CATEGORY 3 COMMERCIAL MARINE VESSEL 2022 EMISSIONS INVENTORY

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AIS	Automatic Identification Systems
BSFC	Brake-Specific Fuel Consumption
C3	Category 3
CMV	Commercial Marine Vessel
CO	Carbon Monoxide
CO_2	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
$m^{\wedge 3}$	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
PM	Particulate matter
Reefer	Refrigerated vessels
RM	Residual marine
Ro Ro	Roll on/Roll off
RPM	Revolutions per minute
S-AIS	Satellite automatic identification systems
SO_2	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

1.0 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, hazardous air pollutants (HAPs) and greenhouse gases 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 from EPA emissions programs, such as the emission trading program, Toxics Release Inventory (TRI), and data collected during rule development or compliance testing. 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 the EPA Marine Emissions Tool (MET) for Category 3 (C3) commercial marine vessels (CMV), including the conceptual framework, equations, data sources, and assumptions. A description of the development of the Category 1 and 2 (C1C2) CMV model that computes emission 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.

2.0 AIS Dataset

The EPA received Automated Identification System (AIS) data from United States Coast Guard (USCG) to quantify all ship activity which occurred between January 1 and December 31, 2022. 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 (IMO, 2002). In addition, the USCG has mandated that all commercial marine vessels continuously transmit AIS signals while transiting U.S. navigable waters. 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. baseline. 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).

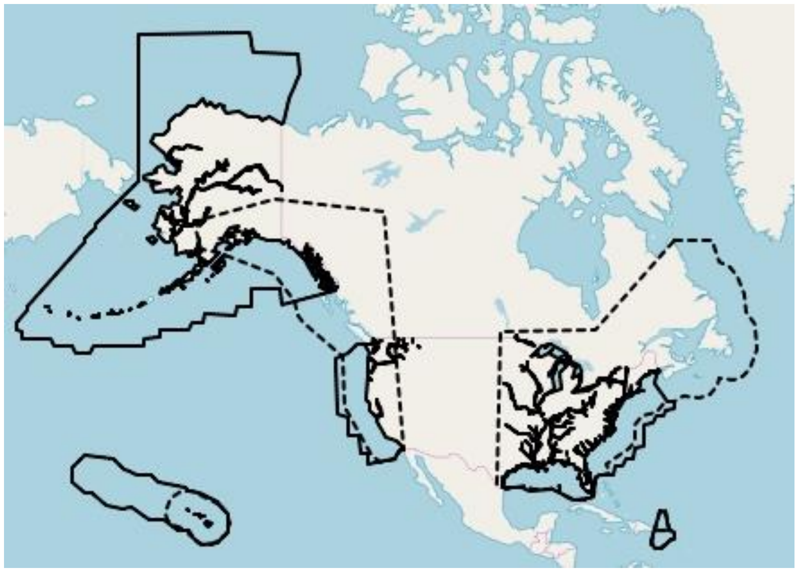


Figure 1 NEI Geographical Extent (Solid) and U.S. ECA (Dashed)

The compiled AIS data include the locations, speeds, drafts, and headings of all vessels with AIS transmitters operating within the specified geographical and time ranges. They also include vessel identifiers, such as the IMO number and Maritime Mobile Service Identifier (MMSI). These data were aggregated to five-minute intervals by the USCG.

3.0 AIS Data Processing

USCG AIS data are delivered as comma separated value (csv) files. The USCG AIS dataset for calendar year 2022 contained a total of 3,065,520,045 records for C1C2 and C3 vessels. The as-received AIS dataset contains anomalous data such as duplicate records, and records from non-vessels. The first step in processing the AIS data is to parse the records into standardized data fields, with non-vessel and duplicated records removed.

AIS data are transmitted by vessels and collected by both satellite (S-AIS) and terrestrial (T-AIS) receivers. Data from both receiver types were included in the 2022 dataset from the USCG. The USCG maintains a network of terrestrial receivers along the coast and inland waterways that provides good spatial coverage of these areas. However terrestrial receivers are limited to receiving line-of-sight transmissions from ships, so the coverage of the T-AIS data diminishes further from the coasts. Satellite receivers provide broad coverage over open ocean, where T-AIS coverage is sparse. However, the temporal sample rate of satellite receivers is limited by the frequency that a satellite passes over a given patch of ocean. Generally, the temporal coverage of S-AIS data is poorer than for T-AIS data. The 2022 AIS dataset from the USCG consisted of 2,216,195,518 T-AIS and 849,324,527 S-AIS records.

The S-AIS and T-AIS datasets were read in for the same month and geographic regions and merged by IMO number, MMSI, or both vessel identifiers. When both datasets reported activity for the same time stamp and vessel, the T-AIS messages were selected over the S-AIS messages, as T-AIS data provides better coverage of the near-shore activity included in this inventory. In some cases, it appears that multiple transmitters without IMO numbers used the same MMSI number. In these cases, it is impossible to distinguish between these transmitters, and multiple messages with the same MMSI and timestamp appear in the data set. Generally, these messages do not belong to commercial vessels, and as such were treated as duplicate messages during this data cleaning process. Altogether, the process removed 1,566,559,551 duplicate records from the dataset.

Additionally, AIS transmitters unrelated to marine vessel combustion sources, such as non-self-propelled vessels, buoys, and helicopters, were identified and removed from the AIS dataset. These non-vessel entities were identified using USCG-verified MMSI patterns, based on information obtained from the USCG Navigation center.[1] In total, 8,006,509 of these records were identified and removed from the data set. The removed records were associated with divers' radios, coastal stations, aids to navigation, search and rescue aircraft and transmitters, man overboard devices, and emergency position indicating radio beacon.

Removing duplicate records and non-vessel records reduced the size of the data set by 51.36%. The resulting cleaned data set contained 1,490,953,985 records out of the total 3,065,520,045 records in the data as received from the USCG as shown in Figure 3.

[1] USCG Navigation Center, Maritime Mobile Service Identity, navcen.uscg.gov/?pageName=mtmmsi.

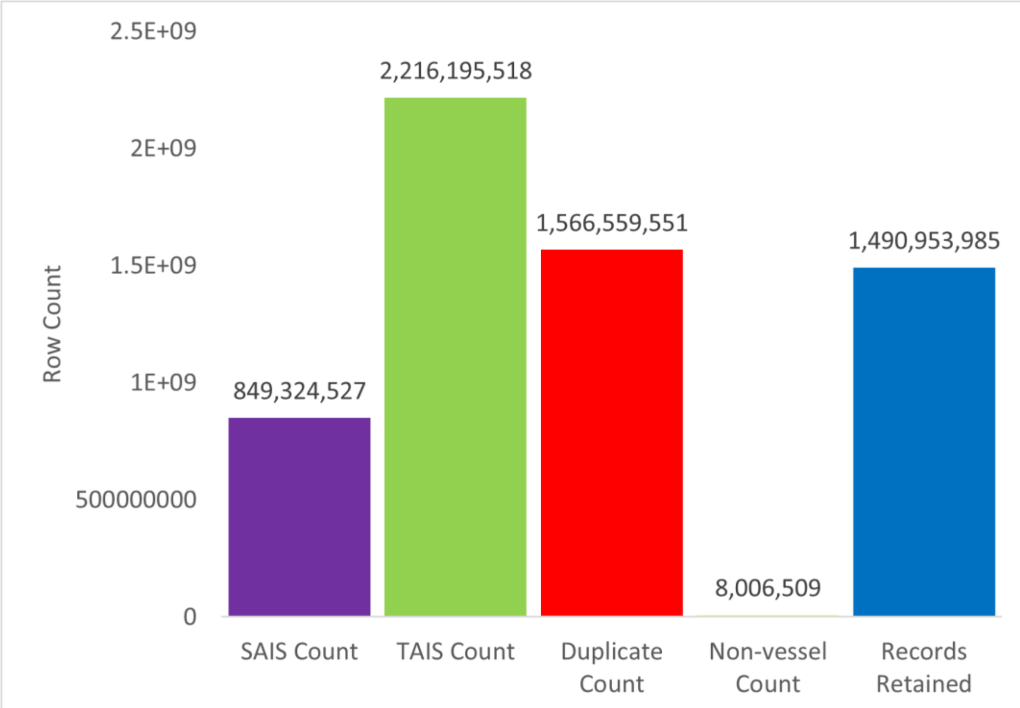


Figure 2 Comparison of Record Retention During Preliminary Processing

4.0 Preparing the Ship Registry Dataset

Ship parameter data were pulled primarily from the Clarksons ship registry and were supplemented and validated by smaller datasets (Clarksons, 2021; U.S. Coast Guard, 2017, 2018; U.S. Department of Transportation, 2017). The supplementary and Clarksons datasets were used to identify unique combinations of MMSI and IMO numbers in the AIS data set and to assign individual vessel characteristics. After filtering, 14% of the vessels identified in the AIS data set had corresponding vessel characteristics. This accounted for 32% of the total number of messages in the AIS data set. This reduced the AIS dataset by 131,336 vessels from 152,910 to 21,574 vessels.

As the ship characteristics data set contained missing values for many vessels, each vessel entry was matched with a unique vessel from the AIS data set. This allowed the assignment of message counts for each vessel to weight averaged values by activity for gap filling data. The AIS data set was first checked for invalid IMO numbers and merged with their matching MMSI numbers. This retained the same coverage of 32% of the total messages in the AIS data set.

The Clarksons vessel number is then attached to each ship in the AIS data set, matching first on IMO number before using the MMSI if no match could be made. These unmatched vessels were dropped, as well as vessels with only one message entry, resulting in the removal of 120,166 vessels. Message counts are aggregated per each vessel and duplicates are removed. Despite this continuous data cleansing, the data contained instances of MMSI numbers matching to two or more IMO numbers and IMO numbers that did not exist in the Clarksons data set. This resulted in a final vessel count of 20,119 unique vessels. Vessel parameters required to calculate ship propulsive power, estimate operating modes, and assign emission factors are listed in Table 1.

Table 1 Ship Parameters

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

4.1 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-1). 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

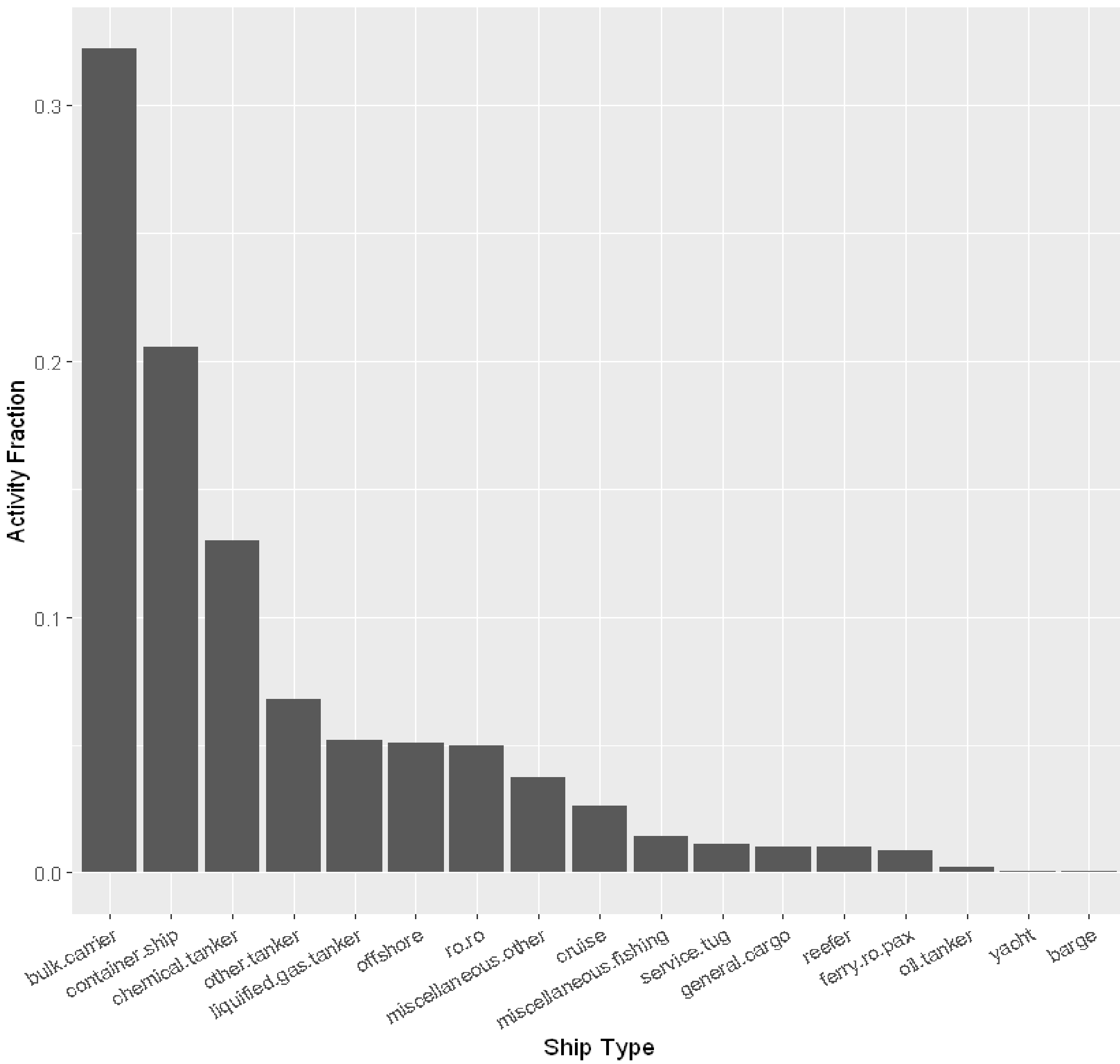


Figure 3 Category 3 AIS Activity Breakdown by Ship Type

4.2 Subtype

The EPA assigned subtypes to each vessel in the ship registry according to its ship type and size class (see Appendix A-2). Subtypes were primarily assigned to best fit with adopted auxiliary and auxiliary boiler engine loads (EPA, 2022). 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. Because cubic meter (m^3)

size information was lacking, the EPA adopted chemical tanker deadweight tonnage (DWT) bins for liquified gas tankers.

4.3 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 (Diesel & Gas Turbine, 2013). 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.

4.4 Ship Parameter Gap Filling

Some vessel fields contain 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 A-3). After gap filling engine categories, there were 13,541 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 A-4). 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 A-5), and fit the length using the following nth root relationship:

$$L = aV^{\frac{1}{n}}$$

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 n^{th} 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 A-6). 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 A-7). (Using an average block coefficient was determined to affect emissions estimates less than calculating one from average input parameters; see Brown & Aldridge, 2018.)

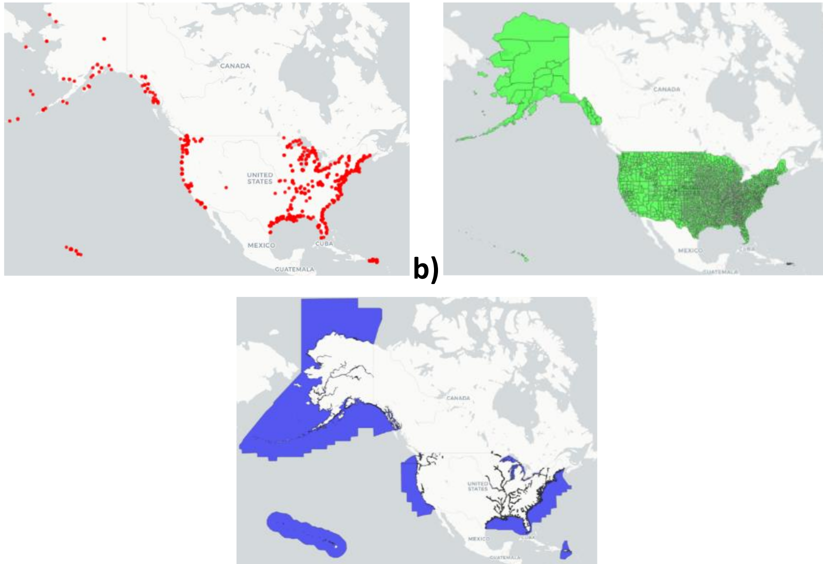
Analysis has shown that gap-filling parameters by vessel subtype averages produces a relatively small difference in estimated emissions (Brown & Aldridge, 2018). Roughly 60% of the AIS activity time for 2022 was allocated to vessels missing hull displacement data. The remaining time is allocated to vessels 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.

Table 2 Gap Filling Methodology

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

4.5 Splitting AIS Data

To organize the AIS data and expedite further processing, the dataset was split by individual vessels and saved to two separate files which contain both the static vessel characteristics and the dynamic AIS data. The vessels were double checked to ensure only C3 vessels were written, had more than a single record, and that a matching IMO and/or MMSI number existed in the Clarksons dataset. This resulted in 13,910 unique vessel files.



a) b) c)

Figure 4 Shapefiles Used for Assigning FIPS including a) NEI Port Shapefile; b) TIGER County Shapefile; c) NEI Shipping Lane Shapefile

4.6 Cleaning the AIS Dataset

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. These duplicates were removed. Erroneous speeds were deemed to be all speeds above 1.5 times the service speed of the vessel (EPA, 2022); these messages were also removed. 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. Vessels were assumed to be operating at maximum draft when AIS-reported draft data were missing.

4.7 Temporal Gaps in AIS Activity

The AIS messages received from the USCG were typically aggregated to five-minute intervals. However, 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.

5.0 Calculating Emissions

This inventory compiles emissions using the methods described in EPA's 2022 Ports Emissions Inventory Guidance. 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 Equation 5-1.

$$Emissions_{interval} = Time_{interval} \times \ Power \times EF \times LLAF \qquad \textbf{Equation 5-1}$$

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

5.1 Calculating Power

Propulsive power was calculated using EPA's Marine Emissions Tools (EPA 2022), specifically with the Holtrop & Mennen numerical ship power model, which follows the form of resistance-based methods, documented in Equation 5-2 (Holtrop & Mennen, 1982).

$$Power\ (kW) = \frac{\rho \times C_T \times \frac{1}{2} \times S \times {V_{reported}}^3}{\eta_T} \qquad \textbf{Equation 5-2}$$

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 (2016) were used. 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, as is customary (MAN Diesel & Turbo; EPA, 2022). 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 (Kristensen & Lutzen, 2012). 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 (2012). EPA adopted upper and lower bounds from SARC Maritime Software and Services (2018) and applied them to these waterplane area coefficients in order to ensure the values were within a realistic range.

5.2 Assigning Operating Mode

Operating mode was determined using geospatial, speed, and propulsive load data using the following rules in order of preference:

1. If a vessel was in anchorage zone (Office for Coastal Management (2022)) 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 (as determined by its overlap with a port in the NEI Ports Shapefile) 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. 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.

5.3 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.

5.4 Fuel Use Assignment

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. All those 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 (EPA, 2010). Marine vessels are assumed to use fuel with 0.5% fuel sulfur levels outside of the ECA.

5.5 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 per kWh) or fuel-based (in units of grams per unit of fuel consumption).

5.5.1 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 what is calculated in Equation 5-1). These emission factors include Nitrogen oxides (NO_x), volatile organic compounds (VOC), carbon monoxide (CO), and hydrocarbons (HC).

NO_x 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. Because Tier III NO_x 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 NO_x 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.

5.5.2 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 (SO_2), and carbon dioxide (CO_2) are calculated using the emission factors presented in EPA's Ports Emissions Inventory Guidance. See Section 3.5.3 for PM, Section 3.5.7 for SO_2, Section 3.5.6 for CO_2. Additionally, see Section 3.5.2 for a discussion on BSFC.

5.6 Low Load Adjustment Factor

EFs are considered to be 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 Equation 5-1. The LLAF factors used were from Table 3.10 in EPA's Ports Emissions Inventory Guidance.

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.

5.7 Missing AIS data for Spring of 2022

For 2022, some data gaps were found in the AIS data available during the period of March 26 through June 30. To address this, emissions data computed for the same period in 2021 were filled into the corresponding days in 2022. The 2021 days of the week selected for the gapfilling were matched to the same days of the week and same week of the year in 2022.

5.8 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.

6.0 Gridding of 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 files needed to support emissions modeling.[2] The scripts use the following process to take emissions attributed to an AIS message and their associated longitudes and output them as aggregated gridded emissions for 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,Y coordinates as:

$$Grid\ Column = \frac{floor(X_{Projected}(m) - X_{Origin}(m))}{Cellwidth(m)}$$

And

$$Grid\ Row = \frac{floor(Y_{Projected}(m) - Y_{Origin}(m))}{Cellwidth(m)}$$

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.

6.1 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 in order to define likely and unlikely C3 locations. This masking raster was then used to remove all emissions from grid cells in unlikely C3 locations.

ERG developed an R function 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

[2] These are developed in the Flat File 2010 format used by the Sparse Matrix Operator Kernel Emissions modeling system (https://cmascenter.org/smoke/documentation/4.8.1/html/ch08s02s07.html#d0e40258).

the daily rasters that were in unlikely C3 locations. Unlikely C3 locations were grid cells in which exclusively interpolated messages existed.

However, 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 6 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.

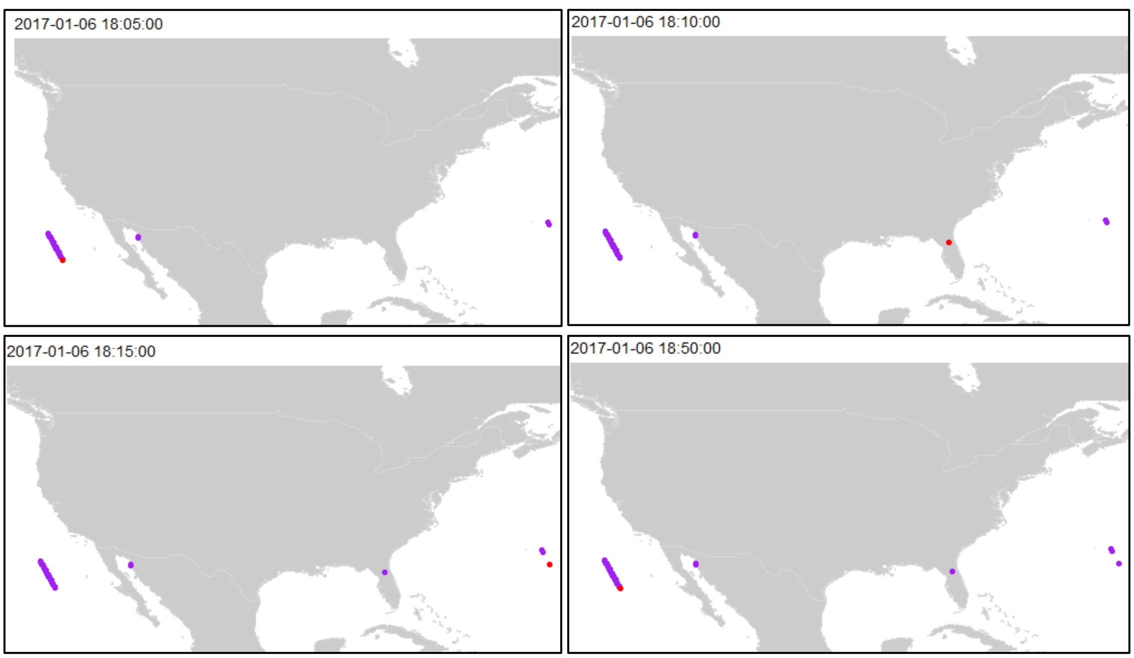


Figure 5 Example of Rogue Messages (Current Activity Message in Red and Past Messages in Purple)

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. ERG developed an R function for this purpose, which 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, such as Table 2 which was created for altering the 12km CONUS raster according to the above findings. This function creates a box for each row of Table 16, 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

However, while the resulting submissions to the air quality modeling platform did use this masking raster, the NEI county-level submissions did not. Instead, counties which exclusively reported interpolated messages were assumed to be unlikely C3 areas and all C3 emissions were set to zero for those counties. Thus, because masks were applied at the grid cell-level for the air quality modeling platform, but the county-level for the NEI platform, certain differences will exist between them.

7.0 2022 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 2020 TIGER County Shapefile, and the NEI Shipping Lane Shapefiles (Figure 4). 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. Those 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 due to Category 3 marine vessels in the NEI area throughout 2022, Table 4 presents emissions by vessel type and Figure 6 shows the geographic distribution of NO_x emissions in U.S. waters. Note that the totals shown in this section do not reflect emissions changes that resulted from application of the masking raster described in Section 6.1.

Table 4 Total 2022 Category 3 emissions in tons for U.S. waters including federal waters

Region	CO	CO_2	NO_X	$PM_{2.5}$	PM_{10}	SO_2	VOC
Alaska	1,043	638,087	7,777	195	212	512	485
Hawaii	170	118,423	1,617	29	32	72	73
Puerto Rico + Virgin Islands	351	234,654	2,694	60	65	148	164
48 states+DC	10,207	6,752,354	84,352	1,686	1,833	4,141	4,676
Federal waters	38,298	17,746,131	320,544	8,123	8,829	20,812	18,955
TOTAL	**50,069**	**25,489,648**	**417,184**	**10,093**	**10,970**	**25,685**	**24,352**

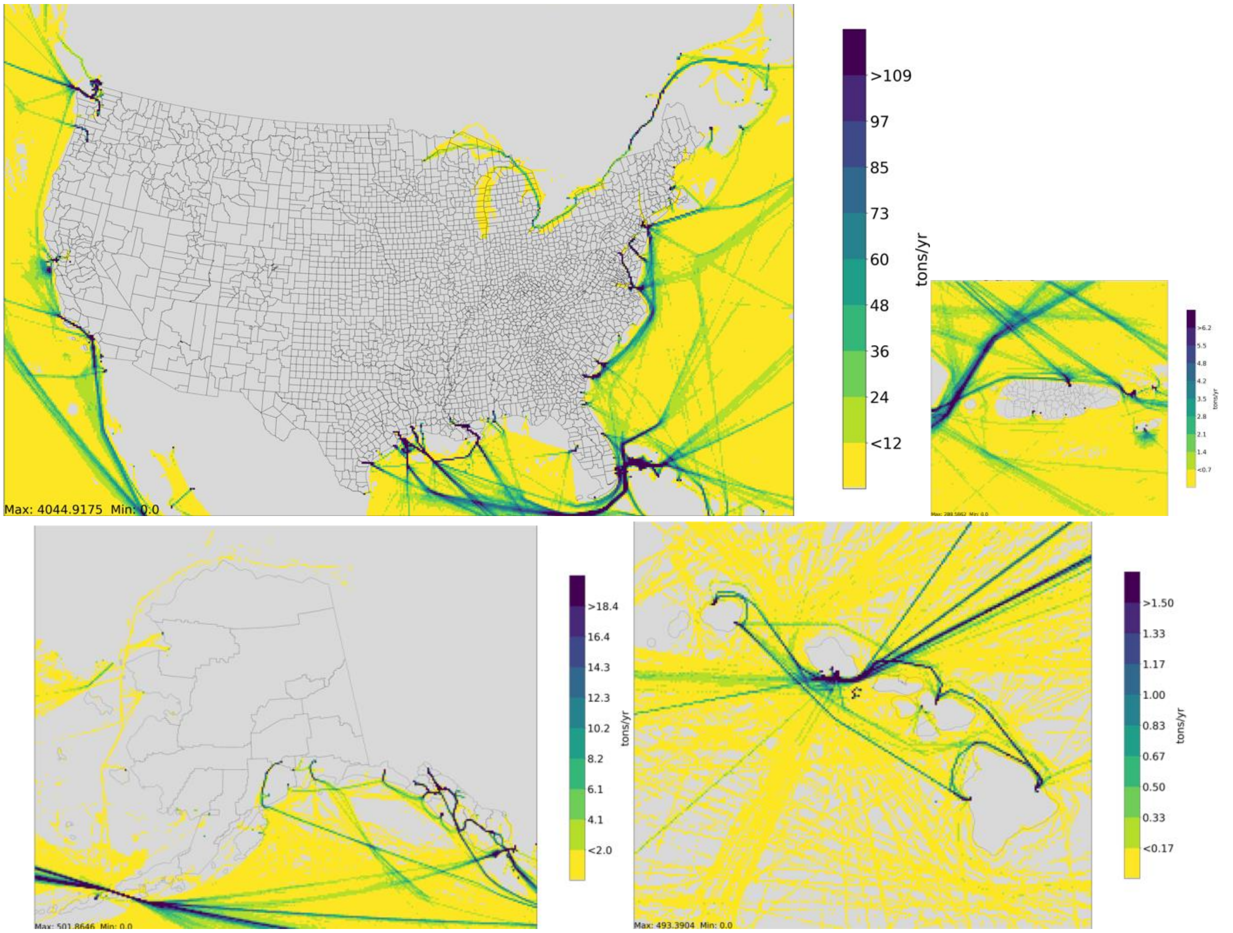


Figure 6 C3 2022 Annual NO_X Emissions

Table 5 Total 2022 Category 3 emissions by ship type (tons unless otherwise indicated)

Ship Category	CO	CO_2	NH_3	NO_X	PM_{10}	$PM_{2.5}$	SO_2	VOC
Bulk Carrier	7,018	3,555,527	32	65,155	1,786	1,643	4,309	3,191
Container Ship	19,204	8,506,797	70	150,665	3,979	3,661	9,058	10,080
Cruise	6,390	3,896,965	23	52,923	1,325	1,219	3,158	2,929
Ferry	56	33,245	0	682	15	14	37	25
Fishing	42	17,293	0	361	17	16	36	29
General Cargo	110	65,663	0	1,161	25	23	61	49
Miscellaneous	604	324,589	3	5,422	146	134	350	289
Offshore	1,161	507,874	4	9,717	226	208	495	594
Refrigerated	356	205,426	2	2,957	121	111	319	155
Ro-Ro	3,189	1,610,916	11	24,738	646	595	1,495	1,462
Tanker	11,477	6,493,547	46	99,677	2,604	2,396	6,197	5,324
Tug	463	271,805	1	3,726	80	73	171	225
Grand Total	**50,069**	**25,489,648**	**194**	**417,184**	**10,970**	**10,093**	**25,685**	**24,352**

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 8 illustrates the relative energy consumption for each ship type by SCC while Table 5 provides total emissions by SCC.

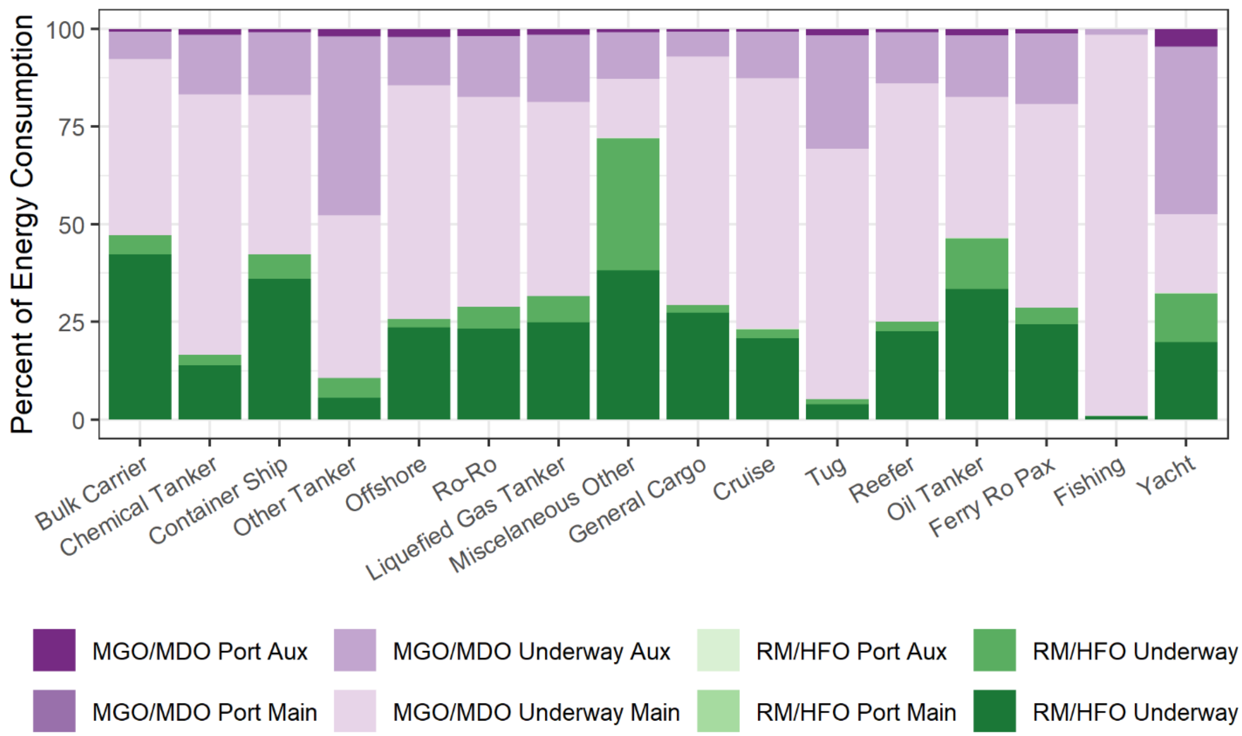


Figure 7 Ship Type Kilowatt Hour Distribution by SCC

Table 6 2022 Category 3 Emissions by Port/Underway, Engine type, and Fuel (tons)

Port/Engine/Fuel	CO	CO_2	NH_3	NO_X	PM_{10}	$PM_{2.5}$	SO_2	VOC
Port	**3,309**	**2,877,614**	**13**	**27,018**	**742**	**683**	**1,802**	**1,368**
Auxiliary	**3,187**	**2,857,383**	**13**	**26,363**	**729**	**671**	**1,789**	**1,249**
Diesel	3,166	2,839,074	13	26,176	711	654	1,731	1,241
Residual	21	18,309	0	187	18	17	57	8
Main	**121**	**20,231**	**0**	**655**	**13**	**12**	**13**	**119**
Diesel	120	20,036	0	648	13	12	12	118
Residual	1	195	0	7	0	0	1	1
Underway	**46,761**	**22,612,034**	**181**	**390,167**	**10,229**	**9,410**	**23,884**	**22,984**
Auxiliary	**11,234**	**8,540,869**	**50**	**94,338**	**2,833**	**2,606**	**7,211**	**4,351**
Diesel	10,120	7,749,014	36	84,701	2,006	1,845	4,725	3,921
Residual	1,114	791,855	15	9,637	827	761	2,486	429
Main	**35,527**	**14,071,165**	**131**	**295,829**	**7,396**	**6,804**	**16,673**	**18,633**
Diesel	27,898	10,825,748	62	216,238	3,487	3,208	6,608	14,972
Residual	7,629	3,245,418	69	79,591	3,909	3,596	10,064	3,661

8.0 Forecasting emissions for analytic years

Future CMV emissions for the analytic years 2026, 2032, and 2038 were projected from the 2022 base year inventory. For this purpose, a set of multiplicative growth factors were calculated using the Freight Analysis Framework Version 5 (FAF5)[3], which is produced by the Bureau of Transportation Statistics (BTS) and supported by the Federal Highway Administration (FHWA). The main sources of the FAF5 include the Commodity Flow Survey (CFS), Business Market Insights (BMI) database, federal agencies such as the U.S. Department of Agriculture (USDA) and U.S. Energy Information Administration (EIA), Municipal Solid Waste (MSW) reports from states and federal facilities, construction and demolition (C&D) databases and Census data (FHWA, 2021). These growth projections follow and expand upon previous methodologies in the EPA Port Emissions Inventory Guidance using updated data (EPA, 2022).

8.1 Commodity Import and Export Data

The FAF5 dataset includes data from base year 2017 developed using the CFS, annual estimates from 2018-2022 using BMI historical data and BTS in-house models (FHWA, 2021; Oak Ridge National Laboratory, 2021). It also includes projections for every 5 years from 2025-2050 using BMI forecasted data and BTS in-house models. The FAF5 contains freight flow data for weight, value, and activity. This data is available for all U.S. states and metropolitan areas. While all transportation modes are in the dataset, for this analysis the only data used is the weight of freight flow (thousands of tons) by water mode. The dataset also details 42 commodity types (Table 7) which are used to identify ship types (Table 8).

Following similar procedures used by the California Air Resource Board (CARB; CARB, 2022), ship types were assigned based on the commodities available. For example, trade tonnage for bulk and aggregate products is used to determine bulk carrier emissions growth factors. Some commodity types may be packaged and shipped in multiple ways are therefore assigned to multiple ship types. Because the growth factors represent a relative change in shipping activity between two years, capturing the relative changes in shipping tonnage is more important than determining the absolute value of the change in shipped tonnage for a given ship type or region

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[33] https://faf.ornl.gov/faf5/Default.aspx

Table 7 Commodity List

• Alcoholic beverages • Animal feed Articles-base metal • Base metals • Basic chemicals • Building stone • Cereal grains • Chemical prods. • Coal • Crude petroleum • Electronics • Fertilizers • Fuel oils • Furniture • Gasoline • Gravel • Live animals/fish • Logs	• Machinery • Meat/seafood • Metallic ores Milled grain prods. • Misc. mfg. prods. • Mixed freight • Motorized vehicles • Natural gas and other fossil products • Natural sands • Newsprint/paper • Nonmetal min. prods. • Nonmetallic minerals	• Other ag prods. • Other foodstuffs • Paper articles • Pharmaceuticals • Plastics/rubber • Precision instruments • Printed prods. • Textiles/leather • Tobacco prods. • Transport equip. • Unknown • Waste/scrap • Wood prods.

Table 8 Ship Type Commodity Assignment

Ship Type	**Commodity**
bulk.carrier/barge	Animal feed, Base metals, Cereal grains, Coal, Fertilizers, Gravel, Logs, Metallic ores, Natural sand, Nonmetal mineral products, Nonmetallic minerals, Plastics/rubber, Waste/scrap
container.ship	Alcoholic beverages, Articles-base metal, Electronics, Furniture, Machinery, Miscellaneous manufacturing products, Newsprint/paper, Paper articles, Pharmaceuticals, Precision instruments, Printed products, Textiles/leather, Tobacco products, Wood products
Cruise	N/A – same as misc
Ferry	N/A - same as misc
Fishing	N/A - same as misc
general.cargo	Base metals, Building stone, Live animals/fish, Machinery, Milled grain products, Mixed freight, Other agricultural products, Other foodstuffs, Tobacco products, Unknown, Wood products

Government	N/A - same as misc
Misc	All (see Table 7)
Offshore	N/A - same as misc
Passenger	N/A - same as misc
Reefer	Meat/seafood, Other foodstuffs
ro.ro	Motorized vehicles, Transport equipment
Tanker	Basic chemicals, Chemical products, Crude petroleum, Fertilizers, Fuel oils, Gasoline, Natural gas and other fossil products, Plastics/rubber
Tour	N/A - same as misc
Tug	N/A - same as misc
vehicle.carrier	Motorized vehicles, Transport equipment

To better identify regional trends and simplify the application of the growth rate factors, the state-level trade dataset was subset into regional groups based on the states' costal adjacency (Table 9). The states and metropolitan areas were filtered by a list of allowed Federal Information Processing Standards (FIPS) codes. In the case of Florida, its trade data was attributed to both the Gulf and Atlantic regions.

Table 9 Geographic Region Assignments

Region	**State**
Alaska	Alaska
Atlantic	Connecticut, Delaware, Florida, Georgia, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, North Carolina, Rhode Island, South Carolina, Virginia, Washington D.C
Gulf	Alabama, Florida, Louisiana, Mississippi, Texas
Hawaii	Hawaii
Inland	Arizona, Arkansas, Colorado, Idaho, Illinois, Indiana, Iowa, Kansas, Kentucky, Michigan, Minnesota, Missouri, Montana, Nebraska, Nevada, New Mexico, North Dakota, Ohio, Oklahoma, Pennsylvania, South Dakota, Tennessee, Vermont, West Virginia, Wisconsin, Wyoming
Pacific	California, Oregon, Washington

8.2 Calculating Growth Rates

After assigning the states to their region and ship types by commodity, the estimated years from 2018-2022 showed a trend of highly variable values across each region, leading to unreasonably large factors when compared against the emissions base year 2022. To account for this, the data points from 2025-2050 were used to generate a linear regression to back cast the base year 2022. A linear interpolation was also applied annually for years 2025-2050 to allow for easier generation and look up of growth factors for any future year. Percent difference graphs were created to show the change in growth in relation to the base year 2022. The shaded regions show the upper and lower bounds for the future projected growth. These values are based on IHS developed alternative macroeconomic scenarios which are included as part of the FAF5 dataset (Oak Ridge National Laboratory, 2021). These scenarios provide alternate projections to the baseline case.

Figure 8 shows the highly variable data before the base year 2022 in which the black point is back casted using the procedure described above to avoid calculating unlikely growth factors. The orange points are values directly from the FAF5 dataset, and the blue points are the annual linear interpolations between the FAF projected values. Figure 9 begins with the base year 2022 removing previous years to display a less variable timeline for the projected growth.

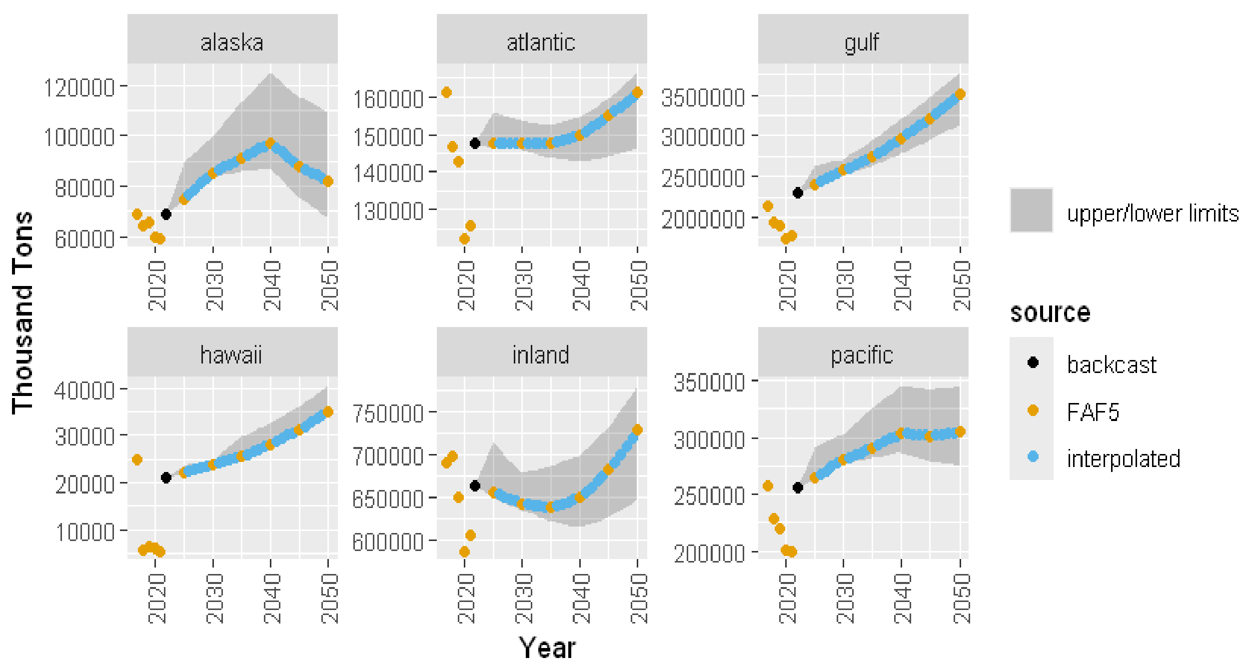

Figure 8 Shipping tonnage averaged by region for all FAF5 years

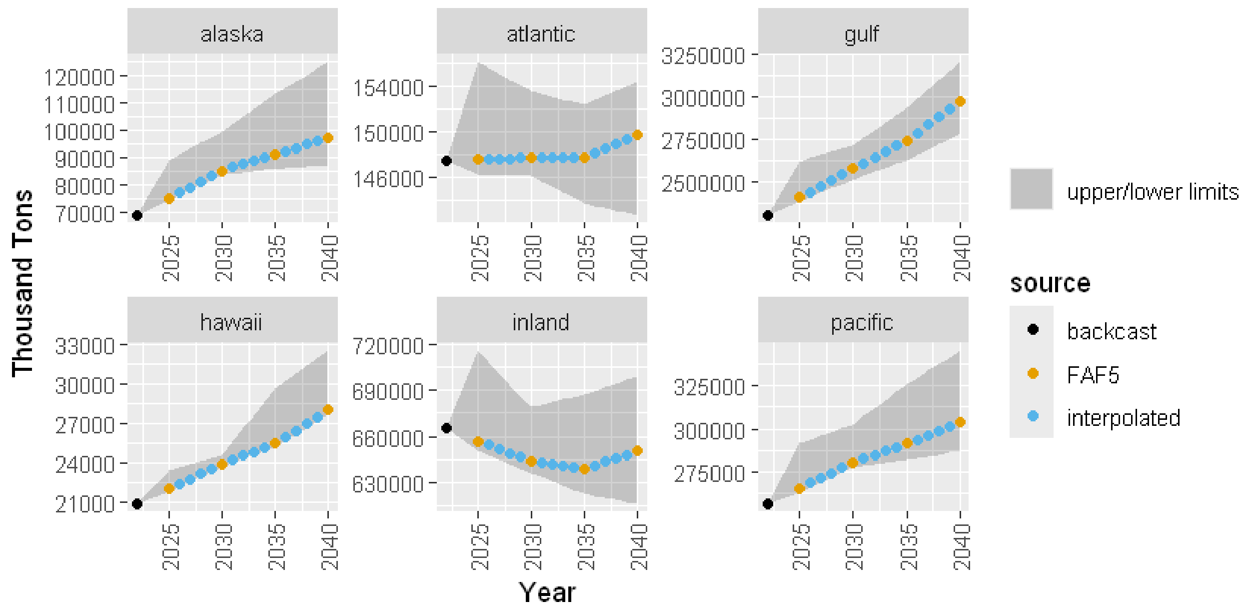

Figure 9 Shipping tonnage averaged by region for projected years only

Emissions growth factors were calculated for each ship type and for each region. Figure 10 shows example projections of bulk carrier growth for each of the six geographic regions. Each of the final growth factors represents a multiplicative adjustment to calculate emissions for the analytic years 2026, 2032, and 2038 from the base year 2022. Some ship types, such as barge or ferry, were not easily matched with commodities available in the FAF5 dataset. Instead, generalized growth factors based on all the commodities in aggregate were applied to these ship types. Appendix C contains a table of the growth factors for the four analytic years for all 96 combinations of ship type and geographic region.

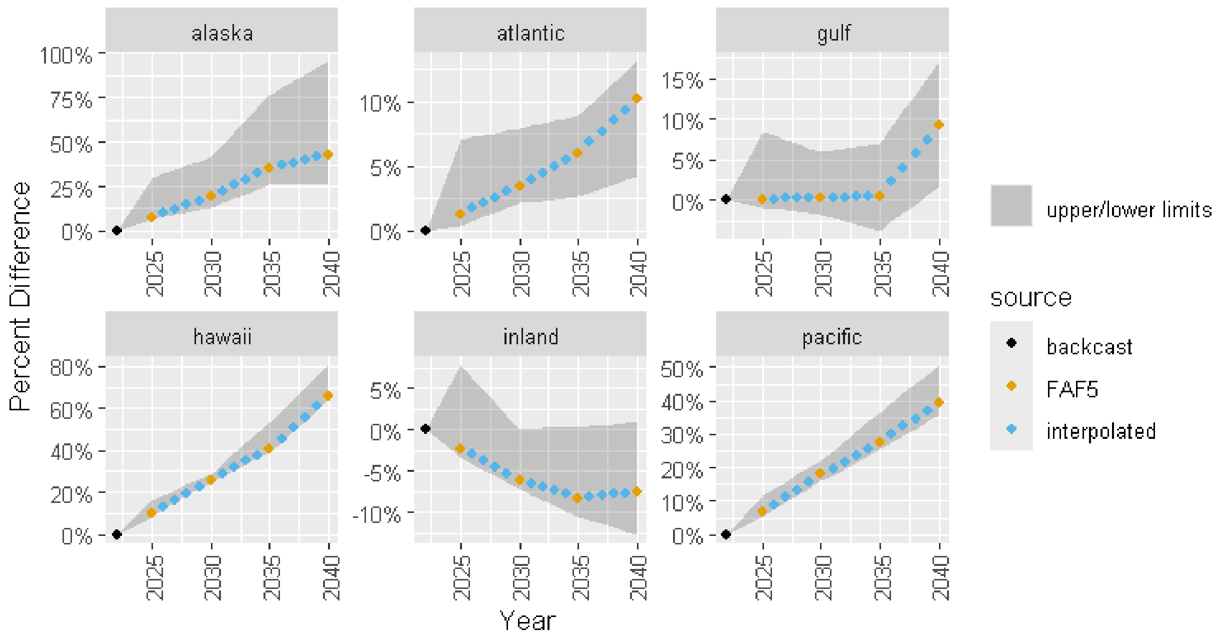

Figure 10 Projected relative growth for bulk carriers by region

8.3 Adjustment for C3 vessel NOx emission projections

For the 2022 Emissions Modeling Platform analytic years, we developed a set of multiplicative adjustment factors for future NOx emissions inventories from Category 3 commercial marine vessels. These factors are intended to be applied to the NOx emissions from inventories projected using the methodology discussed in the preceding sections. The adjustment factors are intended to account for fleet turnover to newer vessels that meet stricter Tier-2 and Tier-3 emissions standards. This analysis uses the U.S. Army Corps of Engineers (USACE) Entrances dataset as a proxy for vessel activity (U.S. Army Corps of Engineers 2023). The vessels identified in the Entrances data are classified by their regulatory tier. The annual vessel activity by tier is fit with linear regressions and forecast into future years. Finally, the forecast activity is combined with tier-specific emission factors to generate fleet-average NOx emission factors for the forecast years. The forecast average rates are normalized against the base inventory year (2022) to generate a final set of adjustment factors for future years.

8.3.1 Recent historic regulatory tier distributions

Entrances data for calendar years 2014 through 2021 was downloaded from the USACE Waterborne Commerce Statistics Center. Vessel specific records from the Entrances data were joined with vessel specific data from Clarksons using the ships' unique IMO numbers. Specifically, each ship's keel-laid date and main engine bore, and stroke were identified. The keel-laid date is used to identify a vessel's regulatory tier, and the bore and stroke data are used to calculate the engine's per-cylinder displacement, which is in-turn used to identify the vessel's category. The Entrances dataset was filtered for C3 vessels which are subject to the NOx regulations being addressed here. Likewise, each ship's engine tier was assigned using its keel-laid date according to the date ranges given in Table.

Table 10 Engine Tiers by Keel-laid date

Engine Tier	Keel-laid date range
Tier 0	1999 and earlier
Tier 1	2000 - 2010
Tier 2	2011 - 2015
Tier 3	2016 and later

Figure 11 shows the distribution of vessel Entrances records by keel-laid date and tier for calendar years 2014-2021. The figure shows the nature of fleet turnover changing when the Tier 3 regulation came into effect in 2016. Rather than maintaining a similar distribution to prior calendar years, starting in 2016 the figure shows a growing number of entrances for Tier 2 vessels with a 2016 keel-laid date, and very little fleet turnover to post-2016 Tier 3 vessels. By 2021 there are a small number of vessel entrances from Tier 3 vessels, but the distribution is significantly changed from the pre-Tier 3 years.

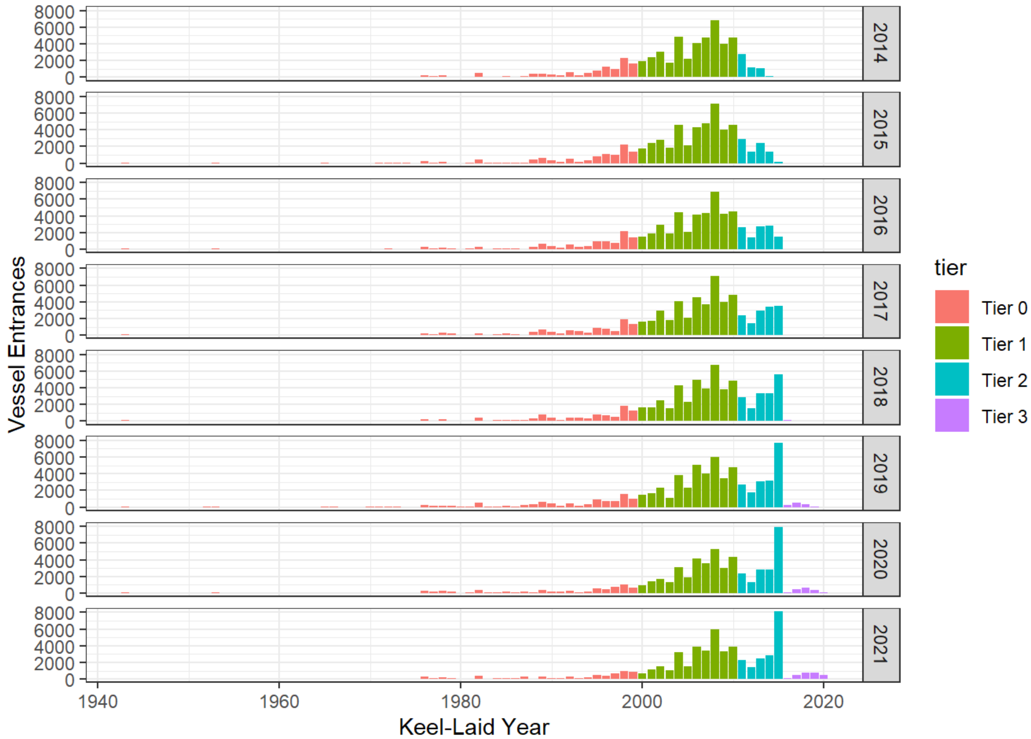

Figure 11 Distributions of C3 vessel entrances by keel-laid year

Figure 12 further illustrates the fleet turnover trends by showing the proportion of entrances from each tier of vessel by calendar year.

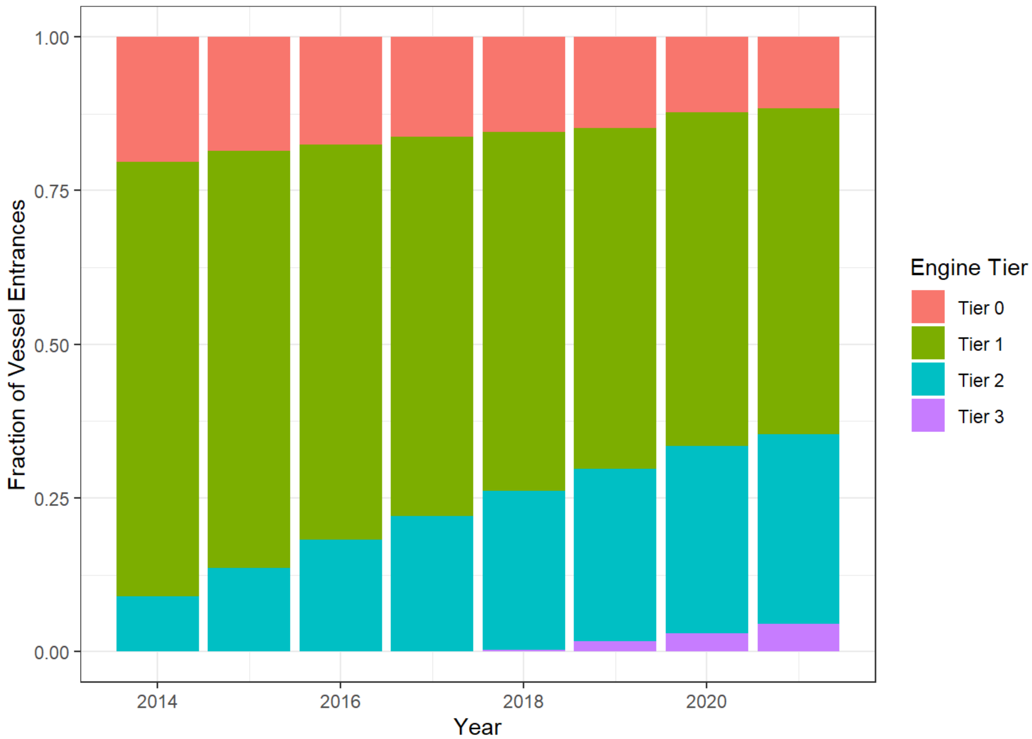

Figure 12 Fraction of vessel entrances for each engine tier by calendar year

8.3.2 Forecasting future vessel activity by engine tier

To estimate future vessel activity by engine tier, we applied linear regressions to the historic activity data for each tier. The regressions were applied to the entrances data from calendar year 2016 onward because 2016 the year where the Tier 3 standard went into effect and resulted in a change in the vessel activity distributions shown above. Figure 13 below shows results of the regressions over the vessel entrances counts by engine tier. The dashed vertical line at 2016 indicates the start year for the regressions. The figure shows vessel entrances for vessels with Tier 0 and Tier 1 engines to be consistently declining both before and after 2016. The trend for Tier 2 engines is less clear cut. The most recent two years ,2020 and 2021 suggest a possible plateau in Tier 2 vessel activity. These points may indicate a peak in Tier 2 vessel activity as the fleet transitions from Tier 2 engines to Tier 3 engines. However, interpreting these two data points difficult especially given the global disruptions in shipping caused by COVID 19 starting in 2020.

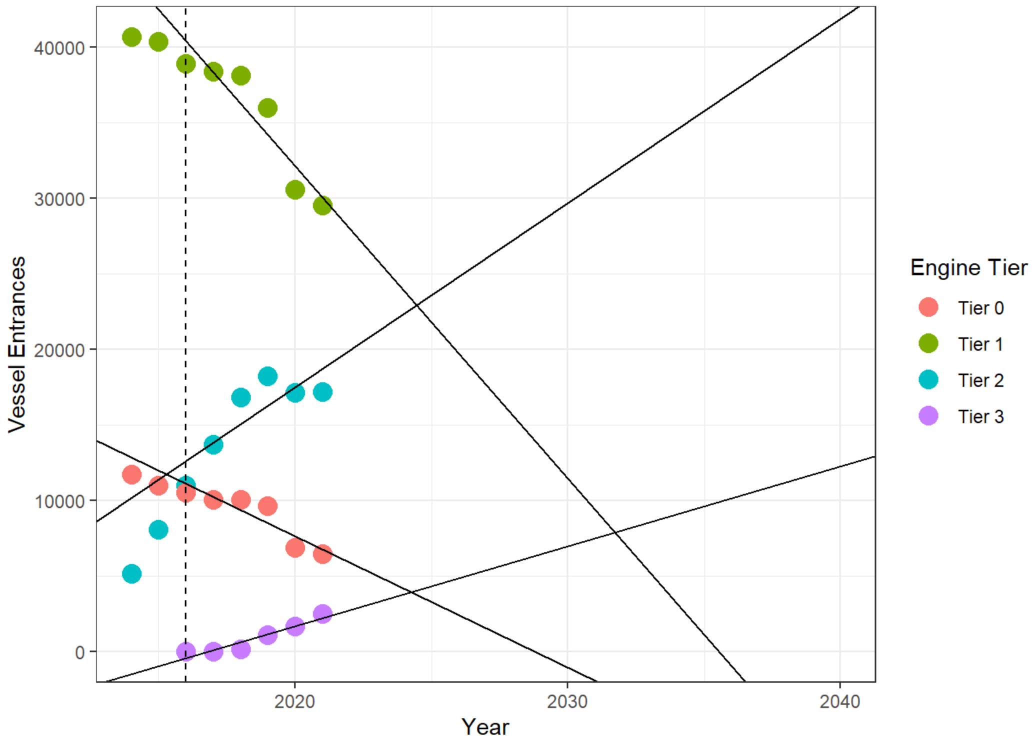

Figure 13 Linear regressions of vessel entrances by engine tier

We transformed the projected vessel entrances data into projected annual vessel activity fractions, by dividing the number of entrances associated with each engine tier by the total number of entrances for each calendar year. For years where Tier 0 and Tier 1 engines were projected to have negative entrances, we assumed that there would be zero vessel activity for the purposes of normalization. Figure 14 shows the resulting normalized fractions of projected vessel activity. The resulting fractions can then be used to weight emission factors to project the change in fleet average emission factores duet to fleet turnover.

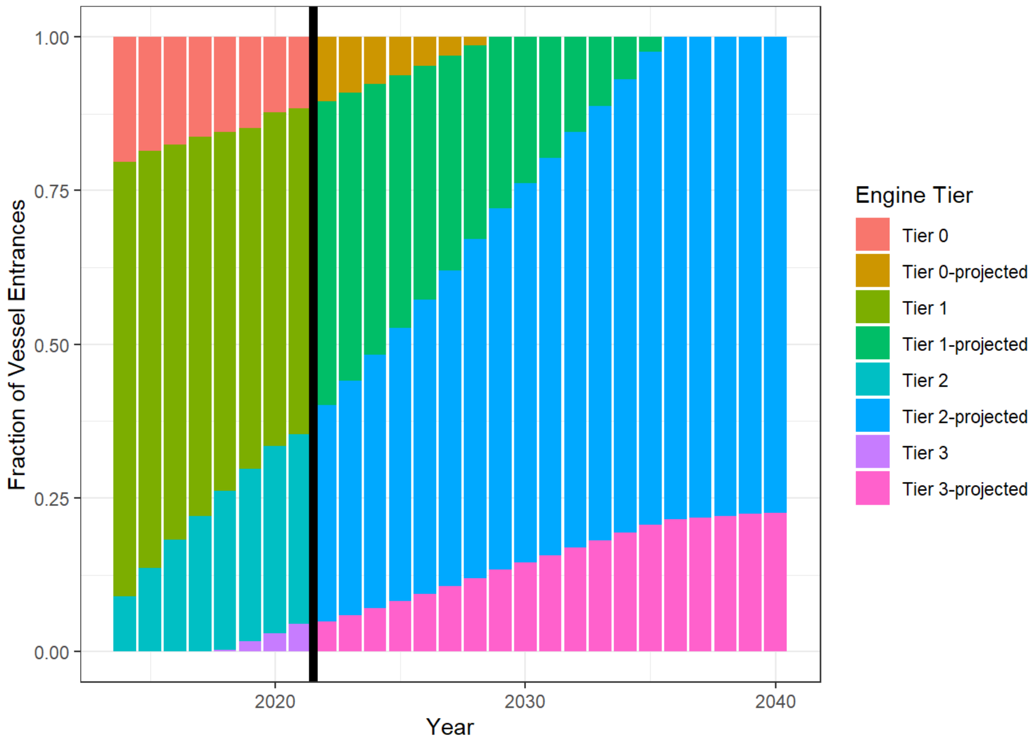

Figure 14 Fraction of vessel entrances by engine tier for historic and projected years

8.3.3 Activity-Weighted Fleet-Average Emission Factors

Using the forecast vessel activity fractions by tier, we generated fleet average NOx emission factors for each year of the analysis. The base emission factors we used came from EPA's Port Emissions Inventory Guidance (EPA 2022) and for simplicity we assumed that the engines are slow speed diesel engines burning ultra-low sulfur ECA fuel. The emission factors are summarized in Table 11 below.

Table 11 NO_x Emission factors by engine tier

Engine Tier	NOx Emission Factor (g/kWh)
Tier 0	17.0
Tier 1	16.0
Tier 2	14.4
Tier 3	3.4

Weighting the emission factors for each calendar year using the fractions from Figure 14, resulted in the projected fleet average NOx emission factors shown in Figure 15. Finally, the fleet average emission rates were normalized to the 2022 base year rate to yield projected scaling factors for calendar years 2022 through 2040. The final scaling factors are presented in Table 12

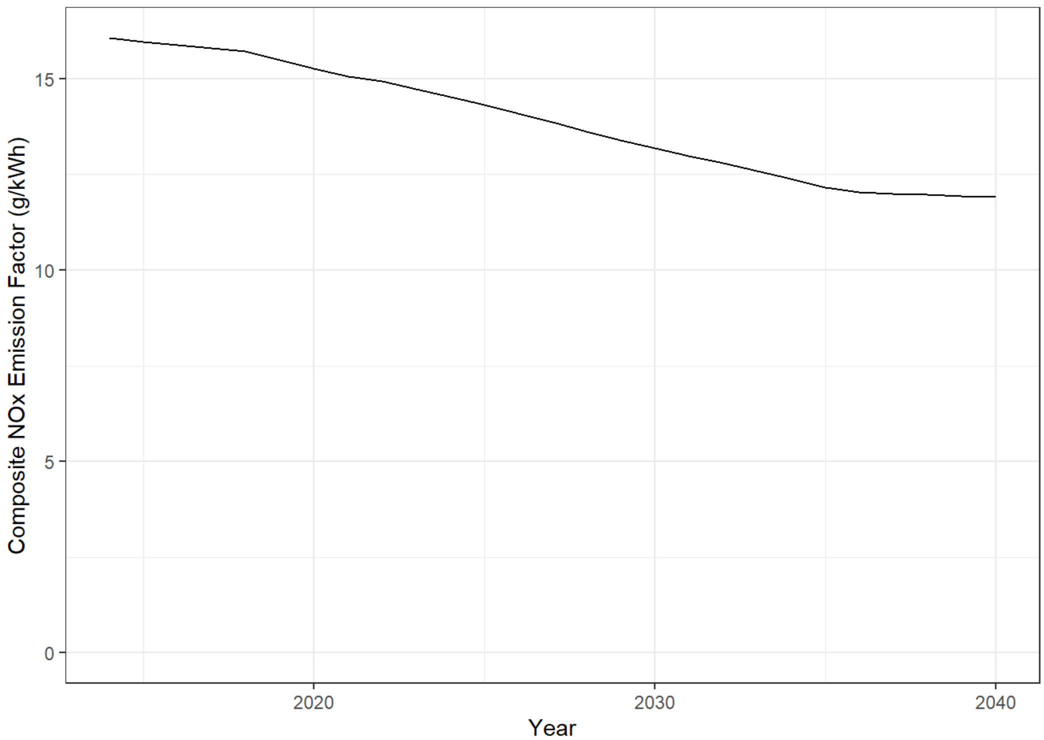

Figure 15 Composite fleet-average NOx emission rates by calendar year

Table 12 Final scaling factors for C3 NOx emissions

Analytic year	Scaling Factor
2022 (base year)	1.00
2026	0.94
2032	0.86
2038	0.80

Table 13 C3 Emissions for Analytic Years Compared to 2022 (tons/yr)

Pollutant	2022	2026	2032	2038
CO	50,069	53,244	58,070	63,639
CO_3	25,489,648	27,038,376	29,380,447	32,070,179
NH_3	194	206	224	244
NO_X	417,184	419,004	414,645	424,963
PM_{10}	10,970	11,634	12,638	13,790
$PM_{2.5}$	10,093	10,703	11,627	12,686
SO_2	25,685	27,212	29,519	32,160
VOC	24,352	25,937	28,353	31,143

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APPENDIX 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
Barge Carrier	Barge
Training Barge	Barge

Clarkson's Vessel Type	Ship Type
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
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
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

Clarkson’s Vessel Type	Ship Type
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
LNG/Regasification	Liquified gas tanker
Ethane/LPG	Liquified gas tanker
Tug, Naval Auxiliary	Tug
Multi-Purpose	Miscellaneous
Work/Repair Vessel	Miscellaneous
Pontoon (Function Unknown)	Barge
Landing Ship (Dock Type)	Miscellaneous
Electricity Generating Pontoon	Barge
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
Replenishment Dry Cargo Vessel	Bulk carrier
Training Ship, Naval Auxiliary	Miscellaneous
Torpedo Boat	Miscellaneous
Floating Crane	Miscellaneous

Clarkson's Vessel Type	Ship Type
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
Replenishment Tanker	Other tanker
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
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

Clarkson's Vessel Type	Ship Type
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
Heavy Load Carrier	Miscellaneous
Icebreaker AGB	Miscellaneous
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
Pipe Laying Barge	Offshore

Clarkson’s Vessel Type	Ship Type
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
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

Clarkson's Vessel Type	**Ship Type**
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
Reefer Fish Carrier	Reefer
Reefer	Reefer
Reefer/General Cargo	Reefer
Reefer/Pallets Carrier	Reefer
Reefer/Ro-Ro Cargo	Reefer
Reefer/Pass /Ro-Ro	Reefer
Research Vessel	Miscellaneous
Research Vessel, Naval Auxiliary	Miscellaneous
Marine Research	Miscellaneous
Research (Inland)	Miscellaneous
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	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
Self Elevating Install Barge	Other Tanker
Accommodation Barge	Offshore
Chemical & Oil Carrier	Chemical tanker

Clarkson's Vessel Type	Ship Type
Asphalt & Bitumen Carrier	Other tanker
Chemical/Products Tanker (Inland)	Chemical tanker
Bunkering Vessel	Other tanker
FPSO	Offshore
Product Carrier	Offshore
Oil Tanker (Inland)	Oil tanker
Tug, Anchor Hoy	Other tanker
Crude Oil Tank Barge	Oil tanker
Waste Disposal Carrier	Other tanker
Chemical Tanker (Inland)	Chemical tanker
Water Carrier	Other tanker
Edible Oil Carrier	Other tanker
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
Tank Ship	Other tanker
Mobile Offshore Drilling Unit	Offshore
Drillship	Offshore
Tanker	Other tanker
Wine Carrier	Other tanker
Accommodation Vessel	Offshore
Anchor Handling Tug/Supply	Offshore
Anchor Handling Tug	Offshore
FSU	Offshore
FSRU	Offshore
LNG/FPSO	Offshore
Slop Reception Vessel	Oil tanker
Water Tanker (Inland)	Other tanker
Semi-Submersible Drilling Rig	Offshore
LNG/FSU	Offshore

Clarkson's Vessel Type	**Ship Type**
Water Tanker, Naval Auxiliary	Other tanker
Bulk/Oil Carrier	Oil tanker
Drilling Tender	Offshore
LPG/FSO	Offshore
Accommodation Unit - Semi Sub	Offshore
Oil & Liquid Gas Carrier	Oil tanker
FPDSO	Offshore
Cylindrical Floating Drill Unit	Offshore
Methanol Carrier	Other tanker
Sulphuric Acid Carrier	Other tanker
Molten Sulphur Carrier	Other tanker
Shuttle Tanker	Oil tanker
Fruit Juice Carrier	Other tanker
Extended Well Test Vessel	Offshore
Chemical & LPG Carrier	Chemical tanker
Phosphoric Acid Carrier	Other tanker
LPG/FPSO	Offshore
Product Carrier/Ro-Ro	Other tanker
Cylindrical Floating Prod Unit	Offshore
Oil Recovery Tanker	Oil tanker
Products/Multi-Purpose Cargo	Other tanker
Cylindrical Floating Accom Unit	Offshore
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
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

ShipType	SizeUnits	SizeMin	SizeMax	SubType
		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
		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

APPENDIX B

Examples of Vessel Parameter Gap Filling Methods

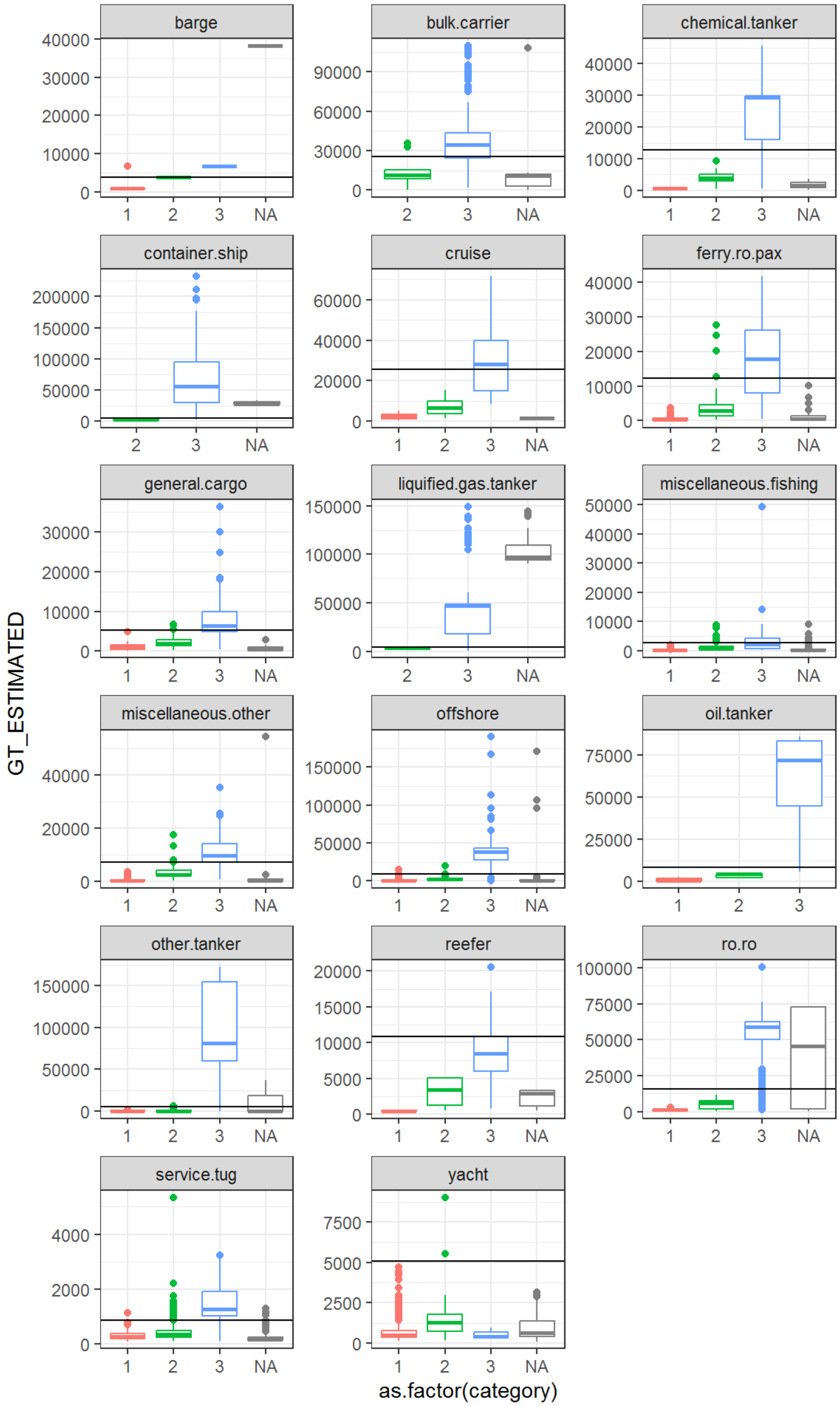

Figure B-1 Engine Category Assignment

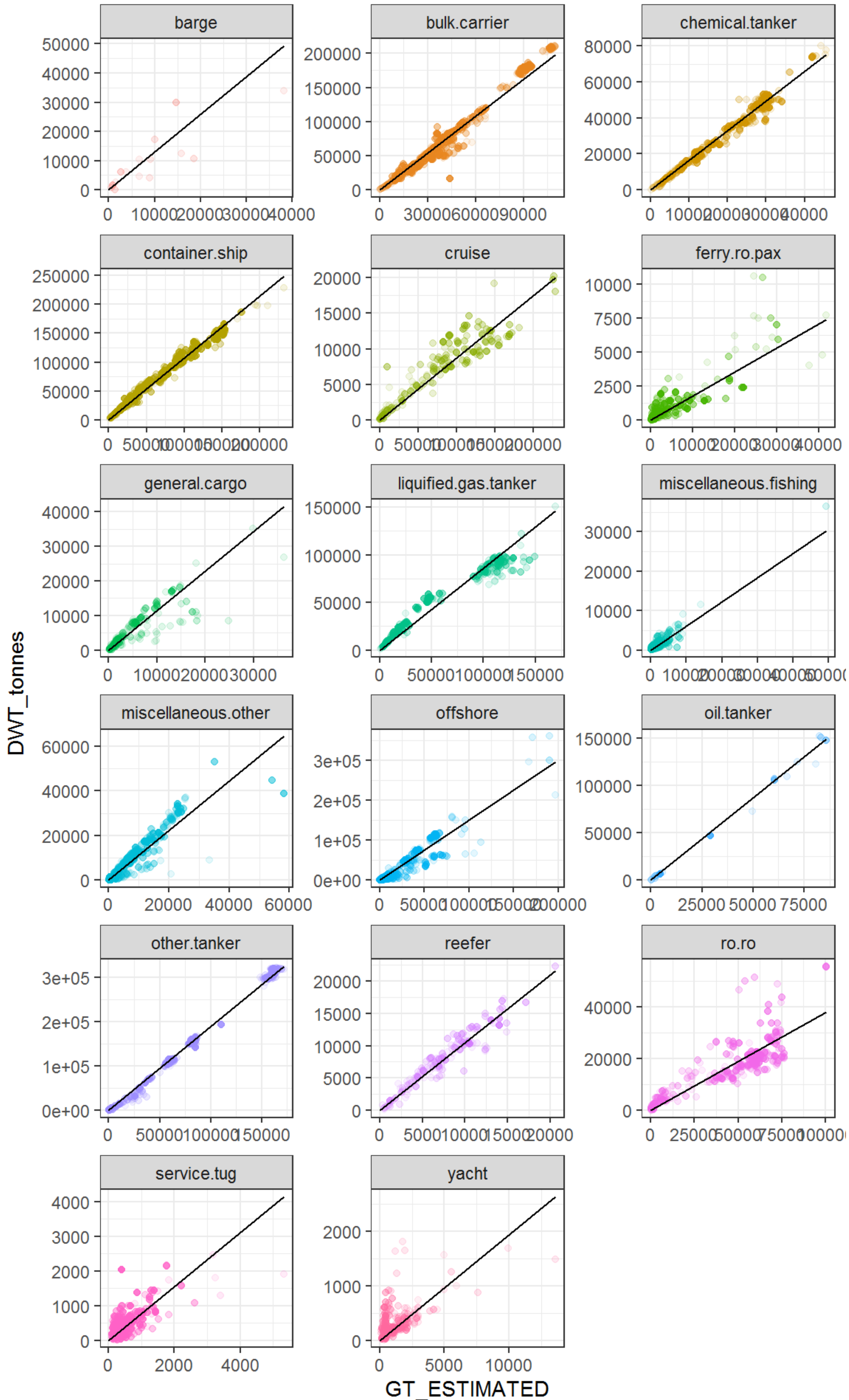

Figure B-2 Deadweight Tonnage Linear Regression with Gross Tonnage

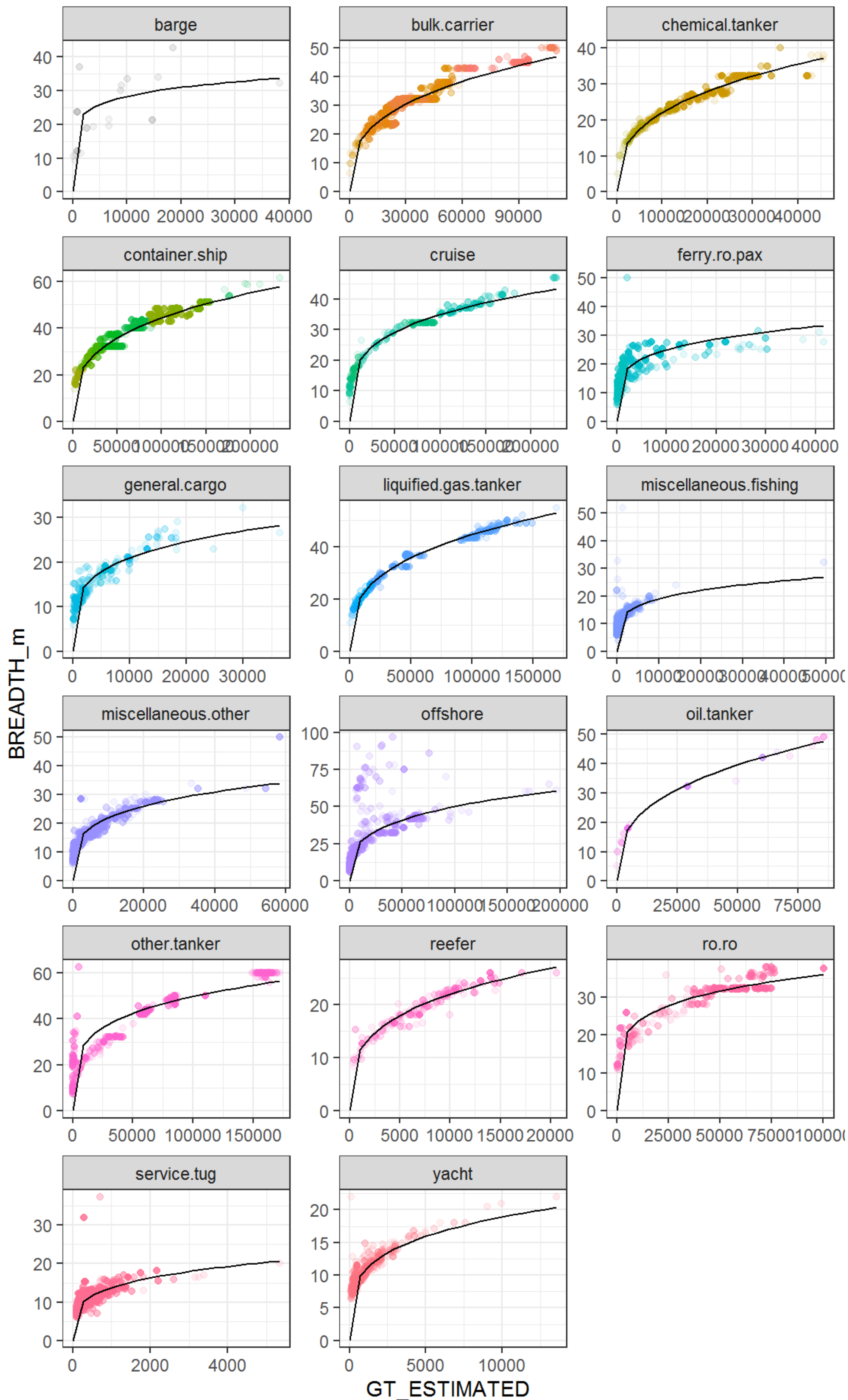

Figure B-3 Ship Breadth n-th Root Fit with Gross Tonnage

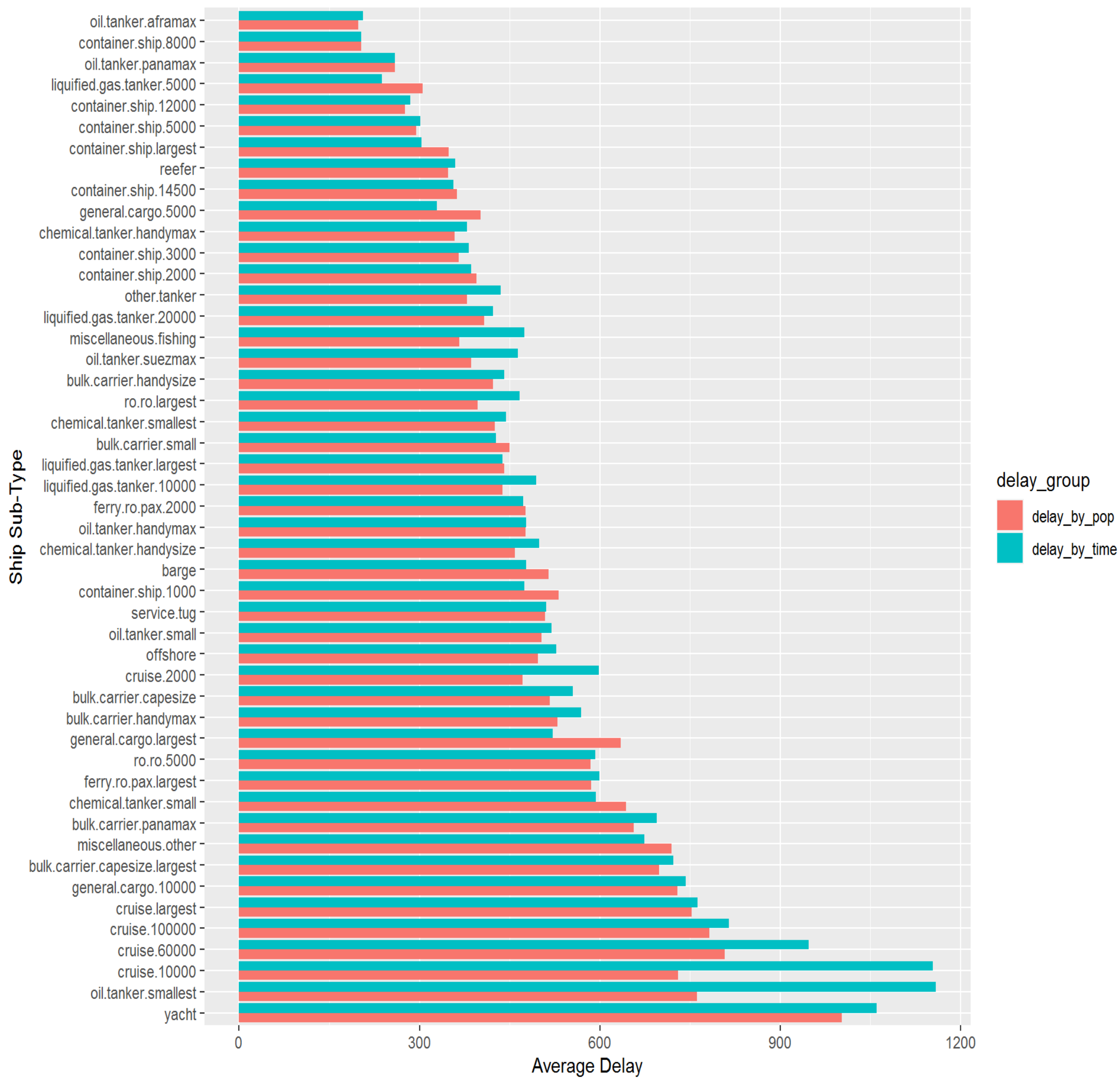

Figure B-3 Average Delay from Keel-laying Date to Build Date (weighted by time or population)

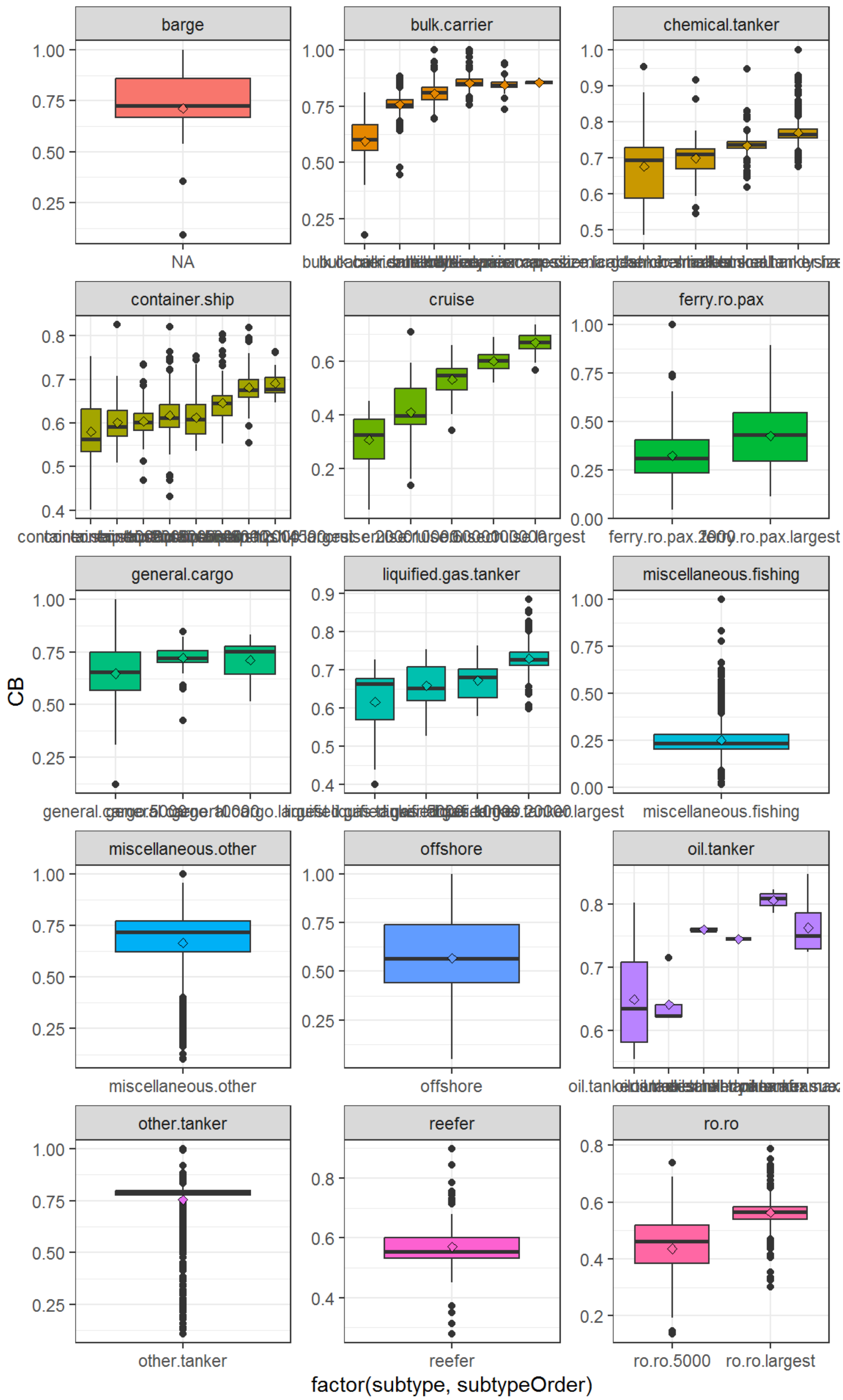

Figure B-4 Median Block Coefficient by Ship Subtype

APPENDIX C

Emission Growth Factors

Table C-1 Growth Rates by Ship Type and Region

Ship Type	Region	2026 Growth Factor	2032 Growth Factor	2038 Growth Factor
barge	Alaska	1.097044351	1.258645687	1.399417183
barge	Atlantic	1.017171201	1.044575449	1.085314879
barge	Gulf	1.001391993	1.003582105	1.057387979
barge	Hawaii	1.130133776	1.318536399	1.556391709
barge	Inland	0.969687755	0.930704544	0.921917278
barge	Pacific	1.089465319	1.216875766	1.346227461
bulk	Alaska	1.097044351	1.258645687	1.399417183
bulk	Atlantic	1.017171201	1.044575449	1.085314879
bulk	Gulf	1.001391993	1.003582105	1.057387979
bulk	Hawaii	1.130133776	1.318536399	1.556391709
bulk	Inland	0.969687755	0.930704544	0.921917278
bulk	Pacific	1.089465319	1.216875766	1.346227461
container	Alaska	1.072877772	1.182084519	1.29914446
container	Atlantic	1.089851307	1.234274499	1.411004394
container	Gulf	1.090433758	1.232583038	1.398431933
container	Hawaii	1.102784526	1.262038083	1.440365434
container	Inland	1.100765205	1.249797844	1.40397408
container	Pacific	1.106365845	1.270707046	1.457932948
cruise	Alaska	1.118389402	1.271774226	1.376261481
cruise	Atlantic	0.999618748	0.998279472	1.004116862
cruise	Gulf	1.058835044	1.146039924	1.247511687
cruise	Hawaii	1.072251334	1.173576767	1.290110714
cruise	Inland	0.981875891	0.960089752	0.963445208
cruise	Pacific	1.046569755	1.109300873	1.16219953
ferry	Alaska	1.073593304	1.198466397	1.362032686
ferry	Atlantic	1.083117827	1.208439227	1.344887822
ferry	Gulf	1.107431382	1.271639144	1.453945851
ferry	Hawaii	1.147631049	1.365336244	1.587956666
ferry	Inland	1.076469116	1.191937416	1.320959994
ferry	Pacific	1.142710201	1.355545266	1.581887619
fishing	Alaska	1.118389402	1.271774226	1.376261481
fishing	Atlantic	0.999618748	0.998279472	1.004116862
fishing	Gulf	1.058835044	1.146039924	1.247511687
fishing	Hawaii	1.072251334	1.173576767	1.290110714
fishing	Inland	0.981875891	0.960089752	0.963445208
fishing	Pacific	1.046569755	1.109300873	1.16219953
general	Alaska	1.094878337	1.239617073	1.399736797
general	Atlantic	1.080263684	1.201786059	1.338214711
general	Gulf	1.061249717	1.155611328	1.263820276
general	Hawaii	1.105253492	1.266036763	1.445615176

Ship Type	Region	GrowthFactor-2026	GrowthFactor-2032	GrowthFactor-2038
general	Inland	1.031199453	1.082745655	1.151826803
general	Pacific	1.09973871	1.25221261	1.421836896
government	Alaska	1.118389402	1.271774226	1.376261481
government	Atlantic	0.999618748	0.998279472	1.004116862
government	Gulf	1.058835044	1.146039924	1.247511687
government	Hawaii	1.072251334	1.173576767	1.290110714
government	Inland	0.981875891	0.960089752	0.963445208
government	Pacific	1.046569755	1.109300873	1.16219953
misc	Alaska	1.118389402	1.271774226	1.376261481
misc	Atlantic	0.999618748	0.998279472	1.004116862
misc	Gulf	1.058835044	1.146039924	1.247511687
misc	Hawaii	1.072251334	1.173576767	1.290110714
misc	Inland	0.981875891	0.960089752	0.963445208
misc	Pacific	1.046569755	1.109300873	1.16219953
offshore	Alaska	1.118389402	1.271774226	1.376261481
offshore	Atlantic	0.999618748	0.998279472	1.004116862
offshore	Gulf	1.058835044	1.146039924	1.247511687
offshore	Hawaii	1.072251334	1.173576767	1.290110714
offshore	Inland	0.981875891	0.960089752	0.963445208
offshore	Pacific	1.046569755	1.109300873	1.16219953
passenger	Alaska	1.118389402	1.271774226	1.376261481
passenger	Atlantic	0.999618748	0.998279472	1.004116862
passenger	Gulf	1.058835044	1.146039924	1.247511687
passenger	Hawaii	1.072251334	1.173576767	1.290110714
passenger	Inland	0.981875891	0.960089752	0.963445208
passenger	Pacific	1.046569755	1.109300873	1.16219953
reefer	Alaska	0.958846099	0.895934892	0.848294202
reefer	Atlantic	1.092565031	1.239522661	1.417402471
reefer	Gulf	1.054403429	1.140036665	1.245292708
reefer	Hawaii	1.091063383	1.235424961	1.407477656
reefer	Inland	1.030189669	1.075128991	1.12851689
reefer	Pacific	1.090821663	1.232835397	1.405991736
ro.ro	Alaska	1.073593304	1.198466397	1.362032686
ro.ro	Atlantic	1.083117827	1.208439227	1.344887822
ro.ro	Gulf	1.107431382	1.271639144	1.453945851
ro.ro	Hawaii	1.147631049	1.365336244	1.587956666
ro.ro	Inland	1.076469116	1.191937416	1.320959994
ro.ro	Pacific	1.142710201	1.355545266	1.581887619
tanker	Alaska	1.123853568	1.283171909	1.390511279
tanker	Atlantic	0.972903945	0.928839642	0.885003481
tanker	Gulf	1.074132284	1.183832549	1.299165138
tanker	Hawaii	1.017798123	1.035116461	1.039237769

Ship Type	Region	GrowthFactor-2026	GrowthFactor-2032	GrowthFactor-2038
tanker	Inland	1.020760397	1.052607733	1.090411048
tanker	Pacific	1.034738621	1.078914808	1.108991316
tour	Alaska	1.118389402	1.271774226	1.376261481
tour	Atlantic	0.999618748	0.998279472	1.004116862
tour	Gulf	1.058835044	1.146039924	1.247511687
tour	Hawaii	1.072251334	1.173576767	1.290110714
tour	Inland	0.981875891	0.960089752	0.963445208
tour	Pacific	1.046569755	1.109300873	1.16219953
tug	Alaska	1.118389402	1.271774226	1.376261481
Tug	Atlantic	0.999618748	0.998279472	1.004116862
Tug	Gulf	1.058835044	1.146039924	1.247511687
Tug	Hawaii	1.072251334	1.173576767	1.290110714
Tug	Inland	0.981875891	0.960089752	0.963445208
Tug	Pacific	1.046569755	1.109300873	1.16219953

APPENDIX D

Emissions by SCC

Table D-1 Emissions by SCC

SCC	Fuel	Ship Type	Port Uway	Engine	CO	CO_2	NH_3	NO_X	PM_{10}	$PM_{2.5}$	SO_2	VOC
2280202313	Diesel	Offshore	Port	Main	2	297	0	9	0	0	0	2
2280202314	Diesel	Offshore	Port	Aux	44	27,931	0	359	8	7	17	17
2280202323	Diesel	Offshore	Underway	Main	696	251,108	2	5,555	86	79	153	395
2280202324	Diesel	Offshore	Underway	Aux	246	155,373	1	1,996	42	39	95	94
2280203313	Diesel	Bulk Carrier	Port	Main	6	1,041	0	34	1	1	1	6
2280203314	Diesel	Bulk Carrier	Port	Aux	397	332,674	1	3,446	84	78	203	155
2280203323	Diesel	Bulk Carrier	Underway	Main	3,783	1,576,404	9	32,909	493	454	962	1,807
2280203324	Diesel	Bulk Carrier	Underway	Aux	939	799,285	4	8,337	202	186	487	367
2280204313	Diesel	Fishing	Port	Main	0	1	0	0	0	0	0	0
2280204314	Diesel	Fishing	Port	Aux	1	552	0	10	0	0	0	0
2280204323	Diesel	Fishing	Underway	Main	9	2,661	0	63	1	1	2	7
2280204324	Diesel	Fishing	Underway	Aux	6	3,998	0	77	1	1	2	2
2280205313	Diesel	Container Ship	Port	Main	77	11,501	0	413	8	7	7	76
2280205314	Diesel	Container Ship	Port	Aux	746	727,239	3	5,984	179	165	443	294
2280205323	Diesel	Container Ship	Underway	Main	11,566	3,660,152	23	83,925	1,289	1,186	2,236	6,753
2280205324	Diesel	Container Ship	Underway	Aux	3,254	2,577,591	12	25,419	662	609	1,572	1,264
2280206313	Diesel	Ferry	Port	Main	0	65	0	2	0	0	0	0
2280206314	Diesel	Ferry	Port	Aux	7	4,698	0	93	1	1	3	3
2280206323	Diesel	Ferry	Underway	Main	26	14,555	0	304	4	4	9	13
2280206324	Diesel	Ferry	Underway	Aux	12	7,501	0	149	2	2	5	5
2280207313	Diesel	General Cargo	Port	Main	0	40	0	1	0	0	0	0
2280207314	Diesel	General Cargo	Port	Aux	14	10,447	0	158	3	2	6	5
2280207323	Diesel	General Cargo	Underway	Main	54	27,030	0	555	8	7	16	26
2280207324	Diesel	General Cargo	Underway	Aux	26	19,893	0	267	5	5	12	10
2280209313	Diesel	Miscellaneous	Port	Main	1	168	0	5	0	0	0	1
2280209314	Diesel	Miscellaneous	Port	Aux	37	23,494	0	343	6	6	14	14
2280209323	Diesel	Miscellaneous	Underway	Main	384	199,230	1	3,282	59	54	122	193
2280209324	Diesel	Miscellaneous	Underway	Aux	65	41,236	0	564	11	10	25	25

SCC	Fuel	Ship Type	Port Uway	Engine	CO	CO_2	NH_3	NO_X	PM_{10}	$PM_{2.5}$	SO_2	VOC
2280210313	Diesel	Ro-Ro	Port	Main	8	1,181	0	41	1	1	1	8
2280210314	Diesel	Ro-Ro	Port	Aux	250	203,255	1	1,913	52	48	124	97
2280210323	Diesel	Ro-Ro	Underway	Main	1,932	792,494	4	14,089	248	229	483	944
2280210324	Diesel	Ro-Ro	Underway	Aux	567	411,317	2	4,336	108	99	251	219
2280211313	Diesel	Tanker	Port	Main	9	1,550	0	52	1	1	1	9
2280211314	Diesel	Tanker	Port	Aux	759	892,135	4	6,609	213	196	544	305
2280211323	Diesel	Tanker	Underway	Main	6,622	2,773,378	15	53,735	868	798	1,692	3,282
2280211324	Diesel	Tanker	Underway	Aux	2,225	1,901,580	9	19,397	481	442	1,160	869
2280213313	Diesel	Tug	Port	Main	0	120	0	3	0	0	0	0
2280213314	Diesel	Tug	Port	Aux	2	1,155	0	15	0	0	1	1
2280213323	Diesel	Tug	Underway	Main	449	263,677	1	3,606	76	69	161	220
2280213324	Diesel	Tug	Underway	Aux	7	4,689	0	65	1	1	3	3
2280214313	Diesel	Refrigerated	Port	Main	0	43	0	2	0	0	0	0
2280214314	Diesel	Refrigerated	Port	Aux	30	24,093	0	231	6	6	15	12
2280214323	Diesel	Refrigerated	Underway	Main	113	45,981	0	866	14	13	28	54
2280214324	Diesel	Refrigerated	Underway	Aux	77	58,727	0	611	15	14	36	30
2280215313	Diesel	Cruise	Port	Main	16	4,029	0	86	2	2	2	16
2280215314	Diesel	Cruise	Port	Aux	880	591,401	3	7,013	158	145	361	338
2280215323	Diesel	Cruise	Underway	Main	2,263	1,219,078	6	17,349	341	314	744	1,279
2280215324	Diesel	Cruise	Underway	Aux	2,694	1,767,824	8	23,482	475	437	1,078	1,034
2280302313	Residual	Offshore	Port	Main	0	9	0	0	0	0	0	0
2280302314	Residual	Offshore	Port	Aux	2	1,064	0	5	1	1	3	1
2280302323	Residual	Offshore	Underway	Main	158	63,415	1	1,673	79	73	199	80
2280302324	Residual	Offshore	Underway	Aux	13	8,675	0	117	9	9	27	5
2280303313	Residual	Bulk Carrier	Port	Main	0	80	0	3	0	0	0	0
2280303314	Residual	Bulk Carrier	Port	Aux	7	5,862	0	74	6	5	18	3
2280303323	Residual	Bulk Carrier	Underway	Main	1,743	739,801	16	19,035	894	823	2,322	799
2280303324	Residual	Bulk Carrier	Underway	Aux	144	100,383	2	1,317	105	97	315	55
2280304313	Residual	Fishing	Port	Main	0	2	0	0	0	0	0	0
2280304314	Residual	Fishing	Port	Aux	0	306	0	6	0	0	1	0

SCC	Fuel	Ship Type	Port Uway	Engine	CO	CO_2	NH_3	NO_X	PM_{10}	$PM_{2.5}$	SO_2	VOC
2280304323	Residual	Fishing	Underway	Main	20	6,008	0	144	10	9	19	17
2280304324	Residual	Fishing	Underway	Aux	6	3,765	0	61	4	4	12	2
2280305313	Residual	Container Ship	Port	Main	0	72	0	3	0	0	0	0
2280305314	Residual	Container Ship	Port	Aux	6	5,427	0	40	5	5	17	2
2280305323	Residual	Container Ship	Underway	Main	3,200	1,269,909	28	31,939	1,570	1,444	3,982	1,553
2280305324	Residual	Container Ship	Underway	Aux	355	254,906	5	2,941	266	244	800	137
2280306323	Residual	Ferry	Underway	Main	10	5,880	0	123	7	6	18	5
2280306324	Residual	Ferry	Underway	Aux	1	546	0	11	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	43	0	1	0	0	0	0
2280307323	Residual	General Cargo	Underway	Main	13	6,397	0	151	7	7	20	6
2280307324	Residual	General Cargo	Underway	Aux	3	1,812	0	28	2	2	6	1
2280309313	Residual	Miscellaneous	Port	Main	0	8	0	0	0	0	0	0
2280309314	Residual	Miscellaneous	Port	Aux	0	138	0	1	0	0	0	0
2280309323	Residual	Miscellaneous	Underway	Main	110	55,596	1	1,158	65	59	174	54
2280309324	Residual	Miscellaneous	Underway	Aux	7	4,719	0	68	5	5	15	3
2280310323	Residual	Ro-Ro	Underway	Main	376	165,733	4	3,927	198	182	520	173
2280310324	Residual	Ro-Ro	Underway	Aux	55	36,937	1	431	39	36	116	21
2280311313	Residual	Tanker	Port	Main	0	17	0	1	0	0	0	0
2280311314	Residual	Tanker	Port	Aux	2	1,608	0	17	2	1	5	1
2280311323	Residual	Tanker	Underway	Main	1,631	747,458	15	17,759	860	791	2,244	770
2280311324	Residual	Tanker	Underway	Aux	229	175,822	3	2,107	181	166	552	89
2280313313	Residual	Tug	Port	Main	0	3	0	0	0	0	0	0
2280313314	Residual	Tug	Port	Aux	0	4	0	0	0	0	0	0
2280313323	Residual	Tug	Underway	Main	4	2,140	0	37	2	2	7	2
2280313324	Residual	Tug	Underway	Aux	0	17	0	0	0	0	0	0
2280314313	Residual	Refrigerated	Port	Main	0	2	0	0	0	0	0	0
2280314314	Residual	Refrigerated	Port	Aux	4	3,306	0	35	3	3	10	2
2280314323	Residual	Refrigerated	Underway	Main	79	34,181	1	849	42	38	107	38
2280314324	Residual	Refrigerated	Underway	Aux	51	39,092	1	362	40	37	123	20

SCC	Fuel	Ship Type	Port Uway	Engine	CO	CO_2	NH_3	NO_X	PM_{10}	$PM_{2.5}$	SO_2	VOC
2280315313	Residual	Cruise	Port	Main	0	1	0	0	0	0	0	0
2280315314	Residual	Cruise	Port	Aux	1	551	0	6	1	1	2	0
2280315323	Residual	Cruise	Underway	Main	287	148,903	3	2,794	174	160	452	166
2280315324	Residual	Cruise	Underway	Aux	249	165,179	3	2,193	175	161	519	96
Grand Total					**50,069**	**25,489,648**	**194**	**417,184**	**10,970**	**10,093**	**25,685**	**24,352**