CATEGORY 3 COMMERCIAL MARINE VESSEL 2023 EMISSIONS INVENTORY

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List of Abbreviations

AIS Automatic Identification Systems

BSFC Brake-Specific Fuel Consumption

C3 Category 3

CMV Commercial Marine Vessel

CO Carbon Monoxide

CO2 Carbon Dioxide

DWT Deadweight tonnage

ECA Emissions Control Area

EF Emission factor

GT Gas turbine

GT-ED Gas turbine-diesel-electric drive

HFO Heavy fuel oil

IHS Information Handling Service

IMO International Maritime Organization

kn Knot

kW Kilowatt

kWh Kilowatt-hour

L/cyl Liters per cylinder

LBP Length along perpendicular

LLAF Low load adjustment factor

LNG Liquified natural gas

lwl Waterline length

m^3 Cubic meter

MDO Marine diesel oil

MGO Marine gas oil

MMSI Maritime Mobile Service Identifier

MSD Medium speed diesel

MSD-ED Medium speed-diesel-electric drive

NOx Nitrogen oxides

PM	Particulate matter
PM2.5	Particulate matter 2.5 microns or less in diameter
PM10	Particulate matter 10 microns or less in diameter
Reefer	Refrigerated vessels
RM	Residual marine
Ro Ro	Roll on/Roll off
RPM	Revolutions per minute
S-AIS	Satellite automatic identification systems
SO2	Sulfur dioxide
SOLAS	Safety of Life at Sea
SSD	Slow speed diesel
ST	Steam turbine
T-AIS	Terrestrial automatic identification systems
TEU	Twenty-foot equivalent units
USCG	United States Coast Guard
VOC	Volatile organic compounds

1 Introduction

The National Emissions Inventory (NEI) and Emissions Modeling Platforms (EMP) are national compilations of air emission estimates of criteria air pollutants (CAPs), the precursors of CAPs, and hazardous air pollutants (HAPs) for mobile, point, and nonpoint emissions sources. The hazardous air pollutants that are included in the EMP are based on Section 112(b) of the Clean Air Act. State, local and tribal air agencies submit emission estimates to EPA and the Agency adds information to supplement the state submittals to provide emissions estimates for the remaining states. The NEI and its derivative modeling platforms are used for various modeling and regulatory analyses performed by EPA, state and local air quality management agencies, and others.

This report documents the development of EPA's emissions inventory for Category 3 (C3) commercial marine vessels (CMV), including the conceptual framework, equations, data sources, and assumptions. Category 3 engines displace more than 30 liters per cylinder and are typically ocean-going vessels. A description of the development of the Category 1 and 2 (C1C2) CMV emissions inventory for vessels with engines having displacement less than 30 liters per cylinder, including the conceptual framework, equations, data sources, and assumptions, is provided in a separate report.

2 AIS Dataset

The EPA purchased Automated Identification System (AIS) data from Spire Global's database to quantify all ship activity which occurred between January 1 and December 31, 2023.[1] The International Maritime Organization's (IMO's) International Convention for the Safety of Life at Sea (SOLAS) requires AIS to be fitted aboard all international voyaging ships with gross tonnage of 300 or more, and all passenger ships regardless of size.[2] In addition, the United States Coast Guard (USCG) has mandated that all commercial marine vessels continuously transmit AIS signals while transiting U.S. navigable waters.[3] As the vast majority of C3 vessels meet these requirements, any omitted from the inventory due to lack of AIS adoption are deemed to have a negligible impact on national C3 emissions estimates.

The activity described by this inventory reflects ship operations within 200 nautical miles of the official U.S. coastline. This boundary is roughly equivalent to the border of the U.S Exclusive Economic Zone and the North American Emission Control Area (ECA), although some non-ECA activity is captured as well (Figure 1). In Figure 1, the NEI Geographic Extent is shown in (blue), the North American and Caribbean ECAs are in red outline, the Ports and Anchorages are orange dots, and the AIS area of interest encompassing the air quality modeling domain are shown within the dashed outline.

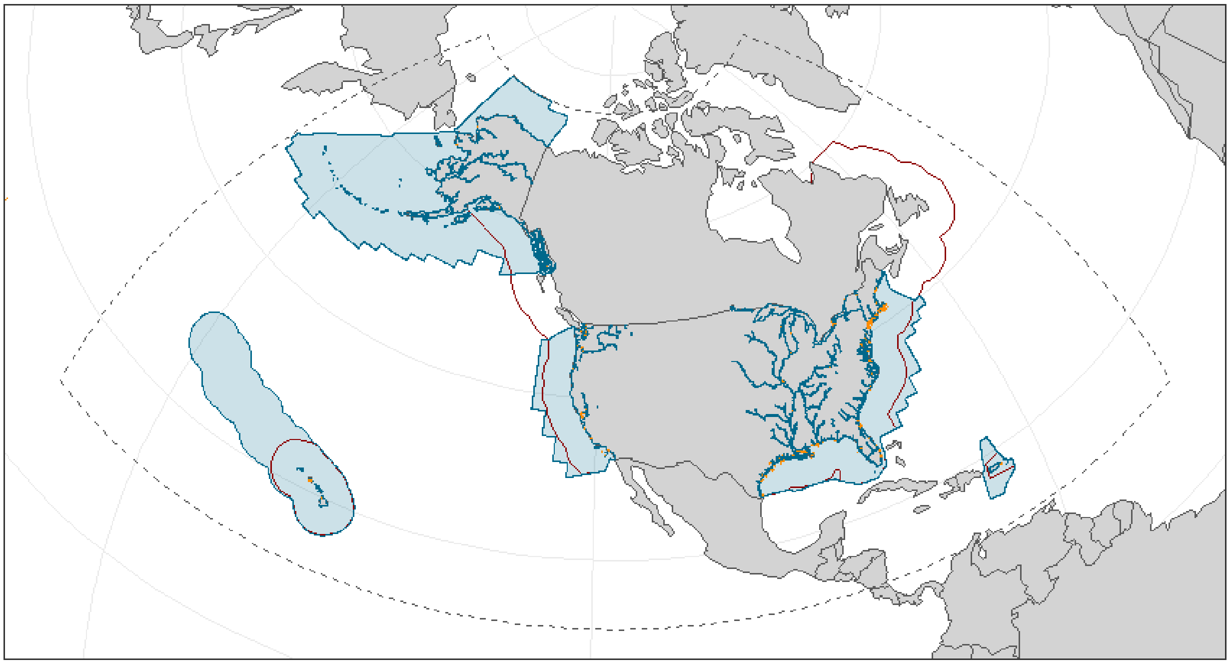

Figure 1 Geographic regions used for the C3 Emissions inventory.

2.1 AIS Pre-Processing

The AIS data were delivered as comma separated value (csv) files that contain AIS records of global ship movements. The global AIS dataset for calendar year 2023 contained a total of 42,247 files totalling 10.6 TB of data. The as-received dataset includes all global vessel operations with a sampling frequency that depends on the geographic coverage of the AIS receiver network. The dataset also contains some anomalous data such as duplicate records, and records from non-vessels. The data fields retained for calculating emissions were: Maritime Mobile Service Identifier (MMSI), timestamp, IMO number, call sign, latitude (degrees), longitude (degrees), speed (knots), Course over ground (degrees), heading (degrees), navigation status, Draught (meters), ship and cargo type, length (meters), width (meters), and receiver. Many of these fields were not directly used for emissions calculations but were retained for QA purposes. Of these fields only MMSI, timestamp, latitude, longitude, speed, and receiver were reported in every row of the csv files. Therefore, MMSI was used as the primary identifier for distinguishing between unique vessels.

The first step in processing the AIS data was to filter the dataset for the records that fall within the geographic domain of the NEI and parse them into standardized data fields, with non-vessel and duplicated records removed. The geographic area of interest was defined as: latitudes between 11.32° and 75.10°, and longitudes between 166.38° and -40.61°. Note that the area of interest spans the anti-meridian (±180°). Non-vessel entities were identified using MMSI patterns, based on information obtained from the USCG Navigation center.[4] Records with MMSI numbers identified as: ship, auxiliary craft associated with a parent ship, or group of ships, were retained. The following MMSI types were dropped: divers' radios, coastal stations, aids to navigation, search and rescue aircraft and transmitters, man overboard devices, and emergency position indicating radio beacon.

The records were then aggregated by MMSI to a standardized five-minute time interval to reduce the size of the dataset and to match the time interval used by EPA to develop previous marine emissions inventories. For this step, dynamic numerical fields (latitude, longitude, speed, course over ground, heading, draught) were averaged over the five-minute interval. For the other fields the most frequent observed value was selected when multiple values were present. The aggregated data were written to a database keyed by MMSI and timestamp for fast data retrieval.

3 Ship Characteristics Dataset

To calculate a ship's emissions, additional information about the ship is needed beyond its position and speed. For that data EPA primarily used the Clarksons ship registry supplemented with and validated by smaller datasets.[5-8] The vessel characteristics data must be matched with the AIS data using a combination of the vessel's IMO number and MMSI number. In addition, not all of the ship characteristics needed to calculate emissions are available for every vessel. This section describes how EPA assembled a ship characteristics dataset based on the observed vessel ID values in the AIS data set, and gap-filled missing fields where required.

3.1 Identifying Observed Ships

EPA developed a list of unique combinations of MMSI and IMO numbers appearing in the filtered and aggregated AIS dataset along with the number of records associated with them. The ID fields in the Clarksons and supplementary datasets were compared against the unique identifiers in the AIS dataset and records with either matching MMSI or IMO number were selected. Of the 250,117 unique combinations of identifiers identified in the AIS data set, 16% had corresponding vessel characteristics. This 16% accounted for 48% of the total number of messages in the AIS data set. Filtering the AIS data for identifiers with known characteristics removed 208,946 combinations of unique identifiers, yielding a total of 41,171 identifier combinations. Of these, there are many combinations of identifiers that only correspond to one record of AIS data, and there are many cases in the AIS data where there are two or more IMO numbers matched to a given MMSI, and some cases where those IMO numbers are not found in the characteristics data set. After dropping the identifiers associated with only one AIS record, there were 27,204 unique vessels in the characteristics dataset that could be matched to AIS records.

The vessel parameters required to calculate ship propulsive power, estimate operating modes, and assign emission factors are listed in Table 1. The following sections describe how missing values were filled for each of these fields.

Table 1 Ship Parameters

Vessel Identification	Vessel Category Determination	Vessel Power Parameters	Vessel Grouping/Emission Factor Parameters
• IMO number • MMSI	• Engine bore • Engine stroke	• Hull displacement (m^3) • Length on perpendicular (m) • Breadth (m) • Total installed propulsive power (kW) • Service Speed (kn)	• Gross tonnage • Deadweight tonnage • Keel-laid year • Propulsion type • Main engine stroke type • Engine revolutions per minute (rpm) • Twenty-foot equivalent units (TEU)

3.2 Ship Type

To fill gaps in vessel characteristics data and assign auxiliary and boiler loads, EPA matched vessel types to less granular ship type groups (see Appendix A). All barges and non-self-propelled vessels were removed from inventory calculations. The resulting database includes the following ship types:

- Bulk carrier
- Chemical tanker
- Container ship
- Cruise
- Ferry/roll-on/passenger vessel
- General cargo
- Liquified gas tanker
- Fishing
- Miscellaneous
- Oil tanker
- Offshore support vessel or drillship
- Other tanker
- Refrigerated vessel (Reefer)
- Roll-on/roll-off (Ro Ro)
- Tug
- Yacht

Figure 2 below shows the fraction of AIS messages associated with each of the ship types.

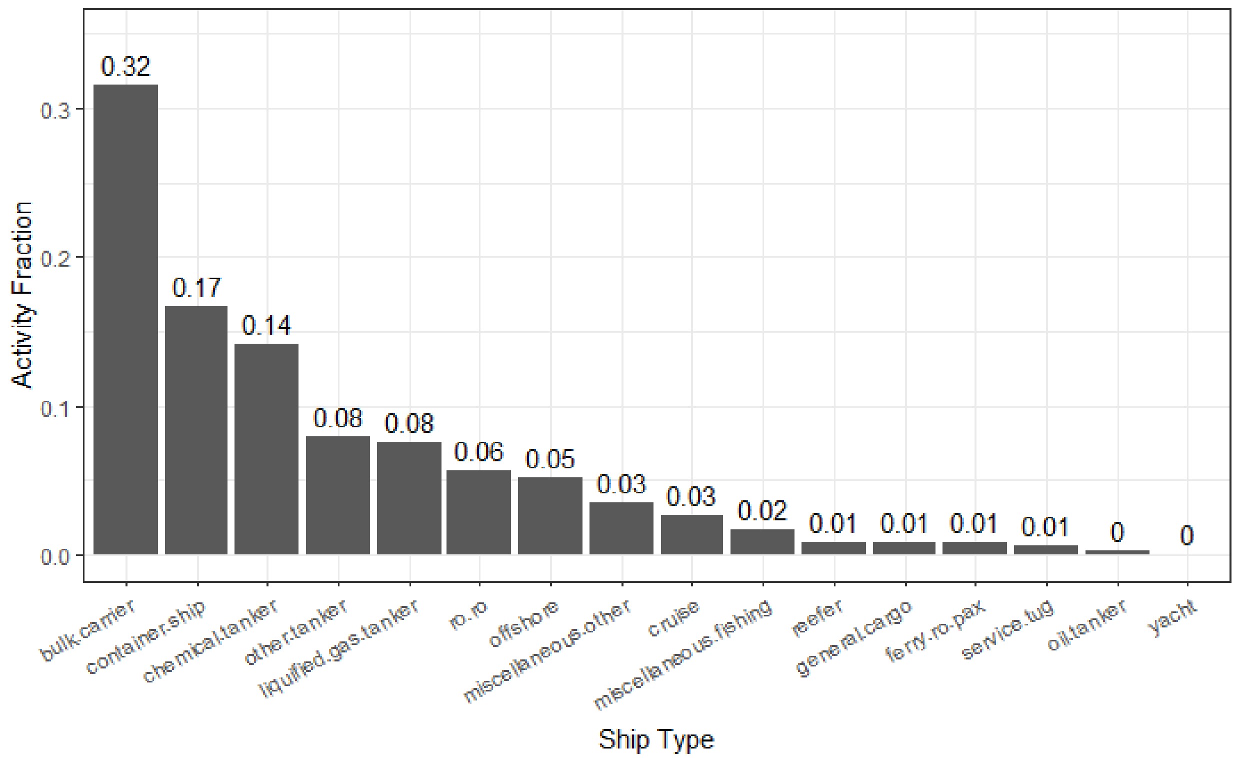

Figure 2 Breakdown of category 3 AIS activity by ship type

3.3 Subtype

The EPA assigned subtypes to each vessel in the ship registry according to its ship type and size class (see Appendix A). Subtypes were primarily assigned to best fit with adopted auxiliary and auxiliary boiler engine loads.[9] However, given the available data, certain adjustments were made in subtype characterization. As the number of vehicles per vehicle carrier was not available, vehicle carrier size classes were adopted from EPA's Ports Emissions Inventory Guidance. All vehicle carrier auxiliary and auxiliary boiler loads are the same, regardless of subtype, and did not need to be altered for this process.

3.4 Engine Type

Vessel engine type is required for the assignment of emission factors (EFs). The majority of the C3 fleet operated with slow-speed diesel (SSD) engines, which are identified as four-stroke engines. Medium-speed diesel (MSD) vessels were identified as those having two-stroke engines. While rpm classifications vary, 500 rpm was deemed to be the most appropriate cutoff between SSD and MSD engines, given the broad band of rpms separating the two groups.[10] EPA used rpm classifications to determine engine type only when engine stroke type information was unavailable. Gas turbine (GT) and steam turbine (ST) engines were determined by a descriptive propulsive type vessel characteristic field. This propulsive type field also allowed for the identification of electric-drive vessels (MSD-ED or GT-ED). Currently, no standardized identification methods are available for liquified natural gas (LNG) engines. All auxiliary engines were assumed to be MSD. Vessels were assigned an engine type using the parameter gap-filling method described below.

3.5 Ship Parameter Gap Filling

Some vessel fields are missing data important for calculating emission factors. The engine category aids in defining the vessel type and limiting the scope of the emissions model by separating C3 and C1C2 vessels. Engine categories were assigned to each ship type using a maximum threshold for the C2 category from the gross tonnage 75th quantile plus 1.5 times the interquartile range. Ships above this value were assigned the C3 category (see Appendix B.2.1). After gap filling engine categories, there were 16,603 C3 vessels.

The remaining ship parameters were gap filled using various methods, including linear regressions, non-linear least squares estimates ("nth root" fits), median values, averages, or modes. The appropriate method was dependent on the parameter in question. In cases where a parameter was being filled based on a parameter with an analogous physical unit, (e.g. Length between perpendiculars and length overall, or Deadweight Tonnage and Gross Tonnage) linear regressions were used to relate the parameters (see Appendix B.1). In the cases where a parameter with units of length was being gap-filled from a parameter with units of volume or mass (e.g. ship breadth and gross tonnage) we assumed that the relationship between length and volume was roughly cubic (see Appendix B.1), and fit the length using the following nth root relationship:

$$L = aV^{\frac{1}{n}} \qquad \text{Eq. 1}$$

Where L is the length parameter, and V is the volume parameter. Values of n that do not equal 3 indicate that the three linear dimensions length, breadth, and draft do not scale at the same rate with increasing ship volume. The quality of both the linear and nth root fits, was assessed through an analysis of R squared values and data visualization.

If a parameter did not have a clear physical relationship to another known parameter, or if a regression produced a poor correlation, the median value was taken for each ship type and sub type to fill the missing data. For parameters where data could not be entirely filled after the first method was applied, multiple techniques were used to reduce as much missing data as possible. Both "Length Between Perpendiculars" and "Total installed propulsive power" required multiple methods to fill all remaining gaps in the data.

Vessel subtypes were assigned after deadweight tonnage was gap filled to increase the coverage of assigned subtypes. Displacement was calculated after lightweight tonnage was gap filled by summing light-displacement tonnage with deadweight tonnage.

Missing keel year was estimated by generating an average delay using the difference in time between the keel-build date and the keel-laying date for each ship subtype (see Appendix B.1). These values were weighted by both population and time (message count) and compared. The values weighted by time were chosen as the weighted by population values showed unrealistic values for ships with small populations (i.e., cruise ships and yachts).

The most appropriate method for assigning the main engine stroke was using the "Engine Cycle" mode for each ship subtype and applying it for the missing data. Once the main engine stroke data are filled, the missing engine types are assigned by searching for key words in the data set which describe the "Engine Derived Power Type" in conjunction with the main engine stroke.

Block coefficients are a function of vessel hull displacement, waterline length, breadth, and draft. For vessels missing just one of these function inputs, values were filled using the median value by ship subtype (see Appendix B.2.4).

Analysis has shown that gap-filling parameters by vessel subtype averages produces a relatively small difference in estimated emissions.[11] Roughly 60% of the AIS activity time for 2023 was allocated to vessels missing hull displacement data. The remaining time is allocated to vessels for which hull displacement were filled by back-calculating from block coefficients averaged by subtype, ship category, engine type, and tier. For the remaining vessel parameters, less than 6% of AIS activity time was allotted to missing data. The gap-filling methodologies used for each parameter are summarized in Table 2. All of the gap-filling values and coefficients for each ship parameter and subtype are listed in Appendix B.2.

Table 2 Gap filling methodologies used for each ship parameter

Parameter	**Gap Filling Methodology**
Deadweight Tonnage	Linear regression from gross tonnage
Lightweight Tonnage	Linear regression from gross tonnage
Length Between Perpendiculars	Linear regression from length overall n^{th} root fit from gross tonnage
Summer load line draft	n^{th} root fit from gross tonnage
Ship breadth	n^{th} root fit from gross tonnage
Total installed propulsive power	Linear regression from "ENGINE_DERIVED_TOTAL_MECHANICAL_GENERATED_KW" Median value by ship subtype
Service Speed	Median value by ship subtype
Keel-laying date	Average delay between keel-build and key-laying date by ship subtype
TEU	Linear regression from gross tonnage
Main engine stroke	Mode by ship subtype
Block Coefficient CB	Median value by ship subtype

4 Calculating Emissions

This inventory compiles emissions using the methods described in EPA's 2022 Ports Emissions Inventory Guidance and implemented in EPA's Marine Emissions Tools.[9,12] Emissions are calculated for each marine vessel represented in both the AIS activity and ship registry datasets, for each time interval between consecutive AIS messages and allocated to the location of the message before the interval. Emissions are calculated according to the following equation:

$$Emissions_{interval} = Time_{interval} \times Power \times EF \times LLAF \qquad \text{Eq. 2}$$

where:

Emissions	=	mass of emissions estimated for each time interval between AIS messages for each vessel, typically calculated in grams and then converted to tons when emissions are aggregated
Time	=	length of time between AIS messages, measured in hours
Power	=	calculated in kWh for each AIS message, for each vessel, for each of the three engine groups on a vessel: propulsive (main), auxiliary, and auxiliary boiler engines
EF	=	assigned emission factors for each engine group on the vessel
LLAF	=	low load adjustment factor, a unitless factor that reflects increasing propulsive emissions during low load operations and varies according to the calculated propulsive power

Emissions were calculated for each unique C3 ship identified in the gap-filled ship characteristics dataset. The emissions for ships were calculated in parallel and combined afterwards to create a final overall inventory. In total emissions were calculated for 16,603 ships.

4.1 Preparing Ship AIS Data

Before the emissions calculations, erroneous vessel activity messages were identified and removed from the dataset. Some duplicate messages, associated with the same vessel identifier and time stamp, were reported and removed. Erroneous speeds were deemed to be all speeds above 1.5 times the service speed of the vessel; these messages were also removed. [9] Removing erroneous messages created gaps, which were filled in during later processing steps. Activity messages report vessel draft, a parameter required for ship propulsive power modeling. Ships were assumed to be operating at maximum draft when AIS-reported draft data were missing.

4.2 Temporal Gaps in AIS Activity

As described previously, EPA aggregated the AIS data to five-minute intervals. However, for a given vessel, there were some intervals longer than five minutes between vessels' consecutive messages, suggesting cases in which transmissions were not sent or received, or in which a vessel left the study area and then returned. EPA analyzed these gaps to determine whether they reflected activity outside the geographical extent of the received AIS data. This analysis was completed by extrapolating vessel activity, assuming a constant speed and heading, from that of the previous message to gap, and comparing extrapolated positions to the AIS dataset boundaries. All gaps reflecting activity out of the AIS geographical area were omitted from the emissions inventory. For AIS data within the area of study, temporal gaps of less than 24 hours were filled by linearly interpolating location, speed, and draft data at five-minute intervals. For gaps greater than 24 hours, there was too much uncertainty in a vessel's movement to interpolate the data. Therefore, emissions were not estimated for these long durations.

4.3 Calculating Main Engine Power

Propulsive power was calculated using EPA's Marine Emissions Tools, specifically with the Holtrop & Mennen numerical ship power model, which follows the form of resistance-based methods, documented in Eq. 3.[12,13]

$$Power\ (kW) = \frac{\rho \times C_T \times \frac{1}{2} \times S \times V_{reported}^{\ 3}}{\eta_T} \qquad \text{Eq. 3}$$

where:

ρ = sea water density

$V_{reported}$ = AIS-reported speed before the message interval

C_T = vessel's hull resistance coefficient

S = hull surface area

η_T = engine efficiency

Where available vessel attributes were not sufficient to calculate certain Holtrop & Mennen parameters, such as transverse bulb area, transom area, longitudinal position center of buoyancy, and center of bulb above keel line, methodologies from Rakke were used.[14] Vessels were assumed to be operating in calm, 15℃ water conditions with clean and normal hulls. In accordance with this, a 15% service margin was applied.[9,15] The midship section coefficient was assumed to be 0.995 for bulk and tankers, 0.95 for passenger vessels, 0.92 for tugs, and 0.98 for all other ship types.[16] Passenger ship types were assumed to have two propellers and all other vessels were assumed to have one propeller. The waterplane area coefficient was calculated according to methodologies in Kristensen & Lutzen.[16] EPA adopted upper and lower bounds from SARC Maritime Software and Services and applied them to these waterplane area coefficients in order to ensure the values were within a realistic range.[17]

4.4 Assigning Operating Mode

Operating mode was determined using geospatial, speed, and propulsive load data. For anchorage and port activity shapefiles from NOAA and EPA were used. [18,19] The operating modes were assigned using the following rules in order of preference:

1. If a vessel was in anchorage zone and had a speed less than or equal to 3 knots, it was assigned the anchorage operating mode.
2. If a vessel was in a port area and had a speed less than or equal to one knot, it was assigned the berth operating mode.
3. If a vessel's speed was more than 1 knot with a propulsion engine load factor less than or equal to 20%, it was assigned the maneuvering mode.
4. If a vessel's propulsion engine load factor was more than 20%, it was assigned the transit operating mode.

These rules are consistent with the general considerations presented in EPA's Ports Emissions Inventory Guidance.[9] If a vessel's operation was not covered by the above rules (e.g., traveling less than 1 knot outside of an anchorage zone or port area), it was assigned to the anchorage operating mode. Figure 3 shows an example of the shape files used for operating mode assignment. In Figure 3 the map covers the area surrounding the ports of New York and New Jersey. Red polygons indicate port shapes, and orange polygons indicate anchorage areas. The blue region is a buffered coastline shape used to filter out data over land but still capture small deviations near shore. County lines in black are from the US Census 2023 TIGER shape files.[19,18,22]

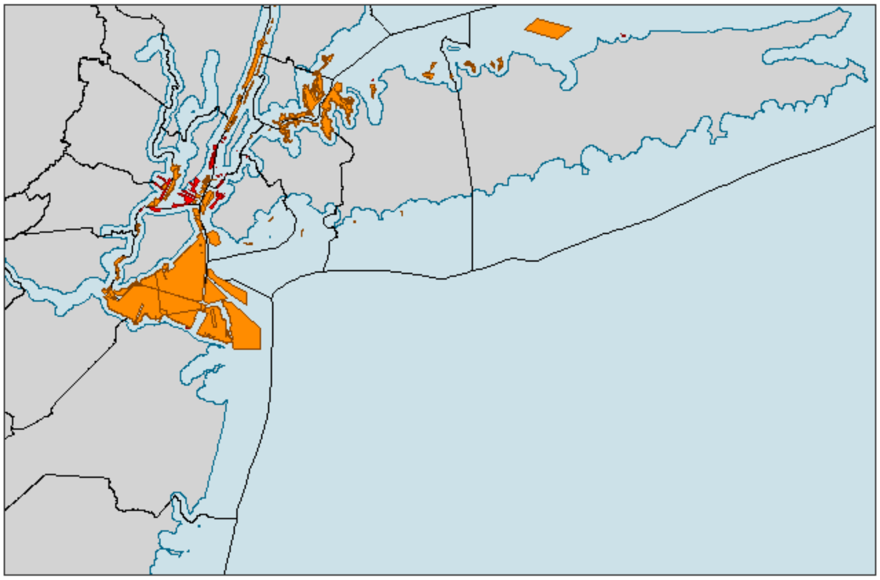

Figure 3 Example map illustrating the shape files used for assigning operating mode.

4.5 Calculating Auxiliary and Boiler Power

Auxiliary engines support electrical generators for auxiliary vessel power. Auxiliary boiler engines supply steam and hot water for heating and other auxiliary requirements on marine vessels. Auxiliary and boiler power cannot be calculated directly using AIS data and is not estimated in Clarkson's ship registry dataset; rather, defaults must be used. Auxiliary engine and boiler load defaults were adopted from EPA's Ports Emissions Inventory Guidance Tables E.1 and E.2, respectively.[9]

4.6 Assigning Fuel Type

All C3 marine vessels are assumed to use distillate marine gas oil (MGO) or marine diesel oil (MDO) fuel during operations within the North American ECA in order to comply with fuel sulfur regulations. C3 vessels outside the ECA are assumed to use residual marine (RM) or heavy fuel oil (HFO). Some uncertainty exists in this assignment, as the usage of blended fuels, or of scrubber adoption with high sulfur fuels, within these regions, is not known.

For the current inventory, fuel sulfur values are set to 0.1% for all vessel activity within the ECA in accordance with fuel sulfur regulations.[20] Marine vessels are assumed to use fuel with 0.5% fuel sulfur levels outside of the ECA.

4.7 Emission Factors

Emission factors (EFs) are generally assigned according to engine type, engine group, tier and fuel sulfur level. MSD-ED and GT-ED adopt MSD and GT EFs, respectively. EFs can either be energy-based (in units of grams of pollutant per kWh) or fuel-based (in units of grams of pollutant per unit of fuel consumption).

4.7.1 Energy-based Emission Factors

Energy-based emission factors can be used directly with energy-based activity (i.e., activity in terms of kWh, which is calculated in Eq. 2). These emission factors include nitrogen oxides (NOx), volatile organic compounds (VOC), carbon monoxide (CO), and hydrocarbons (HC).

NOx EFs are applied according to engine group, engine type, fuel type, engine tier, and propulsive engine load as described in EPA's Ports Emissions Inventory Guidance, Section 3.5.1.[9] Because Tier III NOx emission standards only apply within the ECA, emission rates for Tier III vessels operating outside the ECA are assumed to be equivalent to the Tier II NOx rates.

VOC, CO, and HC EFs are applied according to engine group and engine type as described in EPA's Ports Emissions Inventory Guidance, Section 3.5.4.[9]

4.7.2 Fuel-based Emission Factors

Fuel-based emission factors must first be paired with brake-specific fuel consumption (BSFC) before they can be used with energy-based activity. BSFC rates can be used to estimate fuel consumption from energy-based activity, which then allows the fuel-based emission factors to be used.

Particulate matter (PM), sulfur dioxide (SO2), and carbon dioxide (CO2) are calculated using the emission factors presented in EPA's Ports Emissions Inventory Guidance. See Sections: 3.5.3 for PM, 3.5.7 for SO2, and 3.5.6 for CO2. Additionally, see the Ports Emissions Inventory Guidance Section 3.5.2 for a discussion on BSFC.[9]

4.8 Low Load Adjustment Factor

EFs are treated as constant when a vessel's modeled propulsive engine load represents more than 20% of its total installed propulsive power. Below that threshold, EFs tend to increase as the engine load decreases. This trend results because diesel engines are less efficient at low loads and the BSFC tends to increase. To account for this, low load adjustment factors (LLAFs) are applied in Eq. 2. The LLAF factors used were from Table 3.10 in EPA's Ports Emissions Inventory Guidance.[9]

Modeled emissions from vessels with electric-drive engines (MSD-ED or GT-ED) were assigned LLAFs of one for all pollutants. These vessels generate power with several smaller engines, some of which, it is assumed, shut down as power demand decreases to ensure that no engines are operating at lower inefficient loads, enhancing overall efficiency and reducing fuel consumption.

4.9 HAP Specific Profiles

The hazardous air pollutants (HAP) are calculated from the criteria pollutants estimated as described above. The HAP speciation profiles are from EPA's Ports Emissions Inventory Guidance, Appendix D. The fractions reported in D.1 were multiplied by the emissions of their assigned basis pollutant to complete this calculation.[9]

5 Gridding Emissions

In order to include the results of the inventory in the national air quality modeling platform which requires hourly emissions by modeling grid cell, scripts were written to grid the estimated C3 emissions into hourly flat files needed to support emissions modeling using the Sparse Matrix Operator Kernel Emissions (SMOKE) modeling system.[21] The scripts use the following process to take emissions attributed to the latitude and longitude coordinates of AIS messages and output them as aggregated gridded emissions for each cell within a given grid definition. The grid origin, grid dimensions, and map projection used for the grid are provided as an input to the scripts.

First the spatial coordinates of the emissions are transformed to the LCC projection of the desired grid with the origin at the lower left corner of the grid. Next the grid cell location was calculated from the X and Y coordinates as:

$$Grid\ Column = \frac{floor\left(X_{Projected}(m) - X_{Origin}(m)\right)}{Cellwidth(m)} \quad \text{Eq. 4}$$

And

$$Grid\ Row = \frac{floor\left(Y_{Projected}(m) - Y_{Origin}(m)\right)}{Cellwidth(m)} \quad \text{Eq. 5}$$

The emissions estimates are then aggregated by grid cell row, and column, date, hour, SCC, port ID, and FIPS code. Finally, the gridded emissions are output following the format of an hourly Flat File 2010 (FF10) file.

5.1 Masking Raster

The MET includes interpolated data points between all AIS messages associated with non-hoteling activity intervals greater than five minutes. This was done with the intention that each underway emissions estimation should represent the same activity duration. However, some messages were interpolated to locations that cannot contain C3 activity, like narrow inland waterways and shallow water bodies. Therefore, because interpolated messages were included in the rasterization process described above, a masking raster was required to define likely and unlikely C3 locations. This masking raster was then used to remove all emissions from grid cells in unlikely C3 locations.

An R function was developed to create the initial masking raster. This function creates a single, annual raster of non-interpolated C3 activity with the intention to remove all emissions from the daily rasters that were in unlikely C3 locations. Unlikely C3 locations were grid cells in which exclusively interpolated messages existed.

An analysis of the 12km CONUS masking raster brought to light certain anomalies in non-interpolated data which may also result in unlikely emissions locations. The non-interpolated masking raster reported odd inland activity such as that near Assateague, MD and Clear Lake, CA. This is like activity found in the 2017 data around Gainesville, FL and up the Mississippi River where C3 activity is not likely. These emissions were determined to be the result of “rogue” messages within the raw AIS dataset initially received from the US Coast Guard. Rogue messages can easily be identified by analyzing a single vessel’s path. Figure 4 shows an example of a single vessel transiting along the west coast of Mexico, with red dots signifying the message associated with the timestamp reported above the image and the purple dots signifying past messages. Within the span of 45 minutes, AIS reports activity messages for this vessel inland near Gainesville, FL, in the Atlantic Ocean, and back in its likely true position along the west coast of Mexico.

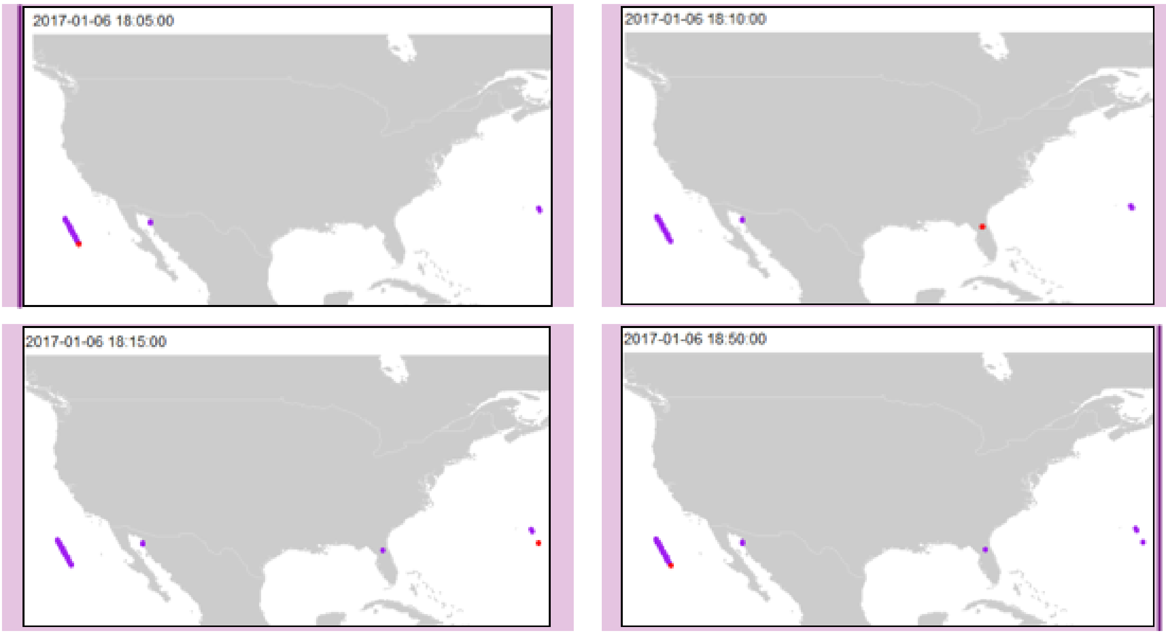

Figure 4 Example of Rogue AIS Messages (Current Activity Message in Red and Past Messages in Purple)

Given that a single vessel reported a non-interpolated message near Gainesville, FL, and given the rogue nature of this message, it is evident that C3 activity is not likely near Gainesville, FL. Similar analysis was done to determine the unlikelihood of C3 activity up the Mississippi River and near Cape Coral, FL.

Thus, the non-interpolated masking raster was altered to account for the findings in this analysis. An R function was developed for this purpose. It reads in the annual, non-interpolated raster described above and converts all raster values to either NA, to represent unlikely C3 activity areas, or 1, to represent likely C3 activity locations. It also reads in a table, (Table 3 provides a small example) which was created for altering the 12km CONUS raster according to the above findings. This function creates a box for each row in the table, using the longitude and latitude minimum and maximum, and assigns all grid cell values within that box the value in the "Assign Grid Values" field. This allows for manual adjustments of likely and unlikely activity areas. The function then outputs a single raster, with only values of 1 or NA, to show likely and unlikely C3 activity areas. All emissions in the daily rasters which were in unlikely grid cells in the masking raster were set to 0.

Table 3 12km CONUS Masking Raster Adjustments

lngMin	lngMax	latMin	latMax	Description	Assign Grid Values
-75.7	-75.1	37.7	38.0	Assateague	NA
-123.0	-122.3	38.5	39.2	Clear Lake	NA

6 Emissions Summary

The emissions data were parsed into daily files so that emissions could be analyzed consecutively. Entities that reported only a single AIS record throughout the year of data were removed, because at minimum two records are needed per ship to calculate activity durations. Consecutive hoteling activity of each ship were aggregated in the dataset to reduce the size. Hoteling records were aggregated to no more than an hour, to ensure that hourly rasterized emissions properly represented hoteling activity. Time and distance were calculated between each consecutive record of each vessel's annual transit and allocated to the record following the activity duration, with time calculated in hours and distance calculated in meters using the haversine method of calculating great-circle distances between two points. Activity intervals exceeding 24 hours were omitted from emissions estimates as this would suggest that the transmitter may have been turned off or the vessel was docked with the engine off.

Each remaining AIS record was assigned a state and county Federal Information Processing Standard (FIPS) code for NEI aggregation purposes. FIPS codes were assigned using three shapefiles: the NEI Port Shapefile, the 2023 TIGER County Shapefile, and the NEI Shipping Lane Shapefiles (Figure 3).[19,22] If an AIS record reported from a location within the NEI Port Shapefile, it would receive the FIPS associated with that port polygon. In addition, records found to be located within port polygons were assigned port Source Classification Codes (SCCs), while all others were assigned underway SCCs. Otherwise, if an AIS message did not report from a port but did report from a location within a TIGER County shapefile, it would receive the FIPS associated with that county shape. Messages that fall within the polygon of a Canadian province or Mexican state, extending into their federal waters, are assigned a six-digit FIPS code for the region starting with a "1" for Canada and "2" for Mexico. Finally, if an AIS message reported from within the shipping lane shapefiles, but not within the TIGER County or port shapefiles (i.e., federal waters), the message is assigned a FIPS of 98001 that indicates that the message falls outside of US, Canadian, or Mexican territorial waters.

Table 4 presents the total estimated emissions from Category 3 marine vessels in the NEI area throughout 2023, Table 5 presents emissions by vessel type and Figure 5 shows the geographic distribution of NOx emissions in U.S. waters. Note that the totals shown in this section do not reflect adjustments that resulted from application of the masking raster described in 5.1.

Table 4 Total 2023 Category 3 emissions in tons for U.S. waters including federal waters (tons)

Region	**CO**	**CO_2**	**NH_3**	**NO_X**	**$PM_{2.5}$**	**PM_{10}**	**SO_2**	**VOC**
Alaska	1,671	1,026,741	6	17,122	294	319	758	760
Hawaii	219	148,222	1	2,263	37	40	90	94
Puerto Rico + Virgin Islands	488	313,632	2	4,411	81	88	198	230
48 states + DC	10,211	6,633,516	32	94,742	1,668	1,813	4,079	4,741
Federal Waters	40,323	18,675,575	166	373,979	8,621	9,370	22,248	19,660
TOTAL	**52,912**	**26,797,686**	**207**	**492,517**	**10,701**	**11,630**	**27,373**	**25,485**

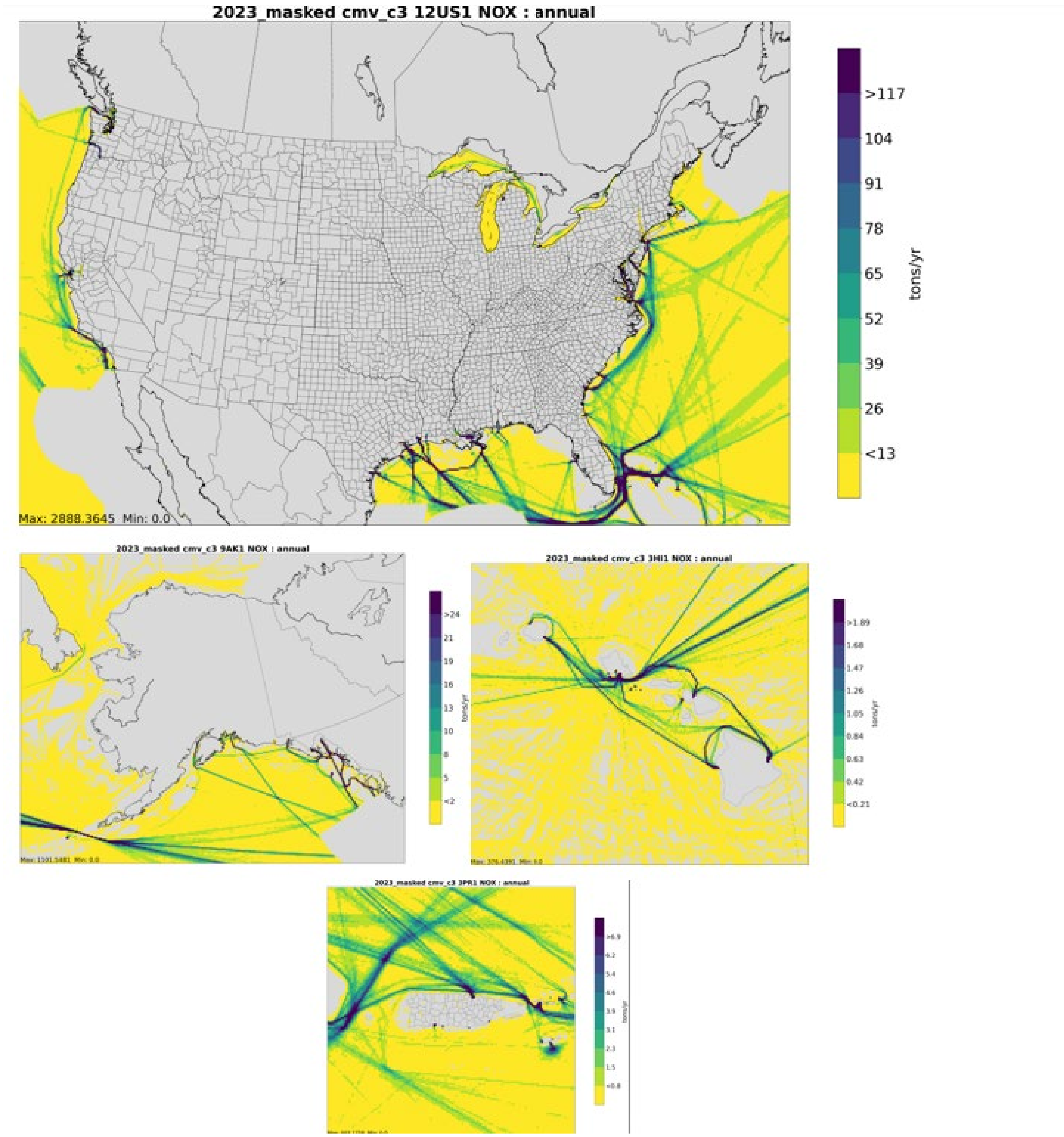

Figure 5 2023 Annual C3 NO_X Emissions

Table 5 Total 2023 Category 3 emissions in tons by ship type in U.S. waters (tons)

Ship Category	CO	CO_2	NH_3	NO_X	PM_{10}	$PM_{2.5}$	SO_2	VOC
Bulk Carrier	6,850	3,436,254	33	70,202		1,838	4,473	3,127
Container Ship	17,992	7,609,054	65	158,177	3,667	3,374	8,379	9,314

Ship Category	CO	CO_2	NH_3	NO_X	PM_{10}	$PM_{2.5}$	SO_2	VOC
Cruise Ship	8,641	5,245,679	31	83,852	1,618	1,618	4,190	3,950
Ferry, Passenger	55	32,051	0	654	14	15	37	26
Fishing	50	20,682	0	420	23	21	50	35
General Cargo	91	53,370	0	955	23	21	52	41
Miscellaneous	587	308,374	3	6,191	144	132	347	282
Offshore	1,195	517,356	4	11,311	227	209	495	621
Refrigerated	258	148,118	2	3,098	100	92	272	113
Ro-Ro	3,399	1,714,819	12	34,853	698	643	1,620	1,571
Tanker	13,356	7,456,423	54	118,123	3,063	2,818	7,296	6,188
Tug	439	255,505	1	4,684	75	69	161	217
TOTAL	**52,913**	**26,797,685**	**205**	**492,520**	**11,629**	**10,702**	**27,372**	**25,485**

Energy consumption in units of Kilowatt-hours (kWhrs) was calculated for each engine type for each vessel by multiplying the activity durations per AIS interval and the assigned power estimation based on AIS reported speed, and Clarksons installed power ratings and service speed. The energy consumption was summed by ship type and by SCC. Figure 4 illustrates the relative energy consumption for each ship type by SCC while Table 6 and Table 7 provides total emissions by port/underway, engine type, and fuel (tons).

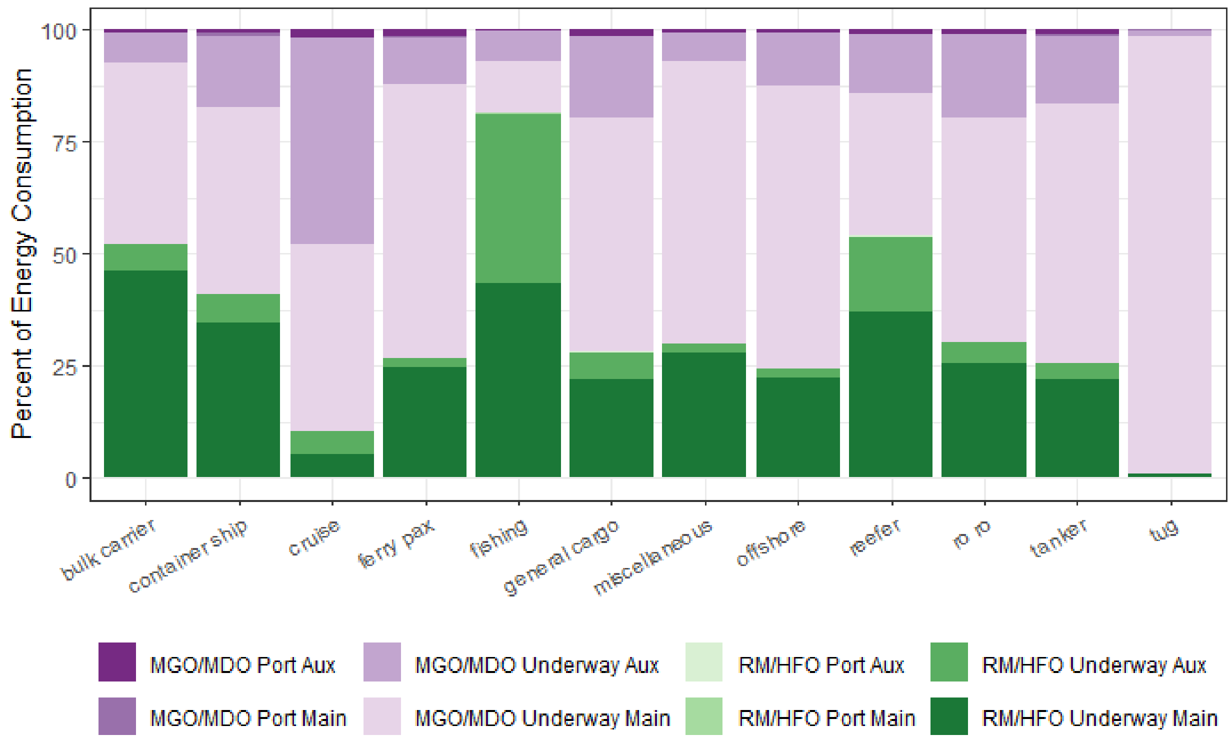

Figure 6 Ship-type energy distribution by SCC

Table 6 2023 Category 3 Emissions by Port, Engine type, and Fuel in U.S. Waters (tons)

Engine	**Fuel**	**CO**	**CO2**	**NH3**	**NOx**	**PM2.5**	**PM10**	**SO2**	**VOC**
Aux	**Diesel**	3,116	2,801,652	12	30,352	645	701	1,708	1,222
Aux	**Residual**	22	19,100	0	240	18	19	60	9
Aux	**Total**	**3,138**	**2,820,752**	**12**	**30,592**	**663**	**720**	**1,768**	**1,231**
Main	**Diesel**	244	68,208	1	1,881	26	28	42	185
Main	**Residual**	1	184	-	6	-	-	1	1
Main	**Total**	**245**	**68,392**	**1**	**1,887**	**26**	**28**	**43**	**186**
	Total	**3,383**	**2,889,144**	**13**	**32,479**	**689**	**748**	**1,811**	**1,417**

Table 7 2023 Category 3 Emissions by Underway, Engine type, and Fuel in U.S. Waters (tons)

Engine	**Fuel**	**CO**	**CO2**	**NH3**	**NOx**	**PM2.5**	**PM10**	**SO2**	**VOC**
Aux	**Diesel**	10,571	7,939,509	37	103,814	1,899	1,899	4,842	4,091
Aux	**Residual**	1,284	915,736	17	13,152	879	956	2,875	495
Aux	**Total**	**11,855**	**8,855,245**	**54**	**116,966**	**2,778**	**2,778**	**7,717**	**4,586**
Main	**Diesel**	29,494	11,584,660	65	255,000	3,398	3,694	7,071	15,597
Main	**Residual**	8,181	3,468,638	74	88,073	3,835	4,169	10,775	3,887
Main	**Total**	**37,675**	**15,053,298**	**139**	**343,073**	**7,233**	**7,863**	**17,846**	**19,484**
	Total	**49,530**	**23,908,543**	**193**	**460,039**	**10,011**	**10,011**	**25,563**	**24,070**

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8 Appendices

A Ship Type and Subtype Assignments

Table A-1 Ship Type Map

Clarkson's Vessel Type	Ship Type
Offshore Launch Barge/Pontoon	Barge
Crane Barge	Barge
Derrick Lay Barge	Barge
Deck Cargo Barge	Barge
Split Hopper Barge	Barge
General Cargo Barge	Barge
Products Tank Barge	Barge
Deck Cargo Pontoon	Barge
Covered Bulk Cargo Barge	Barge
Crane Pontoon	Barge
Maintenance Platform	Barge
Chemical Tank Barge	Barge
Maintenance Pontoon	Barge
Chemical/Products Tank Barge	Barge
Barge (Function Unknown)	Barge
Bulk Aggregates Barge	Barge
Hopper Barge	Barge
Oil Storage Barge	Barge
Bulk Dry Storage Barge	Barge
Water Tank Barge	Barge
Open Bulk Cargo Barge	Barge
Deck Cargo Pontoon, Semi Sub	Barge
Cement Storage Barge	Barge
Bulk Cement Barge	Barge
Drill Barge	Barge
Bitumen Tank Barge	Barge
Trans Shipment Barge	Barge
Vehicle Carrying Barge	Barge
Liquid Mud Barge	Barge
Cement Mixing Barge	Barge
Inland Drilling Barge	Barge
Freight Barge	Barge
Tank Barge	Barge
Public Tankship/Barge	Barge
Barge Carrier, Naval Auxiliary	Barge

Clarkson's Vessel Type	**Ship Type**
Barge Carrier	Barge
Training Barge	Barge
Pontoon (Function Unknown)	Barge
Electricity Generating Pontoon	Barge
Bulk Carrier	Bulk carrier
Cement Carrier	Bulk carrier
Limestone Carrier	Bulk carrier
Ore Carrier	Bulk carrier
Urea Carrier	Bulk carrier
Open Hatch Carrier	Bulk carrier
Chip Carrier	Bulk carrier
Forest Product Carrier	Bulk carrier
Stone Chip Carrier	Bulk carrier
Gypsum Carrier	Bulk carrier
Ore & Sulphuric Acid Carrier	Bulk carrier
Miscellaneous Dry Bulk	Bulk carrier
Slurry Carrier	Bulk carrier
Salt Carrier	Bulk carrier
Replenishment Dry Cargo Vessel	Bulk carrier
Chemical & Oil Carrier	Chemical tanker
Chemical/Products Tanker (Inland)	Chemical tanker
Chemical Tanker (Inland)	Chemical tanker
Chemical & LPG Carrier	Chemical tanker
Fully Cellular Container	Container ship
Container Ship (Inland)	Container ship
Cruise Ship	Cruise
Cruise (Inland)	Cruise
Passenger (Uninspected)	Cruise
Passenger (Inspected)	Cruise
Pass /Car Ferry	Ferry Ro pax
Passenger Catamaran Vessel	Ferry Ro pax
Passenger (Inland)	Ferry Ro pax
Passenger Vessel	Ferry Ro pax
Passenger/Ro-Ro (Inland)	Ferry Ro pax
Passenger/Cargo Vessel	Ferry Ro pax
Ferry	Ferry Ro pax
Passenger Barge (Uninspected)	Ferry Ro pax
Passenger Barge (Inspected)	Ferry Ro pax
Air Cushion Ferry	Ferry Ro pax
Pass /Car Catamaran Vessel	Ferry Ro pax

Clarkson's Vessel Type	Ship Type
Live Fish Carrier (Well Boat)	Fishing
Fishing Vessel	Fishing
Fish Feed Carrier	Fishing
Stern Trawler	Fishing
Fishery Patrol Vessel	Fishing
Trawler	Fishing
Fishery Research Vessel	Fishing
Fishery Support Vessel	Fishing
Commercial Fishing Vessel	Fishing
Fish Processing Vessel	Fishing
Fishing Tender	Fishing
Whale Catcher	Fishing
Fish Factory Ship	Fishing
Seal Catcher	Fishing
Factory Stern Trawler	Fishing
General Cargo	General cargo
General Cargo (Inland)	General cargo
Deck Cargo Carrier	General cargo
Landing Craft	General cargo
Trans Shipment Vessel	General cargo
Ore/Oil Carrier	General cargo
Industrial Vessel	General cargo
Freight Ship	General cargo
Livestock Carrier	General cargo
Aggregate Carrier	General cargo
Palletised Cargo Carrier	General cargo
Log Tipping Ship	General cargo
Miscellaneous Cargo	General cargo
Heavy Lift Cargo Vessel	General cargo
General Cargo/Passenger (Inland)	General cargo
LPG Carrier	Liquified gas tanker
LPG Tank Barge	Liquified gas tanker
Lng Tanker (Inland)	Liquified gas tanker
LPG Carrier (Inland)	Liquified gas tanker
Lng Tank Barge	Liquified gas tanker
Ethylene/LPG	Liquified gas tanker
LNG Carrier	Liquified gas tanker
LNG Bunkering Vessel	Liquified gas tanker
CO2 Carrier	Liquified gas tanker
LNG/Ethylene/LPG	Liquified gas tanker

Clarkson's Vessel Type	**Ship Type**
LNG/Regasification	Liquified gas tanker
Ethane/LPG	Liquified gas tanker
Multi-Purpose	Miscellaneous
Work/Repair Vessel	Miscellaneous
Landing Ship (Dock Type)	Miscellaneous
Submarine Tender	Miscellaneous
Munitions Carrier	Miscellaneous
Attack Vessel, Naval	Miscellaneous
Salvage Vessel	Miscellaneous
Destroyer	Miscellaneous
Patrol Vessel, Naval	Miscellaneous
Electricity Generating Vessel	Miscellaneous
Unknown Function, Naval/Auxiliary	Miscellaneous
Search & Rescue	Miscellaneous
Frigate	Miscellaneous
Corvette	Miscellaneous
Minehunter	Miscellaneous
Training Ship, Naval Auxiliary	Miscellaneous
Torpedo Boat	Miscellaneous
Floating Crane	Miscellaneous
Minelayer	Miscellaneous
Weapons Trials Vessel	Miscellaneous
Training Ship	Miscellaneous
Torpedo Recovery Vessel	Miscellaneous
Anti-Pollution Vessel	Miscellaneous
Other Activities (Inland)	Miscellaneous
Icebreaker	Miscellaneous
Crane Vessel, Naval Auxiliary	Miscellaneous
Permanent Shore Facility	Miscellaneous
Oilfield Pollution Control	Miscellaneous
ERRV	Miscellaneous
Unclassified	Miscellaneous
UNSPECIFIED	Miscellaneous
Unknown	Miscellaneous
Public Vessel, Unclassified	Miscellaneous
School Ship	Miscellaneous
Public Freight	Miscellaneous
Motor Lifeboat	Miscellaneous
Aids to Navigation Boat	Miscellaneous
Cutter	Miscellaneous

Clarkson's Vessel Type	Ship Type
Motor Surf Boat	Miscellaneous
Transportable Port Security Boat	Miscellaneous
Response Boat-Medium	Miscellaneous
Special Purpose Craft - Heavy Weather	Miscellaneous
Special Purpose Craft - Near Shore Lifeboat	Miscellaneous
Special Purpose Craft - Screening Vessel	Miscellaneous
Utility Boat - Big	Miscellaneous
Patrol Boat - Island Class	Miscellaneous
Medium Endurance Cutter	Miscellaneous
High Endurance Cutter	Miscellaneous
Coastal Patrol Boat - Marine Protector Class	Miscellaneous
Inland Construction Tenders	Miscellaneous
National Security Cutter	Miscellaneous
Icebreaking Tug - Bay Class	Miscellaneous
Unique	Miscellaneous
Fast Response Cutter - Sentinel Class	Miscellaneous
Defender Class Boat	Miscellaneous
Tank Landing Craft	Miscellaneous
Standby Safety/Guard	Miscellaneous
Troopship	Miscellaneous
Repair Vessel, Naval Auxiliary	Miscellaneous
Pearl Shells Carrier	Miscellaneous
Mining Vessel	Miscellaneous
Diving Vessel, Naval Auxiliary	Miscellaneous
Naval Small Craft	Miscellaneous
Hospital Vessel, Naval Auxiliary	Miscellaneous
Car Park	Miscellaneous
Submarine Salvage Vessel	Miscellaneous
Minesweeper	Miscellaneous
Cruiser	Miscellaneous
Torpedo Trials Vessel	Miscellaneous
Multi-Purpose/Heavy Lift Cargo	Miscellaneous
Salvage Vessel, Naval Auxiliary	Miscellaneous
Infantry Landing Craft	Miscellaneous
Mooring	Miscellaneous
Shopping Complex	Miscellaneous
Pollution Control Vessel	Miscellaneous
Amphibious Assault Ship LHA	Miscellaneous
Command Vessel	Miscellaneous
Helicopter Carrier	Miscellaneous

Clarkson's Vessel Type	**Ship Type**
Heavy Load Carrier	Miscellaneous
Icebreaker AGB	Miscellaneous
Research Vessel	Miscellaneous
Research Vessel, Naval Auxiliary	Miscellaneous
Marine Research	Miscellaneous
Research (Inland)	Miscellaneous
Pipe Laying Barge	Offshore
Cutter Suction/Bucket Wheel Dredger	Offshore
Backhoe/Dipper/Grab Dredger	Offshore
Barge Unloading Dredger	Offshore
Crew Boat	Offshore
Seismic Support	Offshore
Utility/Workboat	Offshore
Derrick/Lay Vessel	Offshore
Bucket Ladder Dredger	Offshore
Special Equipment Dredger	Offshore
Suction Dredger	Offshore
Hydrographic Survey	Offshore
Cable, Umbilicals & FP/Flowline Lay	Offshore
Cable Layer (Fibre Optic)	Offshore
Dredger (Unspecified)	Offshore
Other Dredger	Offshore
Crew Tender	Offshore
Crew/Fast Supply Vessel	Offshore
Suction Hopper Dredger	Offshore
Dredging Pontoon	Offshore
Windfarm Crew/Supply Tender	Offshore
Oceanographic Survey	Offshore
Dredging (Inland)	Offshore
Transport (Heavy Lift)	Offshore
Supply Tender	Offshore
Trailing Suction Hopper Dredger	Offshore
Grab Dredger Pontoon	Offshore
Tension Leg Platform	Offshore
SPAR	Offshore
Dredgers (Stone Dumping, Fallpipe)	Offshore
Platform Supply	Offshore
Geophysical Survey	Offshore
Oil Recovery	Offshore
Offshore Supply Vessel	Offshore

Clarkson's Vessel Type	**Ship Type**
Arctic Survey Boat	Offshore
Inland Buoy Tender	Offshore
Seagoing Buoy Tender	Offshore
Coastal Buoy Tender - Keeper Class	Offshore
River Buoy Tenders	Offshore
Seagoing Buoy Tender/ Icebreaker	Offshore
River Buoy Tender	Offshore
Buoy/Lighthouse Tender	Offshore
Diving Support	Offshore
Seismic Survey	Offshore
Multi-Functional Support	Offshore
Maintenance	Offshore
Miscellaneous Offshore Service	Offshore
Offshore Crew Tender	Offshore
Rov/Submersible Support	Offshore
Pipe Layer	Offshore
Cable Layer, Naval Auxiliary	Offshore
Crew Boat, Naval Auxiliary	Offshore
Gravel/Stone Discharge	Offshore
Steam Supply Pontoon	Offshore
Accommodation Barge	Offshore
FPSO	Offshore
Product Carrier	Offshore
Well Stimulation	Offshore
Accommodation Unit - Self Elevating	Offshore
Mini Tension Leg Platform	Offshore
Jack-up Production Unit	Offshore
Semi-Submersible Production Unit	Offshore
Floating Production Unit	Offshore
Heavy Lift/Crane Ship	Offshore
FSO	Offshore
Self Elevating Install Vessel	Offshore
Buoyant Tower	Offshore
Jack-up Drilling Rig	Offshore
Semi-Submersible Heavy Lift	Offshore
Supply	Offshore
Mobile Offshore Drilling Unit	Offshore
Drillship	Offshore
Accommodation Vessel	Offshore
Anchor Handling Tug/Supply	Offshore

Clarkson’s Vessel Type	Ship Type
Anchor Handling Tug	Offshore
FSU	Offshore
FSRU	Offshore
LNG/FPSO	Offshore
Semi-Submersible Drilling Rig	Offshore
LNG/FSU	Offshore
Drilling Tender	Offshore
LPG/FSO	Offshore
Accommodation Unit - Semi Sub	Offshore
FPDSO	Offshore
Cylindrical Floating Drill Unit	Offshore
Extended Well Test Vessel	Offshore
LPG/FPSO	Offshore
Cylindrical Floating Prod Unit	Offshore
Cylindrical Floating Accom Unit	Offshore
Oil Tanker (Inland)	Oil tanker
Crude Oil Tank Barge	Oil tanker
Slop Reception Vessel	Oil tanker
Bulk/Oil Carrier	Oil tanker
Oil & Liquid Gas Carrier	Oil tanker
Shuttle Tanker	Oil tanker
Oil Recovery Tanker	Oil tanker
Replenishment Tanker	Other tanker
Self Elevating Install Barge	Other Tanker
Asphalt & Bitumen Carrier	Other tanker
Bunkering Vessel	Other tanker
Tug, Anchor Hoy	Other tanker
Waste Disposal Carrier	Other tanker
Water Carrier	Other tanker
Edible Oil Carrier	Other tanker
Tank Ship	Other tanker
Tanker	Other tanker
Wine Carrier	Other tanker
Water Tanker (Inland)	Other tanker
Water Tanker, Naval Auxiliary	Other tanker
Methanol Carrier	Other tanker
Sulphuric Acid Carrier	Other tanker
Molten Sulphur Carrier	Other tanker
Fruit Juice Carrier	Other tanker
Phosphoric Acid Carrier	Other tanker

Clarkson's Vessel Type	Ship Type
Product Carrier/Ro-Ro	Other tanker
Products/Multi-Purpose Cargo	Other tanker
Reefer Fish Carrier	Reefer
Reefer	Reefer
Reefer/General Cargo	Reefer
Reefer/Pallets Carrier	Reefer
Reefer/Ro-Ro Cargo	Reefer
Reefer/Pass /Ro-Ro	Reefer
Ro-Ro Cargo (Inland)	RoRo
Pure Car Carrier	RoRo
Ro-Ro Freight/Passenger	RoRo
Logistics Vessel (Naval RoRo Cargo)	RoRo
Ro-Ro	RoRo
Ro-Ro/Lo-Lo	RoRo
Ro-Ro/Container	RoRo
Tug, Naval Auxiliary	Tug
Tug	Tug
Fire-fighting Tug	Tug
Towing/Pushing (Inland)	Tug
Towing Vessel	Tug
Small Harbor Tug	Tug
Ocean-going Salvage Tug	Tug
Ocean-going Tug	Tug
Motor Yacht	Yacht
Yacht (Sailing)	Yacht
Recreational	Yacht

Table A-2 Ship Subtype Map

ShipType	SizeUnits	SizeMin	SizeMax	SubType
Bulk Carrier	Deadweight	0	10,000	Bulk carrier small
		10,000	35,000	Bulk carrier handy size
		35,000	60,000	Bulk carrier handy max
		60,000	1 00E+05	Bulk carrier pana max
		100,000	2 00E+05	Bulk carrier cape size
		200,000	Inf	Bulk carrier cape size largest
Chemical Tanker	Deadweight	0	5,000	Chemical tanker smallest
		5,000	10,000	Chemical tanker small
		10,000	20,000	Chemical tanker handy size
		20,000	Inf	Chemical tanker handy max

ShipType	SizeUnits	SizeMin	SizeMax	SubType
Container Ship	TEU	0	1,000	Container ship 1000
		1,000	2,000	Container ship 2000
		2,000	3,000	Container ship 3000
		3,000	5,000	Container ship 5000
		5,000	8,000	Container ship 8000
		8,000	12,000	Container ship 12000
		12,000	14,500	Container ship 14500
		14,500	Inf	Container ship largest
General Cargo	Deadweight	0	5,000	General cargo 5000
		5,000	10,000	General cargo 10000
		10,000	Inf	General cargo largest
Liquified Gas Tanker	Deadweight	0	5,000	Liquified gas tanker 5000
		5,000	10,000	Liquified gas tanker 10000
		10,000	20,000	Liquified gas tanker 20000
		20,000	Inf	Liquified gas tanker largest
Oil Tanker	Deadweight	0	5,000	Oil tanker smallest
		5,000	10,000	Oil tanker small
		10,000	20,000	Oil tanker handy size
		20,000	60,000	Oil tanker handy max
		60,000	80,000	Oil tanker pana max
		80,000	120,000	Oil tanker afra max
		120,000	2 00E+05	Oil tanker suez max
		200,000	Inf	Oil tanker vlcc
Other Tanker	Deadweight	0	Inf	Other tanker
Ferry Pax	Gross Tonnage	0	2,000	Ferry pax 2000
		2,000	Inf	Ferry pax largest
Cruise	Gross Tonnage	0	2,000	Cruise 2000
		2,000	10,000	Cruise 10000
		10,000	60,000	Cruise 60000
		60,000	1 00E+05	Cruise 100000
		100,000	Inf	Cruise largest
Ferry Ro Pax	Gross Tonnage	0	2,000	Ferry Ro pax 2000
		2,000	Inf	Ferry Ro pax largest
Reefer	Deadweight	0	Inf	Reefer
Ro Ro	Gross Tonnage	0	5,000	RoRo 5000
		5,000	Inf	RoRo largest
Vehicle Carrier	Deadweight	0	10,000	Vehicle carrier 10000

ShipType	SizeUnits	SizeMin	SizeMax	SubType
		10,000	20,000	Vehicle carrier 20000
		20,000	30,000	Vehicle carrier 30000
		30,000	Inf	Vehicle carrier largest
Yacht	Gross Tonnage	0	Inf	Yacht
Service Tug	Gross Tonnage	0	Inf	Tug
Miscellaneous Fishing	Gross Tonnage	0	Inf	Fishing
Offshore	Gross Tonnage	0	Inf	Offshore
Service Other	Gross Tonnage	0	Inf	Service other
Miscellaneous Other	Gross Tonnage	0	Inf	Miscellaneous

B Vessel Parameter Gap Filling Methods

B.1 Example methods used for of the gap-filling

The figures below illustrate the different approaches used to gap-fill ship characteristics data. As described in Section 3.5.

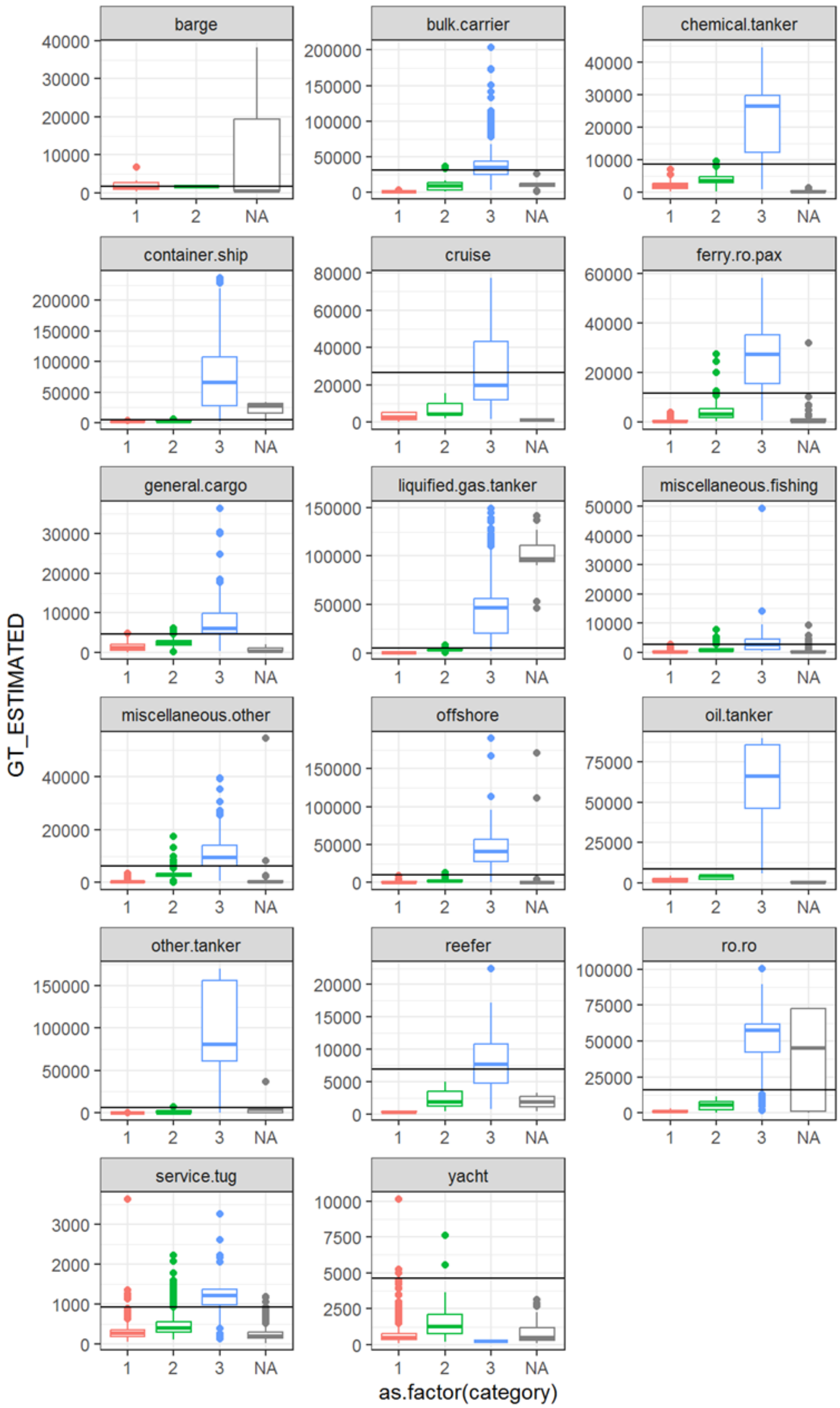

Figure B-1 Engine Category Assignment

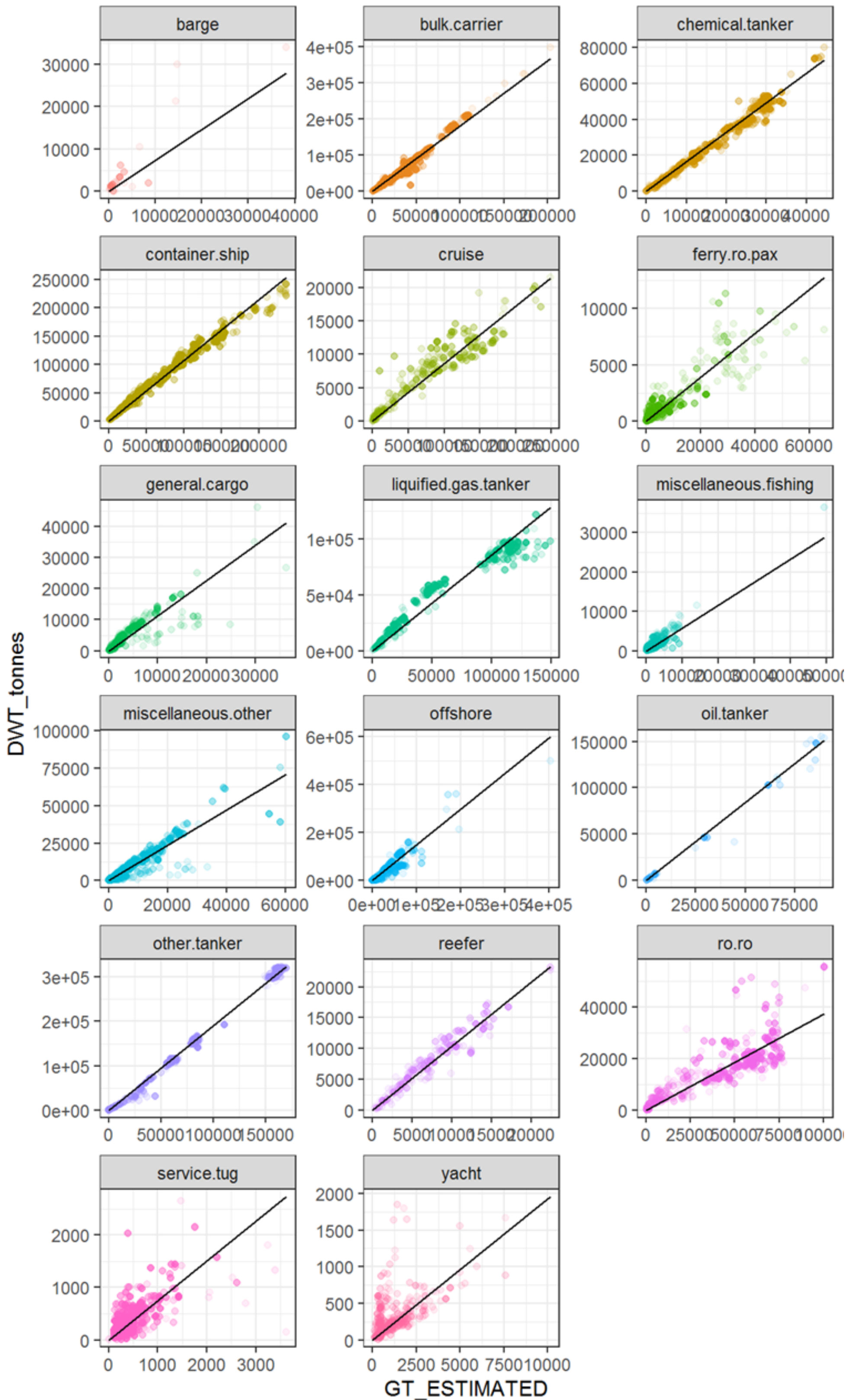

Figure B-2 Deadweight Tonnage - Linear regression from Gross Tonnage

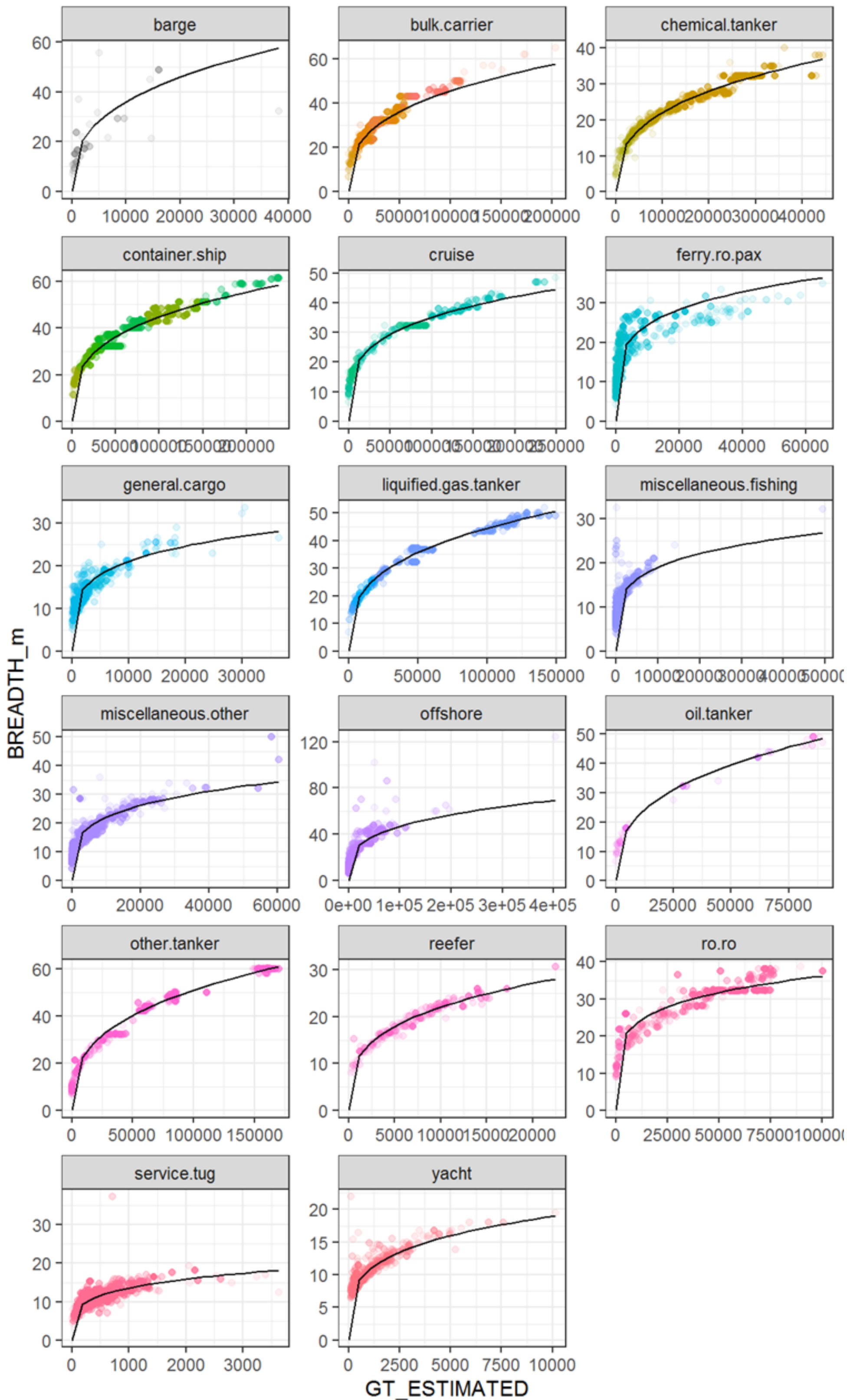

Figure B-3 Ship Breadth – n-th root regression from Gross Tonnage

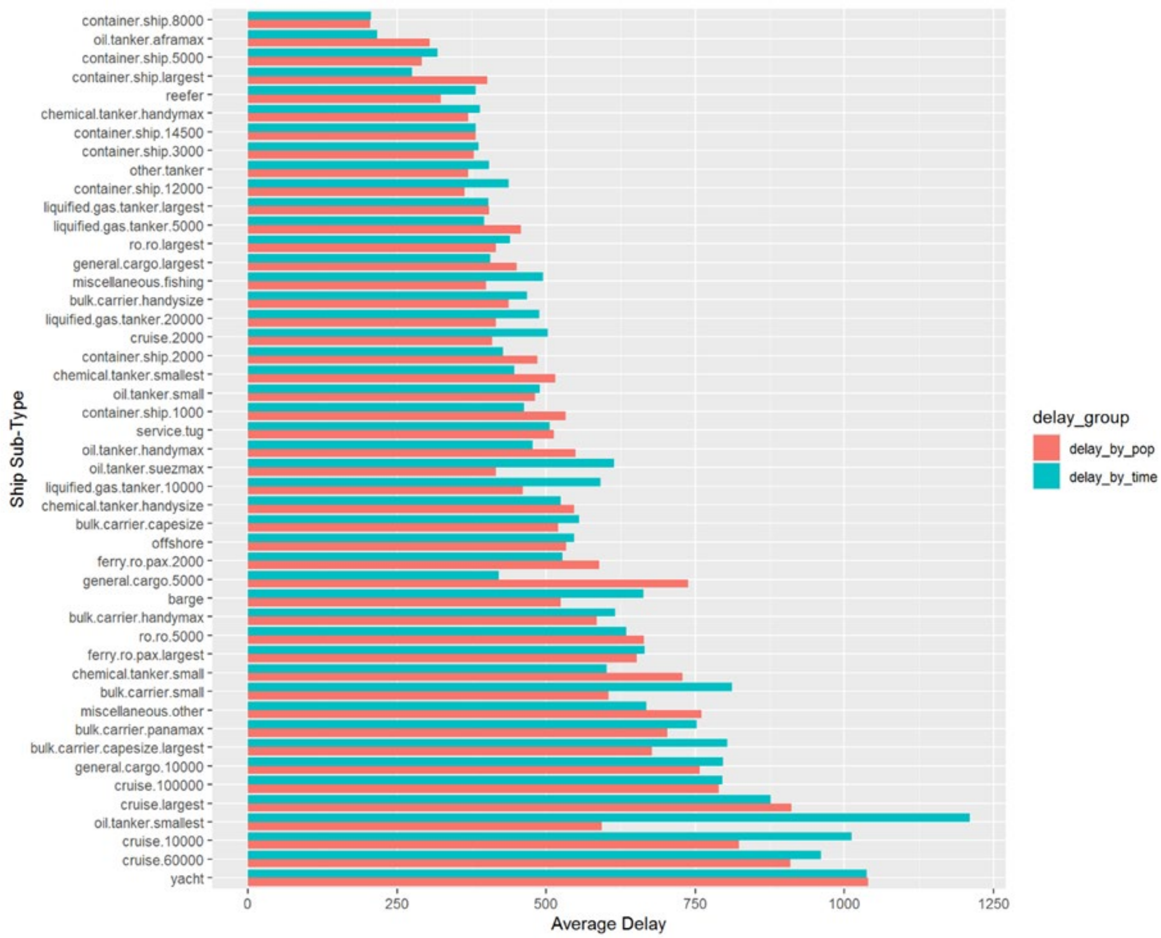

Figure B-3 Average time between Keel-Laid-Date to Build Date (weighted by time of by population)

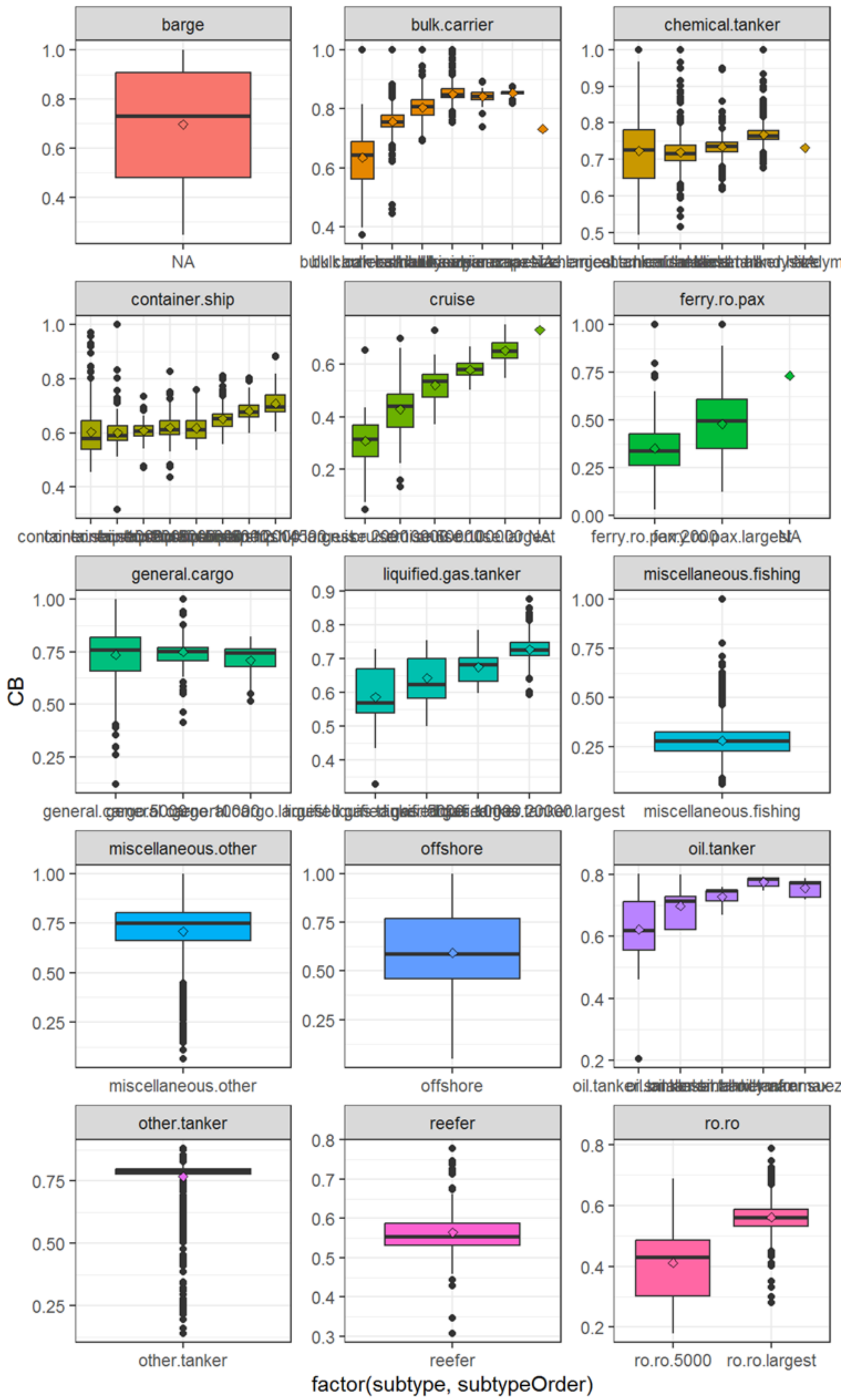

Figure B-4 Block Coefficient – Median value by ship subtype

B.2 Parameters used for gap-filling

The following tables contain the values used to fill each of the different ship parameters

B.2.1 Engine category

Engines above the indicated gross-tonnage threshold are assumed to be C3 vessels

Table B-1 Engine category minimum size by gross tonnage

ShipType	GT(tonnes)
offshore	9700.375
bulk.carrier	30414.5
other.tanker	6574.25
chemical.tanker	8470.5
miscellaneous.other	6163.5
container.ship	5340.75
cruise	26476.88
general.cargo	4662.5
liquified.gas.tanker	4867.25
miscellaneous.fishing	2664.5
service.tug	916
barge	1616
yacht	4642
oil.tanker	8392.25
ferry.ro.pax	11574
ro.ro	16123.75
reefer	6989.5

B.2.2 Deadweight tonnage

Table B-2 Deadweight tonnage from a linear regression of gross tonnage

ShipType	Slope	R^2
offshore	1.487	0.93
bulk.carrier	1.812	0.99
miscellaneous.other	1.181	0.92
other.tanker	1.901	1
barge	0.729	0.68
chemical.tanker	1.649	1
container.ship	1.072	0.99
cruise	0.086	0.95
general.cargo	1.131	0.91
liquified.gas.tanker	0.863	0.97
miscellaneous.fishing	0.584	0.84

ShipType	Slope	R^2
service.tug	0.755	0.81
oil.tanker	1.683	1
ro.ro	0.372	0.91
yacht	0.193	0.61
ferry.ro.pax	0.196	0.79
reefer	1.038	0.99

B.2.3 TEU

Table B-3 containership TEU count from a linear regression of gross tonnage

Ship Type	slope	R^2
container.ship	0.094	0.995

Lightweight tonnage

Table B-4 Lightweight tonnage from a linear regression of gross tonnage

ShipType	Slope	R^2
offshore	0.323	0.99
other.tanker	0.293	0.99
bulk.carrier	0.31	0.96
chemical.tanker	0.373	0.98
barge	0.543	1
cruise	0.42	0.99
liquified.gas.tanker	0.335	0.98
miscellaneous.fishing	0.163	1
container.ship	0.342	0.99
general.cargo	0.45	0.98
miscellaneous.other	0.549	0.99
ro.ro	0.29	0.99
oil.tanker	0.303	1
ferry.ro.pax	0.473	0.97
reefer	0.557	0.98

B.2.4 Block coefficient

Table B-5 Median block coefficient by ship type and subtype

Ship Type	Sub-type	Median Block Coefficient
bulk.carrier	bulk.carrier.small	0.644022
bulk.carrier	bulk.carrier.handysize	0.755376
bulk.carrier	bulk.carrier.handymax	0.809044
bulk.carrier	bulk.carrier.panamax	0.846941

Ship Type	Sub-type	Median Block Coefficient
bulk.carrier	bulk.carrier.capesize	0.842723
bulk.carrier	bulk.carrier.capesize.largest	0.855906
chemical.tanker	chemical.tanker.smallest	0.725739
chemical.tanker	chemical.tanker.small	0.716797
chemical.tanker	chemical.tanker.handysize	0.736111
chemical.tanker	chemical.tanker.handymax	0.765131
container.ship	container.ship.1000	0.57946
container.ship	container.ship.2000	0.591076
container.ship	container.ship.3000	0.605928
container.ship	container.ship.5000	0.612743
container.ship	container.ship.8000	0.612299
container.ship	container.ship.12000	0.653419
container.ship	container.ship.14500	0.676149
container.ship	container.ship.largest	0.695361
cruise	cruise.2000	0.3144
cruise	cruise.10000	0.440018
cruise	cruise.60000	0.536029
cruise	cruise.100000	0.580669
cruise	cruise.largest	0.649528
ferry.ro.pax	ferry.ro.pax.2000	0.339187
ferry.ro.pax	ferry.ro.pax.largest	0.498324
general.cargo	general.cargo.5000	0.759149
general.cargo	general.cargo.10000	0.753563
general.cargo	general.cargo.largest	0.744603
liquified.gas.tanker	liquified.gas.tanker.5000	0.569931
liquified.gas.tanker	liquified.gas.tanker.10000	0.623884
liquified.gas.tanker	liquified.gas.tanker.20000	0.682139
liquified.gas.tanker	liquified.gas.tanker.largest	0.727486
miscellaneous.fishing	miscellaneous.fishing	0.278418
miscellaneous.other	miscellaneous.other	0.75174
offshore	offshore	0.589267
oil.tanker	oil.tanker.smallest	0.619422
oil.tanker	oil.tanker.small	0.71446
oil.tanker	oil.tanker.handymax	0.746874
oil.tanker	oil.tanker.aframax	0.786303
oil.tanker	oil.tanker.suezmax	0.773309
other.tanker	other.tanker	0.789726
reefer	reefer	0.554194
ro.ro	ro.ro.5000	0.43124
ro.ro	ro.ro.largest	0.560244

B.2.5 Length-between-perpendiculars

Table B-6 Length-between-perpendiculars (m) linear regressions from length overall

ShipType	Slope	R^2
barge	0.964	1
bulk.carrier	0.973	1
chemical.tanker	0.954	1
container.ship	0.954	1
cruise	0.893	1
ferry.ro.pax	0.93	1
general.cargo	0.935	1
liquified.gas.tanker	0.967	1
miscellaneous.fishing	0.902	1
miscellaneous.other	0.941	1
offshore	0.945	1
oil.tanker	0.957	1
other.tanker	0.966	1
reefer	0.925	1
ro.ro	0.949	1
service.tug	0.948	1
yacht	0.871	1

Table B-7 Length-between-perpendiculars (m) nth root regression from gross tonnage

ShipType	Slope	R^2
barge	0.964	1
bulk.carrier	0.973	1
chemical.tanker	0.954	1
container.ship	0.954	1
cruise	0.893	1
ferry.ro.pax	0.93	1
general.cargo	0.935	1
liquified.gas.tanker	0.967	1
miscellaneous.fishing	0.902	1
miscellaneous.other	0.941	1
offshore	0.945	1
oil.tanker	0.957	1
other.tanker	0.966	1
reefer	0.925	1
ro.ro	0.949	1
service.tug	0.948	1

ShipType	Slope	R^2
yacht	0.871	1

B.2.6 Summer-load-line draft

Table B-8 Summer-load-line draft (m) nth root regression from gross tonnage

ShipType	a	n	R^2
barge	0.23	2.706	0.872
bulk.carrier	0.227	2.602	0.896
chemical.tanker	0.368	2.899	0.936
container.ship	1.152	4.53	0.905
cruise	0.679	4.64	0.95
ferry.ro.pax	0.502	3.986	0.643
general.cargo	0.402	3.058	0.829
liquified.gas.tanker	2.368	6.876	0.751
miscellaneous.fishing	0.886	4.197	0.73
miscellaneous.other	0.671	3.688	0.892
offshore	0.427	3.129	0.931
oil.tanker	0.475	3.19	0.992
other.tanker	0.338	2.887	0.977
reefer	0.72	3.696	0.838
ro.ro	0.465	3.588	0.888
service.tug	0.683	3.305	0.471
yacht	0.532	3.914	0.566

B.2.7 Breadth

Table B-9 Ship Breadth (m) nth root regression from gross tonnage

ShipType	a	n	R^2
barge	1.442	2.863	0.809
bulk.carrier	1.017	3.027	0.873
chemical.tanker	0.923	2.902	0.977
container.ship	1.318	3.266	0.954
cruise	1.776	3.857	0.983
ferry.ro.pax	3.528	4.752	0.75
general.cargo	2.639	4.433	0.868
liquified.gas.tanker	1.127	3.132	0.979
miscellaneous.fishing	2.604	4.632	0.742
miscellaneous.other	2.28	4.053	0.797
offshore	1.875	3.573	0.93
oil.tanker	0.884	2.847	0.996
other.tanker	1.054	2.97	0.988

ShipType	a	n	R^2
reefer	1.417	3.355	0.936
ro.ro	4.123	5.302	0.869
service.tug	2.835	4.416	0.643
yacht	1.97	4.068	0.842

B.2.8 Propulsive power

Table B-10 Propulsive power (kW) median value by ship type and subype

Ship Type	**Sub–type**	**Median Power (kW)**
bulk.carrier	bulk.carrier.small	1930.5
bulk.carrier	bulk.carrier.handysize	6480
bulk.carrier	bulk.carrier.handymax	8200
bulk.carrier	bulk.carrier.panamax	9659
bulk.carrier	bulk.carrier.capesize	16860
bulk.carrier	bulk.carrier.capesize.largest	16810
chemical.tanker	chemical.tanker.smallest	1850
chemical.tanker	chemical.tanker.small	3063
chemical.tanker	chemical.tanker.handysize	5180
chemical.tanker	chemical.tanker.handymax	8186
container.ship	container.ship.1000	7950
container.ship	container.ship.2000	11800
container.ship	container.ship.3000	21560
container.ship	container.ship.5000	36560
container.ship	container.ship.8000	57100
container.ship	container.ship.12000	58100
container.ship	container.ship.14500	58000
container.ship	container.ship.largest	59300
cruise	cruise.2000	1110
cruise	cruise.60000	11977.5
cruise	cruise.10000	3282
cruise	cruise.100000	46124
ferry.ro.pax	ferry.ro.pax.2000	1609
ferry.ro.pax	ferry.ro.pax.largest	9728
general.cargo	general.cargo.5000	1109
general.cargo	general.cargo.10000	2799
general.cargo	general.cargo.largest	5180
liquified.gas.tanker	liquified.gas.tanker.5000	2662
liquified.gas.tanker	liquified.gas.tanker.10000	4550
liquified.gas.tanker	liquified.gas.tanker.20000	7170
liquified.gas.tanker	liquified.gas.tanker.largest	13668

Ship Type	Sub–type	Median Power (kW)
miscellaneous.fishing	miscellaneous.fishing	736
miscellaneous.other	miscellaneous.other	3784
offshore	offshore	4854
oil.tanker	oil.tanker.smallest	1119.5
oil.tanker	oil.tanker.small	2610
oil.tanker	oil.tanker.handymax	8570.5
oil.tanker	oil.tanker.aframax	16660
oil.tanker	oil.tanker.suezmax	19620
other.tanker	other.tanker	16525
reefer	reefer	6256
ro.ro	ro.ro.5000	2354
ro.ro	ro.ro.largest	14280
service.tug	service.tug	2238
yacht	yacht	2700

B.2.9 Service speed

Table B-11 Median service speed (knots) by ship type and subtype

Ship Type	Sub-type	Median Speed (kn)
bulk.carrier	bulk.carrier.small	11.5
bulk.carrier	bulk.carrier.handysize	14
bulk.carrier	bulk.carrier.handymax	14
bulk.carrier	bulk.carrier.panamax	14.3
bulk.carrier	bulk.carrier.capesize	14.6
bulk.carrier	bulk.carrier.capesize.largest	14.7
chemical.tanker	chemical.tanker.smallest	12
chemical.tanker	chemical.tanker.small	13.5
chemical.tanker	chemical.tanker.handysize	14
chemical.tanker	chemical.tanker.handymax	14.5
container.ship	container.ship.1000	17.5
container.ship	container.ship.2000	19.5
container.ship	container.ship.3000	21.8
container.ship	container.ship.5000	23.8
container.ship	container.ship.8000	25
container.ship	container.ship.12000	24.5
container.ship	container.ship.14500	24
container.ship	container.ship.largest	22.25
cruise	cruise.2000	12
cruise	cruise.10000	15.5
cruise	cruise.60000	19

Ship Type	Sub-type	Median Speed (kn)
cruise	cruise.100000	22
cruise	cruise.largest	22
ferry.ro.pax	ferry.ro.pax.2000	20
ferry.ro.pax	ferry.ro.pax.largest	18
general.cargo	general.cargo.5000	11
general.cargo	general.cargo.10000	12.5
general.cargo	general.cargo.largest	15
liquified.gas.tanker	liquified.gas.tanker.5000	13.6
liquified.gas.tanker	liquified.gas.tanker.10000	15
liquified.gas.tanker	liquified.gas.tanker.20000	16
liquified.gas.tanker	liquified.gas.tanker.largest	17
miscellaneous.fishing	miscellaneous.fishing	12.1
miscellaneous.other	miscellaneous.other	14
offshore	offshore	14
oil.tanker	oil.tanker.smallest	11
oil.tanker	oil.tanker.small	11.9
oil.tanker	oil.tanker.handymax	14.6
oil.tanker	oil.tanker.aframax	14.7
oil.tanker	oil.tanker.suezmax	14.5
other.tanker	other.tanker	15
reefer	reefer	18
ro.ro	ro.ro.5000	13.5
ro.ro	ro.ro.largest	20
service.tug	service.tug	12
yacht	yacht	16

B.2.10 Keel-laid date to Build date delay

Table B12 Keel-laid date to build date delay

Ship Type	Average Delays (days)
offshore	547
bulk.carrier	642
miscellaneous.other	668
other.tanker	404
chemical.tanker	420
barge	661
cruise	881
general.cargo	582
liquified.gas.tanker	422
miscellaneous.fishing	495

Ship Type	Average Delays (days)
service.tug	505
container.ship	369
ro.ro	452
yacht	1037
oil.tanker	535
ferry.ro.pax	615
reefer	381

C Emissions By SCC

C.1 CMV SCC definitions

CMV SCC Decoder

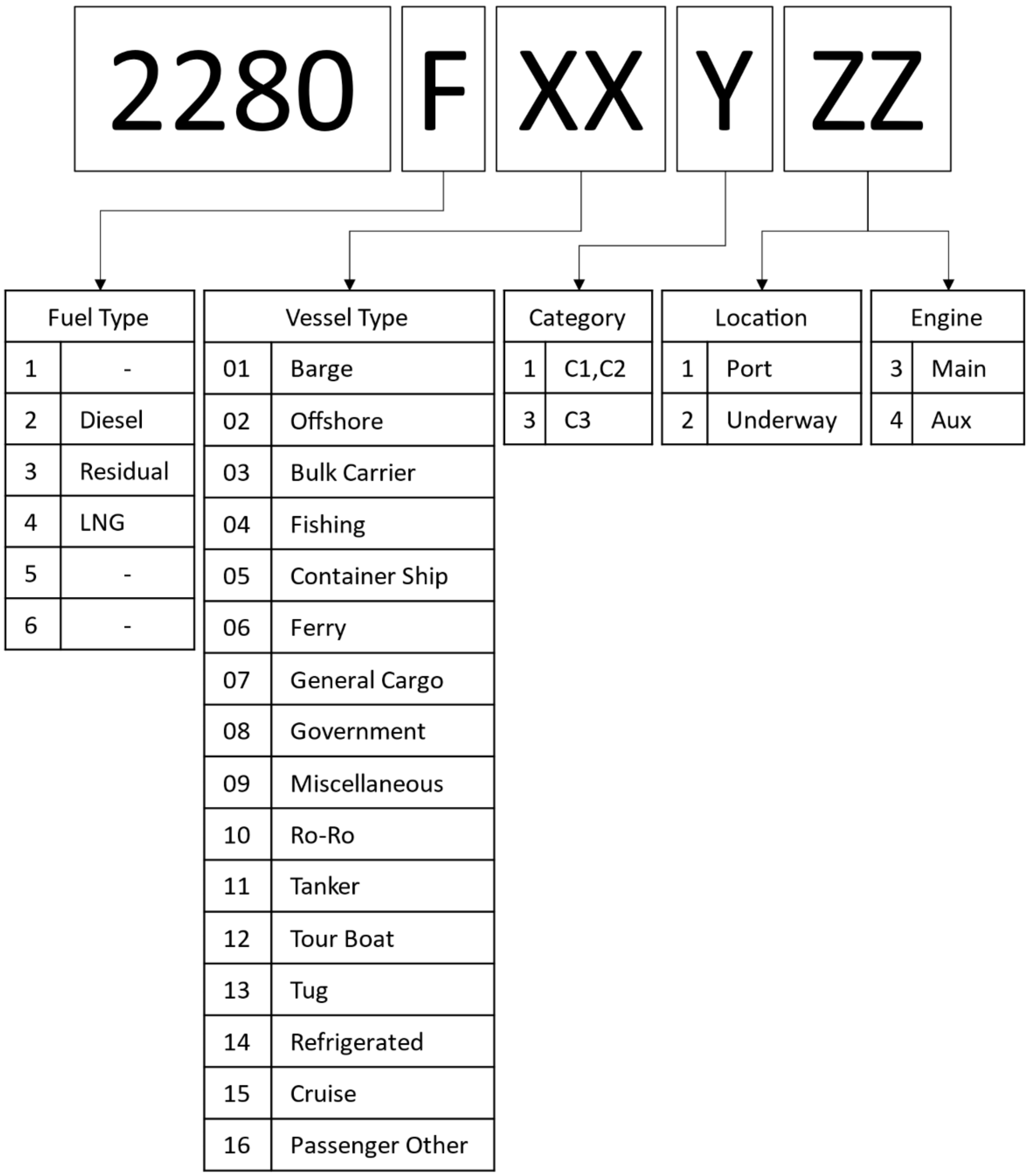

Figure C-1 CMV SCC decoder

C.2 Emissions Table

Table C-1 2023 C3 emissions by SCC in U.S. Waters (tons)

SCC	Fuel	Ship Type	Port/Underway	Engine	CO	CO_2	NH_3	NO_x	PM 2.5	PM 10	SO_2	VOC
2280202313	Diesel	Offshore	Port	Main	3	431	0	14	0	0	0	3
2280202314	Diesel	Offshore	Port	Aux	47	29486	0	493	7	8	18	18
2280202323	Diesel	Offshore	Underway	Main	728	255685	2	6414	82	89	157	424
2280202324	Diesel	Offshore	Underway	Aux	254	161621160942	1	26332623	40	44	99	98
2280203313	Diesel	Bulk Carrier	Port	Main	14	4347	0	116	2	2	3	9
2280203314	Diesel	Bulk Carrier	Port	Aux	352	295754	1	3448	69	75	180	137
2280203323	Diesel	Bulk Carrier	Underway	Main	3504	1456206	8	34907	420	456	888	1683
2280203324	Diesel	Bulk Carrier	Underway	Aux	876	740225	3	8601	173	188	451	342
2280204313	Diesel	Fishing	Port	Main	0	3	0	0	0	0	0	0
2280204314	Diesel	Fishing	Port	Aux	1	588	0	8	0	0	0	0
2280204323	Diesel	Fishing	Underway	Main	7	2555	0	49	1	1	2	6
2280204324	Diesel	Fishing	Underway	Aux	5	2953	0	53	1	1	2	2
2280205313	Diesel	Container Ship	Port	Main	176	51398	0	1437	19	20	31	125
2280205314	Diesel	Container Ship	Port	Aux	652	634898	3	6364	144	156	387	257
2280205323	Diesel	Container Ship	Underway	Main	11245	3546393	22	89438	1135	1234	2167	6358
2280205324	Diesel	Container Ship	Underway	Aux	2468	1898218	9	24900	452	491	1158	957
2280206313	Diesel	Ferry	Port	Main	0	84	0	2	0	0	0	0
2280206314	Diesel	Ferry	Port	Aux	7	4223	0	84	1	1	3	3
2280206323	Diesel	Ferry	Underway	Main	28	15911	0	326	4	5	10	14
2280206324	Diesel	Ferry	Underway	Aux	8	4806	0	95	1	1	3	3
2280207313	Diesel	General Cargo	Port	Main	0	51	0	1	0	0	0	0
2280207314	Diesel	General Cargo	Port	Aux	8	6044	0	85	1	2	4	3
2280207323	Diesel	General Cargo	Underway	Main	44	20710	0	450	6	6	13	22
2280207324	Diesel	General Cargo	Underway	Aux	24	18844	0	252	4	5	11	9
2280209313	Diesel	Miscellaneous	Port	Main	2	619	0	15	0	0	0	2

SCC	Fuel	Ship Type	Port/Underway	Engine	CO	CO_2	NH_3	NO_x	PM 2.5	PM 10	SO_2	VOC
2280209314	Diesel	Miscellaneous	Port	Aux	31	19608	0	336	5	5	12	12
2280209323	Diesel	Miscellaneous	Underway	Main	374	187839	1	3806	52	56	115	189
2280209324	Diesel	Miscellaneous	Underway	Aux	59	37318	0	652	9	10	23	23
2280210313	Diesel	Ro-Ro	Port	Main	10	1728	0	56	1	1	1	9
2280210314	Diesel	Ro-Ro	Port	Aux	246	199286	1	2726	47	51	122	96
2280210323	Diesel	Ro-Ro	Underway	Main	2022	821502	5	19775	238	259	501	1001
2280210324	Diesel	Ro-Ro	Underway	Aux	640	465315	2	6729	112	122	284	247
2280211313	Diesel	Tanker	Port	Main	15	3382	0	103	1	2	2	12
2280211314	Diesel	Tanker	Port	Aux	808	961438	4	7268	211	229	587	325
2280211323	Diesel	Tanker	Underway	Main	7583	3117967	17	63886	905	983	1902	3766
2280211324	Diesel	Tanker	Underway	Aux	2639	2251177	10	22081	524	569	1373	1031
2280213313	Diesel	Tug	Port	Main	1	166	0	4	0	0	0	0
2280213314	Diesel	Tug	Port	Aux	1	773	0	14	0	0	0	0
2280213323	Diesel	Tug	Underway	Main	426	247527	1	4540	66	71	151	212
2280213324	Diesel	Tug	Underway	Aux	8	4871	0	86	1	1	3	3
2280214313	Diesel	Refrigerated	Port	Main	0	42	0	2	0	0	0	0
2280214314	Diesel	Refrigerated	Port	Aux	12	9988		147	2	3	6	5
2280214323	Diesel	Refrigerated	Underway	Main	79	31647	0	872	9	10	19	38
2280214324	Diesel	Refrigerated	Underway	Aux	46	34426	0	560	8	9	21	18
2280215313	Diesel	Cruise	Port	Main	24	5958	0	132	3	3	4	24
2280215314	Diesel	Cruise	Port	Aux	952	639567	3	9380	157	171	390	366
2280215323	Diesel	Cruise	Underway	Main	3453	1880718	9	30536	481	523	1148	1885
2280215324	Diesel	Cruise	Underway	Aux	3544	2320414	11	37182	574	624	1415	1360
2280302313	Residual	Offshore	Port	Main	0	9	0	0	0	0	0	0
2280302314	Residual	Offshore	Port	Aux	0	137	0	2	0	0	0	0
2280302323	Residual	Offshore	Underway	Main	151	62851	1	1633	71	77	197	74
2280302324	Residual	Offshore	Underway	Aux	12	7814	0	131	8	8	25	5
2280303313	Residual	Bulk Carrier	Port	Main	1	105	0	3	0	0	0	1

SCC	Fuel	Ship Type	Port/Underway	Engine	CO	CO_2	NH_3	NO_x	PM 2.5	PM 10	SO_2	VOC
2280303314	Residual	Bulk Carrier	Port	Aux	7	6295	0	74	6	6	20	3
2280303323	Residual	Bulk Carrier	Underway	Main	1919	809366	17	21272	902	981	2541	885
2280303324	Residual	Bulk Carrier	Underway	Aux	177	123956	2	1780	119	130	389	68
2280304313	Residual	Fishing	Port	Main	0	4	0	0	0	0	0	0
2280304314	Residual	Fishing	Port	Aux	1	384	0	7	0	0	1	0
2280304323	Residual	Fishing	Underway	Main	29	8948	0	203	14	15	28	24
2280304324	Residual	Fishing	Underway	Aux	8	5247	0	99	5	6	16	3
2280305313	Residual	Container Ship	Port	Main	0	35	0	1	0	0	0	0
2280305314	Residual	Container Ship	Port	Aux	6	5386	0	65	5	5	17	2
2280305323	Residual	Container Ship	Underway	Main	3046	1182519	26	31650	1342	1459	3709	1461
2280305324	Residual	Container Ship	Underway	Aux	399	290207	5	4322	278	302	911	154
2280306323	Residual	Ferry	Underway	Main	11	6467	0	135	7	7	20	5
2280306324	Residual	Ferry	Underway	Aux	1	560	0	12	1	1	2	0
2280307313	Residual	General Cargo	Port	Main	0	1	0	0	0	0	0	0
2280307314	Residual	General Cargo	Port	Aux	0	99	0	1	0	0	0	0
2280307323	Residual	General Cargo	Underway	Main	12	5742	0	134	6	7	18	6
2280307324	Residual	General Cargo	Underway	Aux	3	1880	0	30	2	2	6	1
2280309313	Residual	Miscellaneous	Port	Main	0	6	0	0	0	0	0	0
2280309314	Residual	Miscellaneous	Port	Aux	0	103	0	2	0	0	0	0
2280309323	Residual	Miscellaneous	Underway	Main	113	58287	1	1298	62	67	183	54
2280309324	Residual	Miscellaneous	Underway	Aux	7	4596	0	83	5	5	14	3
2280310313	Residual	Ro-Ro	Port	Main	0	0	0	0	0	0	0	0
2280310314	Residual	Ro-Ro	Port	Aux	0	0	0	0	0	0	0	0
2280310323	Residual	Ro-Ro	Underway	Main	413	180328	4	4779	199	217	566	191
2280310324	Residual	Ro-Ro	Underway	Aux	69	46660	1	790	45	49	146	26
2280311313	Residual	Tanker	Port	Main	0	13	0	0	0	0	0	0
2280311314	Residual	Tanker	Port	Aux	2	1700	0	17	2	2	5	1
2280311323	Residual	Tanker	Underway	Main	2047	920587	19	22465	987	1072	2799	953

SCC	Fuel	Ship Type	Port/Underway	Engine	CO	CO_2	NH_3	NO_x	PM 2.5	PM 10	SO_2	VOC
2280311324	Residual	Tanker	Underway	Aux	263	200160	4	2303	190	206	628	102
2280313313	Residual	Tug	Port	Main	0	5	0	0	0	0	0	0
2280313314	Residual	Tug	Port	Aux	0	11	0	0	0	0	0	0
2280313323	Residual	Tug	Underway	Main	4	2134	0	40	2	2	7	2
2280313324	Residual	Tug	Underway	Aux	0	19	0	0	0	0	0	0
2280314313	Residual	Refrigerated	Port	Main	0	3	0	0	0	0	0	0
2280314314	Residual	Refrigerated	Port	Aux	5	3777	0	61	4	4	12	2
2280314323	Residual	Refrigerated	Underway	Main	62	26755	1	757	30	32	84	29
2280314324	Residual	Refrigerated	Underway	Aux	54	41480	1	699	39	43	130	21
2280315313	Residual	Cruise	Port	Main	0	2	0	0	0	0	0	0
2280315314	Residual	Cruise	Port	Aux	1	1210	0	11	1	1	4	1
2280315323	Residual	Cruise	Underway	Main	375	204654	4	3707	213	232	623	203
2280315324	Residual	Cruise	Underway	Aux	292	193157	4	2903	188	205	606	112