|---|
| Bollard | WYTL 65614 | 437.5 | 500 | 373 | 163,122 |
| Bonito | WPB 87341 | 874.4 | 3,000 | 2,237 | 1,956,120 |
| Boutwell | WHEC 719 | 3576.3 | 36,000 | 26,845 | 96,006,472 |
| Brant | WPB 87348 | 1397.6 | 3,000 | 2,237 | 3,126,570 |
| Bridle | WYTL 65607 | 574.7 | 500 | 373 | 214,277 |
| Bristol Bay | WTGB 102 | 1734.8 | 2,500 | 1,864 | 3,234,100 |
| Buckthorn | WLI 642 | 622.9 | 600 | 447 | 278,698 |
| Campbell | WMEC 909 | 1953.3 | 7,300 | 5,444 | 10,633,002 |
| Capstan | WYTL 65601 | 644.2 | 500 | 373 | 240,190 |
| Chandeleur | WPB 1319 | 1358.2 | 5,760 | 4,295 | 5,833,783 |
| Charles David | WPC 1107 | 2210.8 | 5,800 | 4,325 | 9,561,841 |
| Charles Sexton | WPC 1108 | 1836.5 | 5,800 | 4,325 | 7,942,971 |
| Chena | WLR 75409 | 1094 | 600 | 447 | 489,477 |
| Cheyenne | WLR 75405 | 338 | 600 | 447 | 151,228 |
| Chinook | WPB 87308 | 1661.5 | 3,000 | 2,237 | 3,716,941 |
| Chippewa | WLR 75404 | 1022.2 | 600 | 447 | 457,353 |
| Chock | WYTL 65602 | 323.6 | 500 | 373 | 120,654 |
| Cimarron | WLR 65502 | 700.6 | 673 | 502 | 351,600 |
| Clamp | WLIC 75306 | 744.5 | 1,320 | 984 | 732,829 |
| Cleat | WYTL 65615 | 683.5 | 500 | 373 | 254,843 |
| Cobia | WPB 87311 | 1426.7 | 3,000 | 2,237 | 3,191,670 |
| Cochito | WPB 87329 | 1581.3 | 3,000 | 2,237 | 3,537,526 |
| Coho | WPB 87321 | 1234.7 | 3,000 | 2,237 | 2,762,147 |
| Confidence | WMEC 619 | 2987 | 5,000 | 3,728 | 11,137,028 |
| Cormorant | WPB 87313 | 843.6 | 3,000 | 2,237 | 1,887,217 |
| Crocodile | WPB 87372 | 1473 | 3,000 | 2,237 | 3,295,248 |
| Cushing | WPB 1321 | 1546.1 | 5,760 | 4,295 | 6,640,857 |
| Cuttyhunk | WPB 1322 | 1805.8 | 5,760 | 4,295 | 7,756,329 |
| Cypress | WLB 210 | 1218 | 6,200 | 4,623 | 5,631,227 |
| Dauntless | WMEC 624 | 2287.1 | 5,000 | 3,728 | 8,527,451 |
| Decisive | WMEC 629 | 2583.1 | 5,000 | 3,728 | 9,631,087 |
| Dependable | WMEC 626 | 2469 | 5,000 | 3,728 | 9,205,665 |
| Diamondback | WPB 87370 | 1066.3 | 3,000 | 2,237 | 2,385,419 |
| Diligence | WMEC 616 | 1979.1 | 5,000 | 3,728 | 7,379,073 |

**Table E-1:** Compilation of Coast Guard Cutter Data

| Vessel Name | Vessel ID | Annual Underway Hours per Vessel (2014) | HP | Engine Power (kW) | kW-hrs |
|---|---|---|---|---|---|
| Dolphin | WPB 87354 | 952.8 | 3,000 | 2,237 | 2,131,509 |
| Dorado | WPB 87306 | 1177.5 | 3,000 | 2,237 | 2,634,185 |
| Drummond | WPB 1323 | 2146.4 | 5,760 | 4,295 | 9,219,284 |
| Eagle NRCB | WIX-327 | 2200.9 | 1,000 | 746 | 1,641,211 |
| Edisto | WPB 1313 | 1727.9 | 5,760 | 4,295 | 7,421,730 |
| Elderberry | WLI 65401 | 407 | 250 | 186 | 75,875 |
| Elm | WLB 204 | 1646.8 | 6,200 | 4,623 | 7,613,715 |
| Escanaba | WMEC 907 | 3801.6 | 7,300 | 5,444 | 20,694,424 |
| Farallon | WPB 1301 | 2250 | 5,760 | 4,295 | 9,664,270 |
| Finback | WPB 87314 | 1229.8 | 3,000 | 2,237 | 2,751,185 |
| Fir | WLB 213 | 1903.1 | 6,200 | 4,623 | 8,798,677 |
| Flying Fish | WPB 87346 | 1730.7 | 3,000 | 2,237 | 3,871,748 |
| Forward | WMEC 911 | 162.7 | 7,300 | 5,444 | 885,675 |
| Frank Drew | WLM 557 | 1324.1 | 3,400 | 2,535 | 3,357,096 |
| Galveston Island | WPB 1349 | 1367.6 | 5,760 | 4,295 | 5,874,158 |
| Gannet | WPB 87334 | 947.2 | 3,000 | 2,237 | 2,118,981 |
| Gasconade | WLR 75401 | 439.5 | 600 | 447 | 196,641 |
| George Cobb | WLM 564 | 955.3 | 3,400 | 2,535 | 2,422,048 |
| Grand Isle | WPB 1338 | 1807.4 | 5,760 | 4,295 | 7,763,201 |
| Greenbrier | WLR 75501 | 1246.4 | 1,080 | 805 | 1,003,796 |
| Haddock | WPB 87347 | 1698.5 | 3,000 | 2,237 | 3,799,714 |
| Halibut | WPB 87340 | 1791.5 | 3,000 | 2,237 | 4,007,764 |
| Hammer | WLIC 75302 | 665.5 | 1,320 | 984 | 655,068 |
| Hammerhead | WPB 87302 | 1794.8 | 3,000 | 2,237 | 4,015,146 |
| Harriet Lane | WMEC 903 | 2030.3 | 7,300 | 5,444 | 11,052,159 |
| Harry Claiborne | WLM 561 | 1236.2 | 3,400 | 2,535 | 3,134,236 |
| Hatchet | WLIC 75309 | 451 | 1,320 | 984 | 443,930 |
| Hawk | WPB 87355 | 1359.1 | 3,000 | 2,237 | 3,040,442 |
| Hawksbill | WPB 87312 | 1783.3 | 3,000 | 2,237 | 3,989,420 |
| Hawser | WYTL 65610 | 560.7 | 500 | 373 | 209,057 |
| Healy | WAGB 20 | 3606.9 | 30,000 | 22,371 | 80,689,946 |
| Henry Blake | WLM 563 | 1197.5 | 3,400 | 2,535 | 3,036,117 |
| Heron | WPB 87344 | 1765.9 | 3,000 | 2,237 | 3,950,494 |
| Hickory | WLB 212 | 1825.2 | 6,200 | 4,623 | 8,438,519 |

**Table E-1:** Compilation of Coast Guard Cutter Data

| Vessel Name | Vessel ID | Annual Underway Hours per Vessel (2014) | HP | Engine Power (kW) | kW-hrs |
|---|---|---|---|---|---|
| Hollyhock | WLB 214 | 2177.7 | 6,200 | 4,623 | 10,068,246 |
| Hudson | WLIC 801 | 939.1 | 500 | 373 | 350,143 |
| Ibis | WPB 87338 | 1421 | 3,000 | 2,237 | 3,178,919 |
| Ida Lewis | WLM 551 | 1263.6 | 3,400 | 2,535 | 3,203,706 |
| James Rankin | WLM 555 | 1307.3 | 3,400 | 2,535 | 3,314,502 |
| Jefferson Island | WPB 1340 | 1593.6 | 5,760 | 4,295 | 6,844,881 |
| Joshua Appleby | WLM 556 | 925.7 | 3,400 | 2,535 | 2,347,001 |
| Juniper | WLB 201 | 1763.1 | 6,200 | 4,623 | 8,151,409 |
| Kanawha | WLR 75407 | 1484.2 | 600 | 447 | 664,061 |
| Kankakee | WLR 75500 | 1326.3 | 540 | 403 | 534,072 |
| Katherine Walker | WLM 552 | 1208.4 | 3,400 | 2,535 | 3,063,753 |
| Kathleen Moore | WPC 1109 | 600.5 | 5,800 | 4,325 | 2,597,198 |
| Katmai Bay | WTGB 101 | 1823.5 | 2,500 | 1,864 | 3,399,459 |
| Kennebec | WLIC 802 | 980.8 | 500 | 373 | 365,691 |
| Key Biscayne | WPB 1339 | 2470.9 | 5,760 | 4,295 | 10,613,087 |
| Key Largo | WPB 1324 | 1865.8 | 5,760 | 4,295 | 8,014,042 |
| Kickapoo | WLR 75406 | 1023.5 | 600 | 447 | 457,934 |
| Kingfisher | WPB 87322 | 1153.4 | 3,000 | 2,237 | 2,580,271 |
| Kiska | WPB 1336 | 1583.8 | 5,760 | 4,295 | 6,802,787 |
| Kittiwake | WPB 87316 | 1326.3 | 3,000 | 2,237 | 2,967,065 |
| Knight Island | WPB 1348 | 1878.4 | 5,760 | 4,295 | 8,068,162 |
| Kodiak Island | WPB 1341 | 881.4 | 5,760 | 4,295 | 3,785,817 |
| Kukui | WLB 203 | 1376.8 | 6,200 | 4,623 | 6,365,413 |
| Legare | WMEC 912 | 2990.7 | 7,300 | 5,444 | 16,280,202 |
| Liberty | WPB 1334 | 1159.8 | 5,760 | 4,295 | 4,981,609 |
| Line | WYTL 65611 | 583.2 | 500 | 373 | 217,446 |
| Long Island | WPB 1342 | 1805 | 5,760 | 4,295 | 7,752,892 |
| Mackinaw | WLBB 30 | 2904.8 | 9,119 | 6,800 | 19,752,748 |
| Mako | WPB 87303 | 774.6 | 3,000 | 2,237 | 1,732,857 |
| Mallet | WLIC 75304 | 899.9 | 1,320 | 984 | 885,793 |
| Manatee | WPB 87363 | 761.2 | 3,000 | 2,237 | 1,702,880 |
| Man-O-War | WPB 87330 | 1229.1 | 3,000 | 2,237 | 2,749,619 |
| Manta | WPB 87320 | 1536.1 | 3,000 | 2,237 | 3,436,409 |
| Maple | WLB 207 | 1482 | 6,200 | 4,623 | 6,851,789 |

**Table E-1:** Compilation of Coast Guard Cutter Data

| Vessel Name | Vessel ID | Annual Underway Hours per Vessel (2014) | HP | Engine Power (kW) | kW-hrs |
|---|---|---|---|---|---|
| Marcus Hanna | WLM 554 | 1373.8 | 3,400 | 2,535 | 3,483,104 |
| Margaret Norvell | WPC 1105 | 2396.1 | 5,800 | 4,325 | 10,363,274 |
| Maria Bray | WLM 562 | 1185.8 | 3,400 | 2,535 | 3,006,453 |
| Marlin | WPB 87304 | 1517.2 | 3,000 | 2,237 | 3,394,128 |
| Matinicus | WPB 1315 | 2126.2 | 5,760 | 4,295 | 9,132,521 |
| Maui | WPB 1304 | 3240.2 | 5,760 | 4,295 | 13,917,408 |
| Mellon | WHEC 717 | 3262.8 | 36,000 | 26,845 | 87,590,504 |
| Midgett | WHEC 726 | 2872 | 36,000 | 26,845 | 77,099,401 |
| Mohawk | WMEC 913 | 88.1 | 7,300 | 5,444 | 479,582 |
| Monomoy | WPB 1326 | 2845.4 | 5,760 | 4,295 | 12,221,651 |
| Moray | WPB 87331 | 1738.6 | 3,000 | 2,237 | 3,889,421 |
| Morgenthau | WHEC 722 | 3154.7 | 36,000 | 26,845 | 84,688,538 |
| Morro Bay | WTGB 106 | 1562.7 | 2,500 | 1,864 | 2,913,263 |
| Munro | WHEC 724 | 2297.8 | 36,000 | 26,845 | 61,684,890 |
| Muskingum | WLR 75402 | 807.1 | 600 | 447 | 361,113 |
| Mustang | WPB 1310 | 1798.4 | 5,760 | 4,295 | 7,724,544 |
| Nantucket | WPB 1316 | 1031.5 | 5,760 | 4,295 | 4,430,531 |
| Narwhal | WPB 87335 | 1702.1 | 3,000 | 2,237 | 3,807,767 |
| Naushon | WPB 1311 | 1725.1 | 5,760 | 4,295 | 7,409,703 |
| Neah Bay | WTGB 105 | 1577.2 | 2,500 | 1,864 | 2,940,295 |
| Northland | WMEC 904 | 3107.7 | 7,300 | 5,444 | 16,917,104 |
| Oak | WLB 211 | 1632 | 6,200 | 4,623 | 7,545,290 |
| Obion | WLR 65503 | 970 | 673 | 502 | 486,800 |
| Ocracoke | WPB 1307 | 895.8 | 5,760 | 4,295 | 3,847,668 |
| Orcas | WPB 1327 | 1250 | 5,760 | 4,295 | 5,369,039 |
| Osage | WLR 65505 | 598.1 | 673 | 502 | 300,160 |
| Osprey | WPB 87307 | 1322.9 | 3,000 | 2,237 | 2,959,459 |
| Ouachita | WLR 65501 | 610.8 | 673 | 502 | 306,534 |
| PAMLICO | WLIC 800 | 640.1 | 500 | 373 | 238,661 |
| Patoka | WLR 75408 | 1132.3 | 600 | 447 | 506,614 |
| Paul Clark | WPC 1106 | 2530.9 | 5,800 | 4,325 | 10,946,292 |
| Pelican | WPB 87327 | 1302.3 | 3,000 | 2,237 | 2,913,375 |
| Pendant | WYTL 65608 | 575 | 500 | 373 | 214,389 |
| Penobscot Bay | WTGB 107 | 1494.9 | 2,500 | 1,864 | 2,786,867 |

**Table E-1:** Compilation of Coast Guard Cutter Data

| Vessel Name | Vessel ID | Annual Underway Hours per Vessel (2014) | HP | Engine Power (kW) | kW-hrs |
|---|---|---|---|---|---|
| Petrel | WPB 87350 | 1682.5 | 3,000 | 2,237 | 3,763,920 |
| Pike | WPB 87365 | 1646.3 | 3,000 | 2,237 | 3,682,937 |
| Polar Star | WAGB-10 | 2508.1 | 78,000 | 58,165 | 145,882,608 |
| Pompano | WPB 87339 | 1603.4 | 3,000 | 2,237 | 3,586,966 |
| Razorbill | WPB 87332 | 1443.2 | 3,000 | 2,237 | 3,228,582 |
| Reef Shark | WPB 87371 | 1684.4 | 3,000 | 2,237 | 3,768,171 |
| Reliance | WMEC 615 | 2718.3 | 5,000 | 3,728 | 10,135,180 |
| Resolute | WMEC 620 | 2700 | 5,000 | 3,728 | 10,066,948 |
| Richard Etheridge | WPC 1102 | 2205.3 | 5,800 | 4,325 | 9,538,053 |
| Ridley | WPB 87328 | 1732 | 3,000 | 2,237 | 3,874,657 |
| Roanoke Island | WPB 1346 | 1806.9 | 5,760 | 4,295 | 7,761,053 |
| Robert Yered | WPC 1104 | 2449.8 | 5,800 | 4,325 | 10,595,530 |
| Saginaw | WLIC 803 | 929.3 | 500 | 373 | 346,489 |
| Sailfish | WPB 87356 | 1660.4 | 3,000 | 2,237 | 3,714,480 |
| Sangamon | WLR 65506 | 684.9 | 673 | 502 | 343,721 |
| Sanibel | WPB 1312 | 1389.8 | 5,760 | 4,295 | 5,969,512 |
| Sapelo | WPB 1314 | 1429.3 | 5,760 | 4,295 | 6,139,174 |
| Sawfish | WPB 87357 | 1509.4 | 3,000 | 2,237 | 3,376,678 |
| Scioto | WLR 65504 | 435.3 | 673 | 502 | 218,458 |
| Sea Devil | WPB 87368 | 501.4 | 3,000 | 2,237 | 1,121,682 |
| Sea Dog | WPB 87373 | 1231.9 | 3,000 | 2,237 | 2,755,883 |
| Sea Dragon | WPB 87367 | 1139.9 | 3,000 | 2,237 | 2,550,070 |
| Sea Fox | WPB 87374 | 692.7 | 3,000 | 2,237 | 1,549,639 |
| Sea Horse | WPB 87361 | 1218.4 | 3,000 | 2,237 | 2,725,682 |
| Sea Lion | WPB 87352 | 1514.1 | 3,000 | 2,237 | 3,387,193 |
| Sea Otter | WPB 87362 | 1645 | 3,000 | 2,237 | 3,680,029 |
| Seahawk | WPB 87323 | 1297.1 | 3,000 | 2,237 | 2,901,742 |
| Seneca | WMEC 906 | 2441.5 | 7,300 | 5,444 | 13,290,572 |
| Sequoia | WLB 215 | 1680.7 | 6,200 | 4,623 | 7,770,446 |
| Shackle | WYTL 65609 | 575.4 | 500 | 373 | 214,538 |
| Shearwater | WPB 87349 | 1618.5 | 3,000 | 2,237 | 3,620,746 |
| Sherman | WHEC 720 | 1820.4 | 36,000 | 26,845 | 48,868,994 |
| Shrike | WPB 87342 | 1115.8 | 3,000 | 2,237 | 2,496,156 |
| Sitkinak | WPB 1329 | 1889.7 | 5,760 | 4,295 | 8,116,699 |

**Table E-1:** Compilation of Coast Guard Cutter Data

| Vessel Name | Vessel ID | Annual Underway Hours per Vessel (2014) | HP | Engine Power (kW) | kW-hrs |
|---|---|---|---|---|---|
| Skipjack | WPB 87353 | 1651.5 | 3,000 | 2,237 | 3,694,570 |
| SLEDGE | WLIC 75303 | 1294.8 | 1,320 | 984 | 1,274,502 |
| Smilax | WLIC 315 | 1008.4 | 600 | 447 | 451,178 |
| Sockeye | WPB 87337 | 1646 | 3,000 | 2,237 | 3,682,266 |
| Spar | WLB 206 | 1736.7 | 6,200 | 4,623 | 8,029,353 |
| Spencer | WMEC 905 | 2783.2 | 7,300 | 5,444 | 15,150,653 |
| Staten Island | WPB 1345 | 1429.3 | 5,760 | 4,295 | 6,139,174 |
| Steadfast | WMEC 623 | 1442.5 | 5,000 | 3,728 | 5,378,360 |
| Steelhead | WPB 87324 | 1173.7 | 3,000 | 2,237 | 2,625,684 |
| Stingray | WPB 87305 | 1586 | 3,000 | 2,237 | 3,548,040 |
| Stratton | WMSL 752 | 3150.9 | 49,875 | 37,192 | 117,187,583 |
| Sturgeon Bay | WPB 87336 | 1546.5 | 3,000 | 2,237 | 3,459,675 |
| Sturgeon Bay | WTGB 109 | 1504 | 2,500 | 1,864 | 2,803,832 |
| Swordfish | WPB 87358 | 1468.1 | 3,000 | 2,237 | 3,284,286 |
| Sycamore | WLB 209 | 1724.9 | 6,200 | 4,623 | 7,974,798 |
| Tackle | WYTL 65604 | 537.5 | 500 | 373 | 200,407 |
| Tahoma | WMEC 908 | 2209 | 7,300 | 5,444 | 12,024,932 |
| Tampa | WMEC 902 | 3563.8 | 7,300 | 5,444 | 19,399,934 |
| Tarpon | WPB 87310 | 1501.9 | 3,000 | 2,237 | 3,359,900 |
| Tern | WPB 87343 | 1368.4 | 3,000 | 2,237 | 3,061,247 |
| Terrapin | WPB 87366 | 1813.3 | 3,000 | 2,237 | 4,056,533 |
| Thetis | WMEC 910 | 3556.3 | 7,300 | 5,444 | 19,359,107 |
| Thunder Bay | WTGB 108 | 1491.5 | 2,500 | 1,864 | 2,780,528 |
| Tiger Shark | WPB 87359 | 1730.2 | 3,000 | 2,237 | 3,870,630 |
| Tybee | WPB 1330 | 1590.7 | 5,760 | 4,295 | 6,832,424 |
| Valiant | WMEC 621 | 1864.6 | 5,000 | 3,728 | 6,952,160 |
| Venturous | WMEC 625 | 2980.9 | 5,000 | 3,728 | 11,114,284 |
| Vigilant | WMEC 617 | 2054.3 | 5,000 | 3,728 | 7,659,456 |
| Vigorous | WMEC 627 | 2589.8 | 5,000 | 3,728 | 9,656,068 |
| VISE | WLIC 75305 | 621.3 | 1,320 | 984 | 611,560 |
| Waesche | WMSL 751 | 3071.9 | 49,875 | 37,192 | 114,249,432 |
| Wahoo | WPB 87345 | 1730.8 | 3,000 | 2,237 | 3,871,972 |
| Walnut | WLB 205 | 1473.8 | 6,200 | 4,623 | 6,813,877 |
| Washington | WPB 1331 | 823.3 | 5,760 | 4,295 | 3,536,264 |

**Table E-1:** Compilation of Coast Guard Cutter Data

| Vessel Name | Vessel ID | Annual Underway Hours per Vessel (2014) | HP | Engine Power (kW) | kW-hrs |
|---|---|---|---|---|---|
| William Flores | WPC 1103 | 2507.1 | 5,800 | 4,325 | 10,843,356 |
| William Tate | WLM 560 | 758.1 | 3,400 | 2,535 | 1,922,071 |
| Willow | WLB 202 | 1158.1 | 6,200 | 4,623 | 5,354,289 |
| Wire | WYTL 65612 | 565.1 | 500 | 373 | 210,697 |
| Wyaconda | WLR 75403 | 627.9 | 600 | 447 | 280,935 |
| Yellowfin | WPB 87319 | 1044.9 | 3,000 | 2,237 | 2,337,545 |

## Appendix F. Marine Vessel HAP Profiles

**Table F-1:** C1/C2 HAP Profile In-port Maneuvering

| Pollutant Code | Pollutant | Associated basis for speciation | Fraction |
|---|---|---|---|
| | Copper | $PM_{10}$ | 9.58E-04 |
| | Zinc | $PM_{10}$ | 5.00E-04 |
| 100414 | Ethylbenzene | VOC | 1.50E-03 |
| 100425 | Styrene | VOC | 1.58E-03 |
| 107028 | Acrolein | VOC | 2.63E-03 |
| 108883 | Toluene | VOC | 2.40E-03 |
| 110543 | n-Hexane | VOC | 4.13E-03 |
| 118741 | HCB | $PM_{10}$ | 2.00E-08 |
| 120127 | Anthracene | $PM_{2.5}$ | 2.78E-05 |
| 123386 | Propionaldehyde | VOC | 4.58E-03 |
| 129000 | Pyrene | $PM_{2.5}$ | 2.93E-05 |
| 1330207 | Xylene | VOC | 3.60E-03 |
| 1336363 | PCB | $PM_{10}$ | 2.50E-07 |
| 16065831 | Chromium III | $PM_{10}$ | 1.65E-05 |
| 18540299 | Chromium VI | $PM_{10}$ | 8.50E-06 |
| 191242 | Benzo[g,h,I,]Perylene | $PM_{2.5}$ | 6.75E-06 |
| 193395 | Indeno[1,2,3-c,d]Pyrene | $PM_{10}$ | 5.00E-06 |
| 205992 | Benzo[b]Fluoranthene | $PM_{10}$ | 5.00E-06 |
| 206440 | Fluoranthene | $PM_{2.5}$ | 1.65E-05 |
| 207089 | Benzo[k]Fluoranthene | $PM_{10}$ | 2.50E-06 |
| 208968 | Acenaphthylene | $PM_{2.5}$ | 2.78E-05 |
| 218019 | Chrysene | $PM_{2.5}$ | 5.25E-06 |
| 50000 | Formaldehyde | VOC | 1.12E-01 |
| 50328 | Benzo[a]Pyrene | $PM_{10}$ | 2.50E-06 |
| 540841 | 2,2,4-trimethylpentane | VOC | 3.00E-04 |
| 56553 | Benz[a]Anthracene | $PM_{2.5}$ | 3.00E-05 |
| 628 | Dioxin | $PM_{10}$ | 2.50E-09 |
| 71432 | Benzene | VOC | 1.53E-02 |
| 7439921 | Lead | $PM_{10}$ | 7.50E-05 |
| 7439965 | Manganese | $PM_{10}$ | 1.53E-06 |
| 7439976 | Mercury | $PM_{10}$ | 2.50E-08 |
| 7440020 | Nickel | $PM_{10}$ | 5.00E-04 |
| 7440382 | Arsenic | $PM_{10}$ | 1.75E-05 |
| 7440439 | Cadmium | $PM_{10}$ | 2.83E-06 |
| 7440473 | Chromium | $PM_{10}$ | |
| 75070 | Acetaldehyde | VOC | 5.57E-02 |

**Table F-1:** C1/C2 HAP Profile In-port Maneuvering

| Pollutant Code | Pollutant | Associated basis for speciation | Fraction |
|---|---|---|---|
| 7782492 | Selenium | $PM_{10}$ | 2.83E-08 |
| 83329 | Acenaphthene | $PM_{2.5}$ | 1.80E-05 |
| 85018 | Phenanthrene | $PM_{2.5}$ | 4.20E-05 |
| 86737 | Fluorene | $PM_{2.5}$ | 3.68E-05 |
| 91203 | Naphthalene | $PM_{2.5}$ | 1.05E-03 |
| $NH_3$ | Ammonia | $PM_{10}$ | 1.00E-02 |

**Table F-2:** C1/C2 HAP Profile Underway

| Pollutant Code | Pollutant | Associated basis for speciation | Fraction |
|---|---|---|---|
| | Copper | $PM_{10}$ | 1.75E-03 |
| | Zinc | $PM_{10}$ | 1.00E-03 |
| 100414 | Ethylbenzene | VOC | 1.25E-03 |
| 100425 | Styrene | VOC | 1.31E-03 |
| 107028 | Acrolein | VOC | 2.19E-03 |
| 108883 | Toluene | VOC | 2.00E-03 |
| 110543 | n-Hexane | VOC | 3.44E-03 |
| 118741 | HCB | $PM_{10}$ | 4.00E-08 |
| 120127 | Anthracene | $PM_{2.5}$ | 2.31E-05 |
| 123386 | Propionaldehyde | VOC | 3.81E-03 |
| 129000 | Pyrene | $PM_{2.5}$ | 2.44E-05 |
| 1330207 | Xylene | VOC | 3.00E-03 |
| 1336363 | PCB | $PM_{10}$ | 5.00E-07 |
| 16065831 | Chromium III | $PM_{10}$ | 3.30E-05 |
| 18540299 | Chromium VI | $PM_{10}$ | 1.70E-05 |
| 191242 | Benzo[g,h,I,]Perylene | $PM_{2.5}$ | 5.63E-06 |
| 193395 | Indeno[1,2,3-c,d]Pyrene | $PM_{10}$ | 1.00E-05 |
| 205992 | Benzo[b]Fluoranthene | $PM_{10}$ | 1.00E-05 |
| 206440 | Fluoranthene | $PM_{2.5}$ | 1.38E-05 |
| 207089 | Benzo[k]Fluoranthene | $PM_{10}$ | 5.00E-06 |
| 208968 | Acenaphthylene | $PM_{2.5}$ | 2.31E-05 |
| 218019 | Chrysene | $PM_{2.5}$ | 4.38E-06 |
| 50000 | Formaldehyde | VOC | 9.35E-02 |
| 50328 | Benzo[a]Pyrene | $PM_{10}$ | 5.00E-06 |
| 540841 | 2,2,4-trimethylpentane | VOC | 2.50E-04 |
| 56553 | Benz[a]Anthracene | $PM_{2.5}$ | 2.50E-05 |
| 628 | Dioxin | $PM_{10}$ | 5.00E-09 |

**Table F-2:** C1/C2 HAP Profile Underway

| Pollutant Code | Pollutant | Associated basis for speciation | Fraction |
|---|---|---|---|
| 71432 | Benzene | VOC | 1.27E-02 |
| 7439921 | Lead | $PM_{10}$ | 1.50E-04 |
| 7439965 | Manganese | $PM_{10}$ | 1.28E-06 |
| 7439976 | Mercury | $PM_{10}$ | 5.00E-08 |
| 7440020 | Nickel | $PM_{10}$ | 1.00E-03 |
| 7440382 | Arsenic | $PM_{10}$ | 3.00E-05 |
| 7440439 | Cadmium | $PM_{10}$ | 5.15E-06 |
| 7440473 | Chromium | $PM_{10}$ | 5.00E-05 |
| 75070 | Acetaldehyde | VOC | 4.64E-02 |
| 7782492 | Selenium | $PM_{10}$ | 5.15E-08 |
| 83329 | Acenaphthene | $PM_{2.5}$ | 1.50E-05 |
| 85018 | Phenanthrene | $PM_{2.5}$ | 3.50E-05 |
| 86737 | Fluorene | $PM_{2.5}$ | 3.06E-05 |
| 91203 | Naphthalene | $PM_{2.5}$ | 8.76E-04 |
| NH3 | Ammonia | $PM_{10}$ | 2.00E-02 |

**Table F-3:** Category 3 Profile In-port Hoteling

| Pollutant Code | Pollutant | Associated basis for speciation | Fraction |
|---|---|---|---|
| | Copper | $PM_{10}$ | 9.08E-04 |
| | Zinc | $PM_{10}$ | 6.00E-04 |
| 118741 | HCB | $PM_{10}$ | 1.60E-08 |
| 120127 | Anthracene | $PM_{2.5}$ | 5.25E-07 |
| 129000 | Pyrene | $PM_{2.5}$ | 5.53E-07 |
| 130498292 | POM as 7-PAH | PM | 4.50E-07 |
| 130498292 | POM as 16-PAH | $PM_{2.5}$ | 2.49E-05 |
| 1336363 | Polychlorinated Biphenyls | $PM_{10}$ | 2.00E-07 |
| 16065831 | Chromium III | $PM_{10}$ | 3.96E-04 |
| 18540299 | Chromium VI | $PM_{10}$ | 2.04E-04 |
| 191242 | Benzo[g,h,I,]Perylene | $PM_{2.5}$ | 1.28E-07 |
| 193395 | Indeno[1,2,3-c,d]Pyrene | $PM_{10}$ | 4.00E-06 |
| 205992 | Benzo[b]Fluoranthene | $PM_{10}$ | 4.00E-06 |
| 206440 | Fluoranthene | $PM_{2.5}$ | 3.12E-07 |
| 207089 | Benzo[k]Fluoranthene | $PM_{10}$ | 2.00E-06 |
| 208968 | Acenaphthylene | $PM_{2.5}$ | 5.25E-07 |
| 218019 | Chrysene | $PM_{2.5}$ | 9.93E-08 |
| 50000 | Formaldehyde | VOC | 1.57E-03 |

**Table F-3:** Category 3 Profile In-port Hoteling

| Pollutant Code | Pollutant | Associated basis for speciation | Fraction |
|---|---|---|---|
| 50328 | Benzo[a]Pyrene | $PM_{10}$ | 2.00E-06 |
| 53703 | Dibenzo[a,h]Anthracene | $PM_{2.5}$ | 0.00E+00 |
| 56553 | Benz[a]Anthracene | $PM_{2.5}$ | 5.67E-07 |
| 628 | Dioxin | $PM_{10}$ | 2.00E-09 |
| 71432 | Benzene | VOC | 9.80E-06 |
| 7439921 | Lead | $PM_{10}$ | 6.00E-05 |
| 7439965 | Manganese | $PM_{10}$ | 5.73E-05 |
| 7439976 | Mercury | $PM_{10}$ | 1.40E-06 |
| 7440020 | Nickel | $PM_{10}$ | 1.54E-02 |
| 7440382 | Arsenic | $PM_{10}$ | 4.00E-04 |
| 7440417 | Beryllium | $PM_{10}$ | 5.46E-07 |
| 7440439 | Cadmium | $PM_{10}$ | 5.90E-06 |
| 7440484 | Cobalt | $PM_{10}$ | 2.92E-04 |
| 75070 | Acetaldehyde | VOC | 2.29E-04 |
| 7723140 | Phosphorous | $PM_{10}$ | 4.38E-03 |
| 7782492 | Selenium | $PM_{10}$ | 9.08E-06 |
| 83329 | Acenaphthene | $PM_{2.5}$ | 3.40E-07 |
| 85018 | Phenanthrene | $PM_{2.5}$ | 7.94E-07 |
| 86737 | Fluorene | $PM_{2.5}$ | 6.95E-07 |
| 91203 | Naphthalene | $PM_{2.5}$ | 1.99E-05 |
| NH3 | Ammonia | $PM_{10}$ | 1.08E-02 |

**Table F-4:** Category 3 Profile In-port Maneuvering

| Pollutant Code | Pollutant | Associated basis for speciation | Fraction |
|---|---|---|---|
| | Copper | $PM_{10}$ | 1.91E-04 |
| | Zinc | $PM_{10}$ | 1.31E-04 |
| 118741 | HCB | $PM_{10}$ | 3.50E-09 |
| 120127 | Anthracene | $PM_{2.5}$ | 5.25E-07 |
| 129000 | Pyrene | $PM_{2.5}$ | 5.53E-07 |
| 130498292 | POM as 7-PAH | $PM_{10}$ | 4.90E-07 |
| 130498292 | POM as 16-PAH | $PM_{2.5}$ | 2.49E-05 |
| 1336363 | PCB | $PM_{10}$ | 4.37E-08 |
| 16065831 | Chromium III | $PM_{10}$ | 1.27E-04 |
| 18540299 | Chromium VI | $PM_{10}$ | 6.53E-05 |
| 191242 | Benzo[g,h,I,]Perylene | $PM_{2.5}$ | 1.28E-07 |
| 193395 | Indeno[1,2,3-c,d]Pyrene | $PM_{10}$ | 8.74E-07 |

**Table F-4:** Category 3 Profile In-port Maneuvering

| Pollutant Code | Pollutant | Associated basis for speciation | Fraction |
|---|---|---|---|
| 205992 | Benzo[b]Fluoranthene | $PM_{10}$ | 8.74E-07 |
| 206440 | Fluoranthene | $PM_{2.5}$ | 3.12E-07 |
| 207089 | Benzo[k]Fluoranthene | $PM_{10}$ | 4.37E-07 |
| 208968 | Acenaphthylene | $PM_{2.5}$ | 5.25E-07 |
| 218019 | Chrysene | $PM_{2.5}$ | 9.93E-08 |
| 50000 | Formaldehyde | VOC | 1.57E-03 |
| 50328 | Benzo[a]Pyrene | $PM_{10}$ | 4.37E-07 |
| 53703 | Dibenzo[a,h]Anthracene | $PM_{2.5}$ | 0.00E+00 |
| 56553 | Benz[a]Anthracene | $PM_{2.5}$ | 5.67E-07 |
| 628 | Dioxin | $PM_{10}$ | 4.37E-10 |
| 71432 | Benzene | VOC | 9.80E-06 |
| 7439921 | Lead | $PM_{10}$ | 1.40E-05 |
| 7439965 | Manganese | $PM_{10}$ | 5.73E-05 |
| 7439976 | Mercury | $PM_{10}$ | 2.71E-07 |
| 7440020 | Nickel | $PM_{10}$ | 3.25E-03 |
| 7440382 | Arsenic | $PM_{10}$ | 8.74E-05 |
| 7440417 | Beryllium | $PM_{10}$ | 5.46E-07 |
| 7440439 | Cadmium | $PM_{10}$ | 2.26E-05 |
| 7440484 | Cobalt | $PM_{10}$ | 5.94E-05 |
| 75070 | Acetaldehyde | VOC | 2.29E-04 |
| 7723140 | Phosphorous | $PM_{10}$ | 1.79E-03 |
| 7782492 | Selenium | $PM_{10}$ | 1.91E-06 |
| 83329 | Acenaphthene | $PM_{2.5}$ | 3.40E-07 |
| 85018 | Phenanthrene | $PM_{2.5}$ | 7.94E-07 |
| 86737 | Fluorene | $PM_{2.5}$ | 6.95E-07 |
| 91203 | Naphthalene | $PM_{2.5}$ | 1.99E-05 |
| NH3 | Ammonia | $PM_{10}$ | 2.38E-03 |

**Table F-5:** Category 3 Profile Underway

| Pollutant Code | Pollutant | Associated basis for speciation | Fraction |
|---|---|---|---|
|  | Copper | $PM_{10}$ | 3.48E-04 |
|  | Zinc | $PM_{10}$ | 2.62E-04 |
| 118741 | HCB | $PM_{10}$ | 6.99E-09 |
| 120127 | Anthracene | $PM_{2.5}$ | 5.25E-07 |
| 129000 | Pyrene | $PM_{2.5}$ | 5.53E-07 |
| 130498292 | POM as 7-PAH | $PM_{10}$ | 4.90E-07 |
| 130498292 | POM as 16-PAH | $PM_{2.5}$ | 2.49E-05 |

**Table F-5:** Category 3 Profile Underway

| Pollutant Code | Pollutant | Associated basis for speciation | Fraction |
|---|---|---|---|
| 1336363 | PCB | $PM_{10}$ | 8.74E-08 |
| 16065831 | Chromium III | $PM_{10}$ | 1.27E-04 |
| 18540299 | Chromium VI | $PM_{10}$ | 6.53E-05 |
| 191242 | Benzo[g,h,I,]Perylene | $PM_{2.5}$ | 1.28E-07 |
| 193395 | Indeno[1,2,3-c,d]Pyrene | $PM_{10}$ | 1.75E-06 |
| 205992 | Benzo[b]Fluoranthene | $PM_{10}$ | 1.75E-06 |
| 206440 | Fluoranthene | $PM_{2.5}$ | 3.12E-07 |
| 207089 | Benzo[k]Fluoranthene | $PM_{10}$ | 8.74E-07 |
| 208968 | Acenaphthylene | $PM_{2.5}$ | 5.25E-07 |
| 218019 | Chrysene | $PM_{2.5}$ | 9.93E-08 |
| 50000 | Formaldehyde | VOC | 1.57E-03 |
| 50328 | Benzo[a]Pyrene | $PM_{10}$ | 8.74E-07 |
| 53703 | Dibenzo[a,h]Anthracene | $PM_{2.5}$ | 0.00E+00 |
| 56553 | Benz[a]Anthracene | $PM_{2.5}$ | 5.67E-07 |
| 628 | Dioxin | $PM_{10}$ | 8.74E-10 |
| 71432 | Benzene | VOC | 9.80E-06 |
| 7439921 | Lead | $PM_{10}$ | 2.62E-05 |
| 7439965 | Manganese | $PM_{10}$ | 5.73E-05 |
| 7439976 | Mercury | $PM_{10}$ | 5.24E-07 |
| 7440020 | Nickel | $PM_{10}$ | 5.89E-03 |
| 7440382 | Arsenic | $PM_{10}$ | 1.75E-04 |
| 7440417 | Beryllium | $PM_{10}$ | 5.46E-07 |
| 7440439 | Cadmium | $PM_{10}$ | 2.26E-05 |
| 7440473 | Chromium | $PM_{10}$ | 1.92E-04 |
| 7440484 | Cobalt | $PM_{10}$ | 1.54E-04 |
| 75070 | Acetaldehyde | VOC | 2.29E-04 |
| 7723140 | Phosphorus | $PM_{10}$ | 5.73E-03 |
| 7782492 | Selenium | $PM_{10}$ | 3.48E-06 |
| 83329 | Acenaphthene | $PM_{2.5}$ | 3.40E-07 |
| 85018 | Phenanthrene | $PM_{2.5}$ | 7.94E-07 |
| 86737 | Fluorene | $PM_{2.5}$ | 6.95E-07 |
| 91203 | Naphthalene | $PM_{2.5}$ | 1.99E-05 |
| NH3 | Ammonia | $PM_{10}$ | 4.77E-03 |