CATEGORY 3 COMMERCIAL MARINE VESSEL 2020 EMISSIONS INVENTORY

Prepared by:

U.S. Environmental Protection Agency
National Vehicle and Fuel Emissions Laboratory
2565 Plymouth Road
Ann Arbor, MI 48105

and

Eastern Research Group, Inc.
1600 Perimeter Park Drive
Morrisville, NC 27312

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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
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	Meter
$m\^{3}$	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
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) is a national compilation 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 NEI 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.

ERG supported EPA in its development of a Category 3 commercial marine vessel model entitled EPA Marine Emissions Tool (MET) component of the 2020 NEI and the corresponding modeling platform, where Category 3 engines are defined as having displacement above 30 liters per cylinder. This report documents the development of the MET, 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. This document is a deliverable under EPA contract EP-C-17-0411, Work Assignment 5-19.

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, 2020. 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).

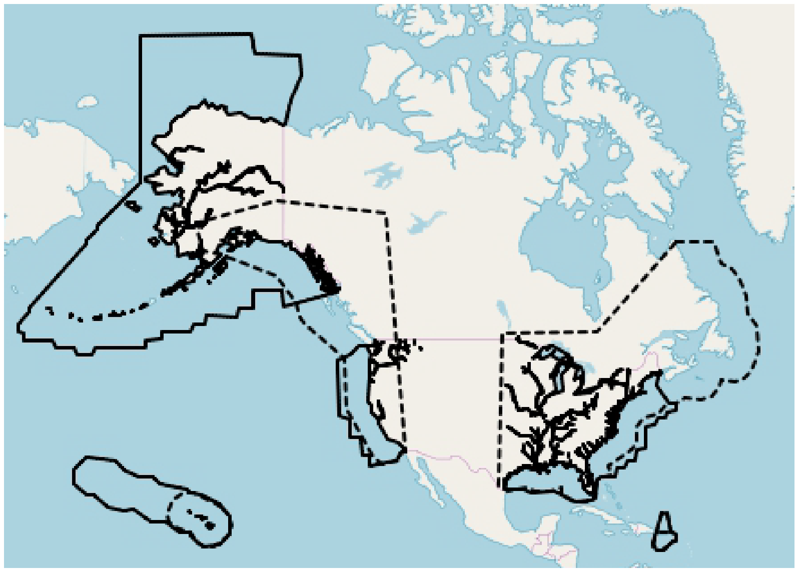

Figure 1. NEI Geographical Extent (Solid) and U.S. ECA (Dashed)

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 often written in a format difficult to read by most common computing programs. To ensure success in preprocessing, AIS data were standardized by parsing records into comma separated columns, with erroneously written records removed. 99.99% of the 1,740,356,397 records received for C1C2 and C3 from the USCG for the 2020 annual dataset were retained and standardized through this process, with the removal of just 62,374 erroneous records.

AIS data are transmitted to both satellite (S-AIS) and terrestrial (T-AIS) receivers (Figure 2). Satellite receivers provide adequate coverage over open ocean, where T-AIS coverage is sparse. However, T-AIS data are more suitable for reporting close-to-shore activity. 1,286,119,698 T-AIS and 454,174,325 S-AIS records were retained from the standardization process. Duplicate records were identified and removed within each dataset, with 153,048,673 duplicates removed from T-AIS files and 898 removed from S-AIS files.

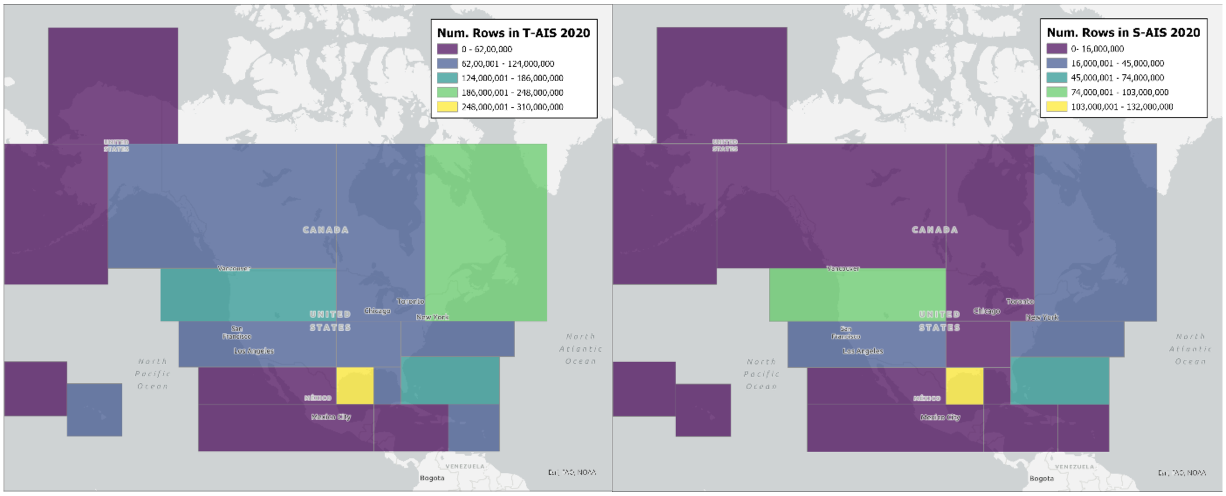

Figure 2. Distribution of Terrestrial and Satellite AIS Data

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 are more suitable for the close-to-shore activity within this inventory. 341,974,594 records appeared in both T-AIS and S-AIS datasets and were subsequently removed from the S-AIS 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 miscellaneous entities were identified using USCG-verified MMSI patterns, based on information obtained from the USCG Navigation center[1] leading to the removal of 70,715 records associated with divers' radios, coastal stations, aids to navigation, search and rescue aircraft and transmitters, man overboard devices, and emergency position indicating radio beacon MMSI patterns were removed. Easily identifiable pleasure craft vessels were also removed, further reducing the dataset by 435,650,562 records. This dataset cleaning reduced the size of the data by 51.6%, with in 843,100,503 records retained out of the total 1,740,294,023 read in for all vessel categories as noted in Figure 3.

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

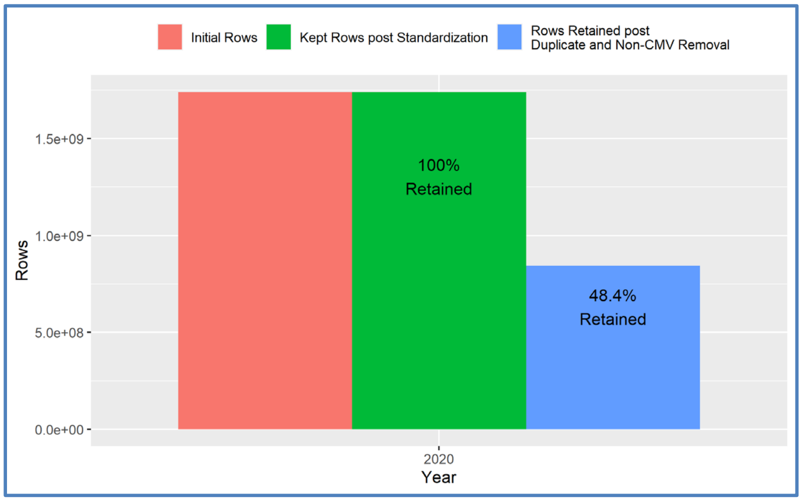

Figure 3. Comparison of Record Retention During Preliminary Processing

After this data cleaning step, the AIS data were parsed into daily files so that AIS messages 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 in order to reduce 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.

Though AIS reports include speed over ground (SOG), an additional speed was calculated using the calculated duration and distance intervals between consecutive records. Records associated with a calculated speed greater than 40 kn helped identify AIS messages that had erroneously reported their location and/or time, as the activity needed to transit to that location at that time for that vessel would have been impossible. These records were removed and time and distance were recalculated across their gap. Erroneous vessels were identified if 30% or more of their daily records were associated with erroneous calculated speeds. These erroneous vessels were removed from that day's emissions estimates. Where time, distance, and calculated speed were considered within reason, but SOG was greater than 40 kn, SOG was replaced by calculated speed, otherwise SOG was used for all emissions estimations calculations. 67.9% of all 2020 AIS records were retained after removal of single record filtering, hoteling aggregation, or erroneous speed calculations.

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.

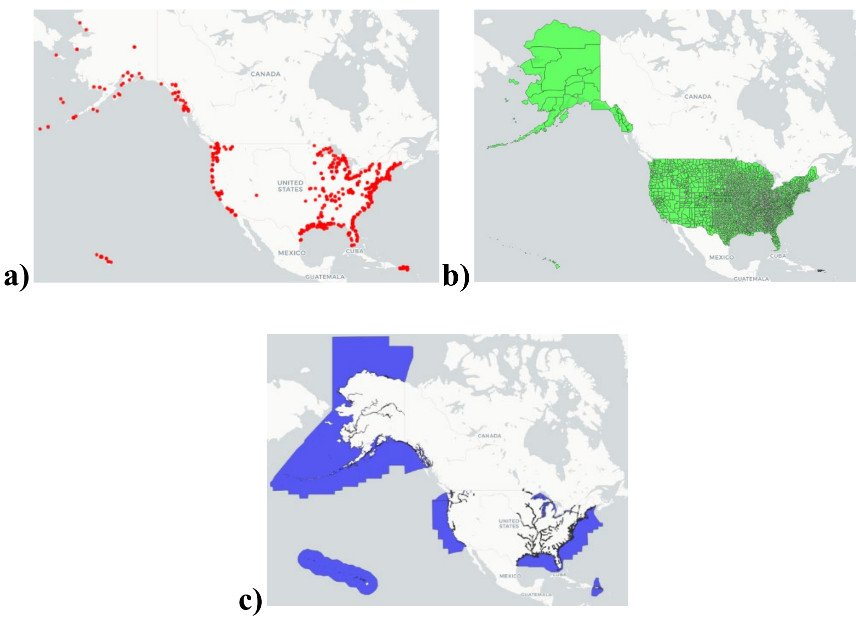

Figure 4. Shapefiles Used for Assigning FIPS including a) NEI Port Shapefile; b) TIGER County Shapefile; c) NEI Shipping Lane Shapefile

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 merged first on IMO number and then on the MMSI. All units were converted to metric units and all data for duplicate IMO numbers were merged. Expected ranges of ship parameter values were calculated for each ship type using the validated data. Where values differed between datasets, the parameter within the expected range was chosen. Vessel parameters required for emissions calculations 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

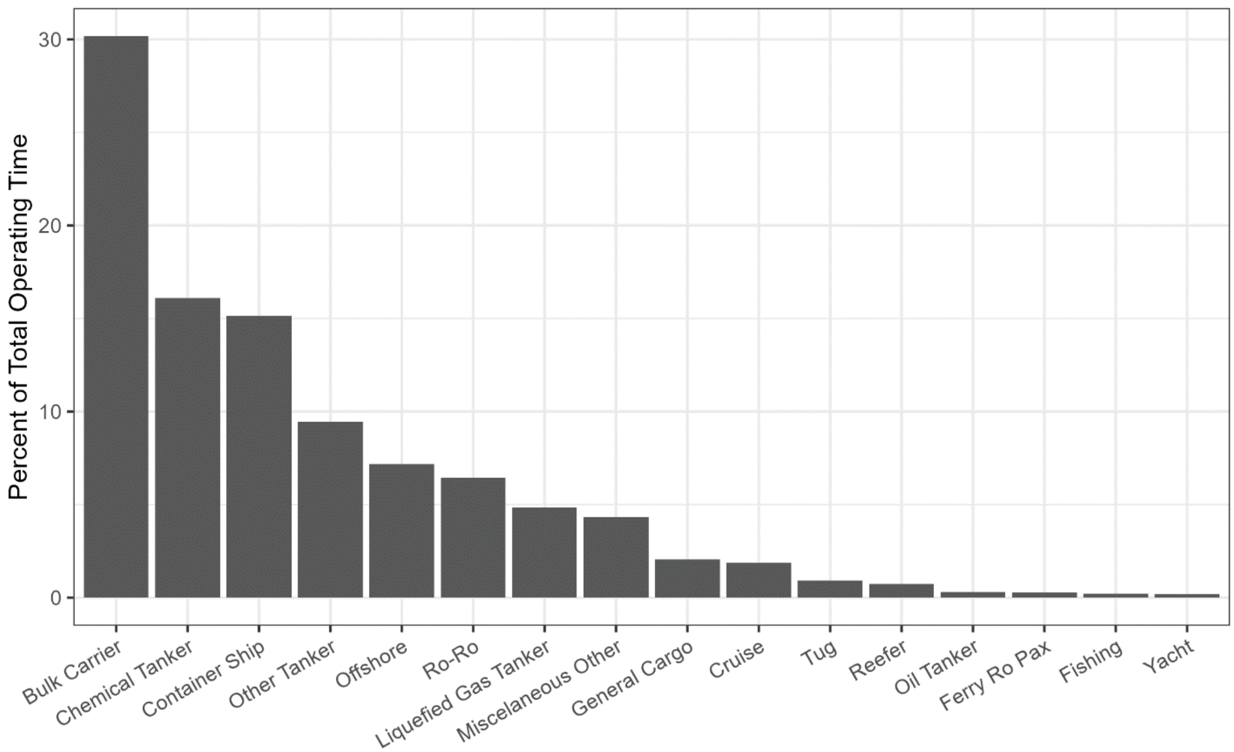

Figure 5. Category 3 AIS Activity Breakdown by Ship Type

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.

These propulsion type, main stroke type, and engine rpm fields either were not available in Clarkson's dataset or did not contain the needed information to complete the engine type classification. For this reason, an older Lloyds Information Handling Service (IHS) dataset was also used to determine engine type for the vessels represented in both datasets (IHS, 2014). The remaining 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. Waterline length (lwl) is typically calculated from length between perpendiculars (lbp). When lbp was missing, lwl was estimated based on a regression analysis using length overall. Missing twenty-foot equivalent (TEU) and DWT vessel size indicators were regressed from gross tonnage for the ship types that required these fields for their subtype assignments. Predicted values were only taken if they were within the expected range of that ship type. Ship types with a single subtype were given that subtype, regardless of whether their size fields were available.

A small portion of vessels could not be assigned subtypes, either because they were missing vessel type (and thus ship type information) or because their size fields could not be filled adequately. These represented 0.6% and 0.04% of the 2020 AIS fleet activity time, respectively; they were removed from the inventory, as these fields are required for the assignment of auxiliary and boiler engine power and the sensitivities to applying average subtypes have not been assessed.

The remaining fields were filled according to the most common parameters seen by vessels in the 2020 AIS vessel activity dataset. Annual time spent within the geographical extent was calculated for each vessel appearing in both the AIS and compiled ship registry datasets.

Missing keel year was estimated from build year (calculated from either the time-weighted or population-weighted average time difference between these dates by subtype). The most common ship category, engine type, and tier in the 2020 fleet were identified by ship type; subtype; and iterative groupings of ship category, engine type, and tier. The most common value at the most granular grouping was prioritized in gap-filling these fields, after which common values determined by less granular groupings were applied.

Similarly, time-weighted averages of the remaining numerical vessel characteristics were calculated at varying levels of granularity of subtype, ship category, engine type, and tier. The time-weighted average at the most granular grouping was prioritized in gap-filling these fields, after which averages determined by less granular groupings were applied. 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 back-calculated from the average applied block coefficient and the remaining input parameters. (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 2020 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.

4.5 Merging AIS data and the Ship Registry Dataset

The IMO vessel identification code is a seven-digit vessel identifier assigned on behalf of the IMO to self-propelled, primarily commercial, seagoing cargo vessels with a gross tonnage of 300 or more or passenger vessels with a gross tonnage of 100 or more. The IMO vessel identification code remains linked to the vessel hull, regardless of changes in names, operations, or owners.

The MMSI is a nine-digit identifier associated with radio transmission of AIS messages. This means that every vessel in the AIS dataset has a unique identifier. However, because the MMSI ID is attached to the transmitter, an operator may fail to report a move of their radio transmitter between vessels. Therefore, the IMO number is prioritized as the matching identifier between the ship registry and AIS datasets. Those unmatched by this identifier were linked using the MMSI number. Each vessel in the linked dataset is assigned a unique ID.

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, 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).

$$Power\ (kW) = \frac{\rho \times C_T \times \frac{1}{2} \times S \times {V_{reported}}^3}{\eta_T}$$ **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°C 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.

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

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[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).

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.

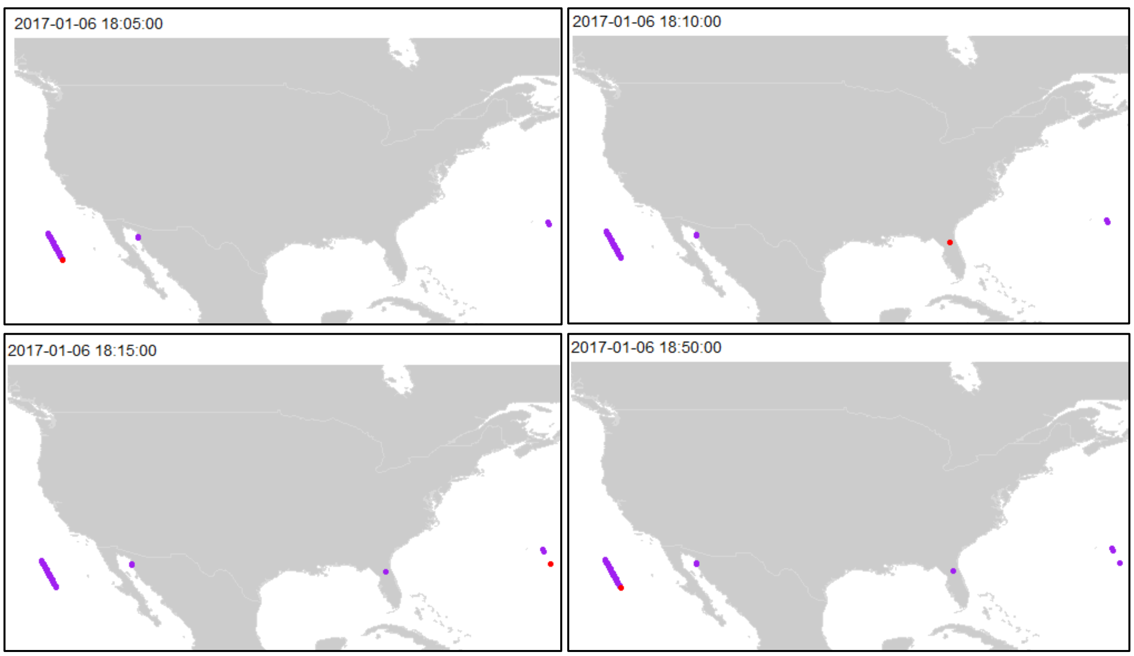

Figure 6. Example of Rogue Messages (Current Activity Message in Red and Past Messages in Purple)

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 2. 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 Summary

Table 3 presents the total estimated emissions due to Category 3 marine vessels in the NEI area throughout 2020, Table 4 presents emissions by vessel type and Figure 7 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 3. Total 2020 Category 3 emissions in tons for U.S. waters including federal waters

CO	CO_2	NO_X	$PM_{2.5}$	PM_{10}	SO_2	VOC
56,486	28,064,099	585,953	25,933	281,878	193,815	26,499

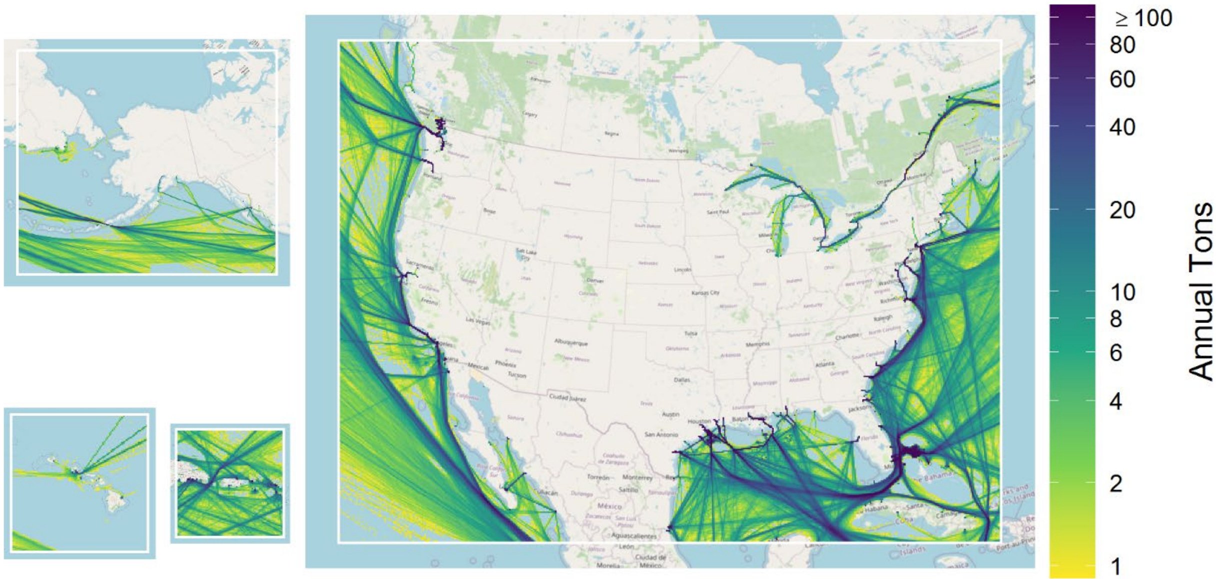

Figure 7. C3 2020 Annual NO_X Emissions

Table 4. Total 2020 Category 3 emissions by ship type (tons unless otherwise indicated)

Ship Type	CO	CO_2	NO_x	$PM_{2.5}$	PM_{10}	SO_2	VOC	Energy (kWh)
Bulk carrier	9,080	4,367,498	97,720	2,782	3,024	7,598	4,127	6.16E+09
Chemical tanker	4,260	2,282,164	43,637	847	920	2,158	1,925	3.1E+09
Container ship	21,913	9,395,697	215,621	5,669	6,162	15,055	10,780	1.28E+10
Cruise ship	3,467	2,162,812	36,489	736	800	1,934	1,498	2.76E+09
General cargo	237	152,271	2,575	49	53	127	101	1.96E+08
Miscellaneous other	643	336,800	6,927	150	163	396	309	4.59E+08
Offshore	1,259	548,559	12,610	242	263	588	641	7.5E+08
Oil tanker	77	48,848	832	16	17	41	36	6.18E+07
Other tanker	3,410	1,748,462	33,705	734	798	1,880	1,668	2.33E+09
Reefer	338	190,660	4,106	138	150	413	148	2.55E+08
Ro Ro	3,544	1,846,281	37,964	763	829	1,979	1,629	2.49E+09
Service tug	89	39,592	746	12	13	25	54	4.78 E+07
Fishing	28	10,558	248	11	11	24	20	1.16E+07
Ferry-Ro-Pax	44	26,085	537	11	12	32	19	3.50E+07
Liquified-gas tanker	3,396	2,164,358	32,199	902	980	2,463	1,535	2.8E+09
Yacht	3	1,805	36	0	1	1	1	2.35E+06

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.

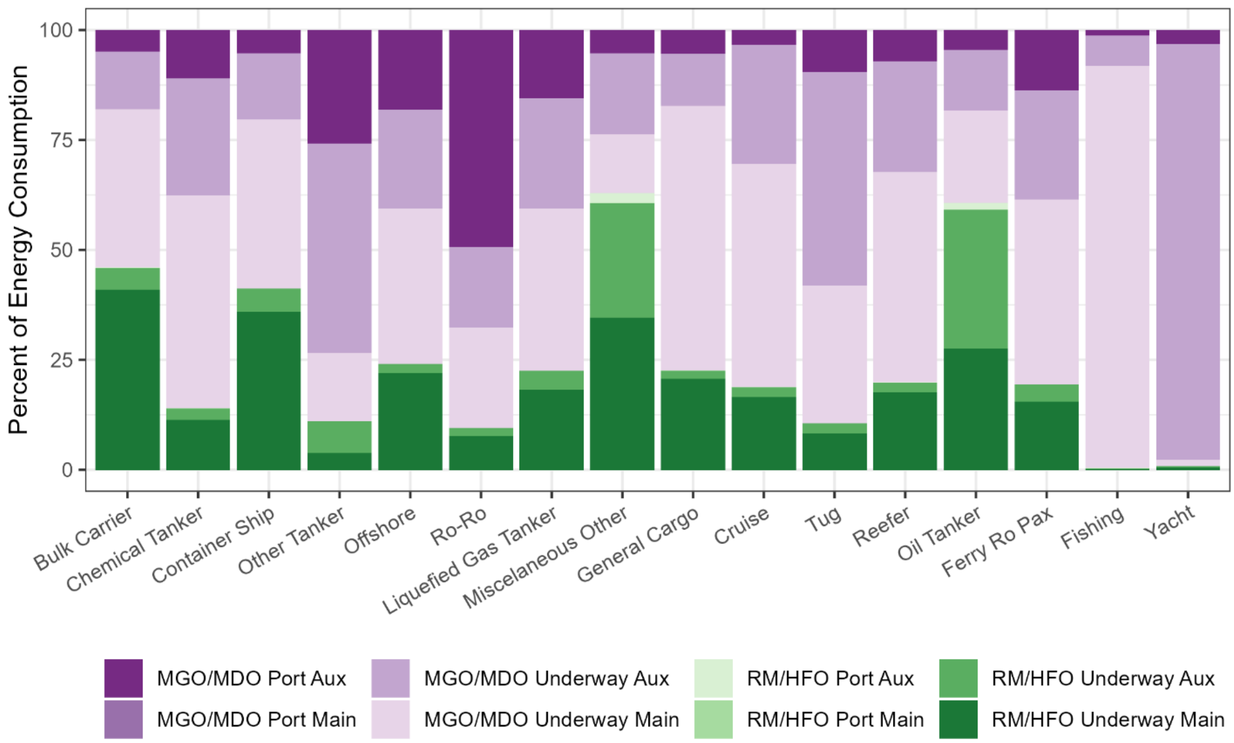

Figure 8. Ship Type Kilowatt Hour Distribution by SCC

Table 5. Category 3 NEI Emissions by SCC (tons)

SCC	Fuel Type	Port Status	Engine Type	CO	CO_2	NO_x	$PM_{2.5}$	PM_{10}	SO_2	VOC
2280002103	MGO/MDO	Port	Main	130	20,153	703	12	13	12	127
2280002104	MGO/MDO	Port	Aux	2,965	2,669,477	31,440	614	668	1,628	1,163
2280002203	MGO/MDO	Underway	Main	24,256	9,237,227	229,185	2,754	2,993	5,638	12,512
2280002204	MGO/MDO	Underway	Aux	7,514	5,779,548	79,296	1,375	1,494	3,524	2,913
2280003103	RM/HFO	Port	Main	4	602	22	1	2	2	4
2280003104	RM/HFO	Port	Aux	1,7	14,646	202	14	15	46	7
2280003203	RM/HFO	Underway	Main	15,091	6,317,487	164,816	7,060	7,674	19,835	7,069
2280003204	RM/HFO	Underway	Aux	1,809	1,283,310	20,287	1,234	1,341	4,028	697

8.0 Limitations

Use of AIS data to develop emission inventories is a significant improvement over early methods that required assumptions about vessel power, operating load and level of activity. Assumptions made in these earlier inventories are replaced with actual vessel specific power data and other attributes provided by classification societies, calculated load factors based on the vessel's actual speed relative it is service speed, and other details related to vessel location and time stamp included in the AIS data stream.

The AIS system continues to evolve and expand coverage, but there are still areas where the VHS signals are missing and there are vessels that do not have transponders or turn off their transponders. In processing the AIS data for 2020, record counts could vary significantly from day to day indicating possible gaps suggesting that the AIS data may underestimate actual activities.

Review of the processed AIS data also indicated that there are distinct periods of satellite outage. This has an impact for sections of shipping lanes that are beyond the range of VHF towers (25-30 miles), particularly for vessels traveling in federal and international waters.

Earlier AIS approaches estimated duration relative to the last known observation. By creating a buffer that extended into international waters, it was possible to identify and address vessels that leave federal waters and return later generating very unreasonably large duration times. But for some vessels, not near the federal/international boundary, there may be long periods of time between observations. It is impossible to tell if these vessels are not operating or if there is a problem with the AIS transponder or receiver. In this version, any last known observation greater than 24 hours is considered suspect, and periods without a signal greater than 24 hours are filtered. Further study is needed to better understand these events.

Though AIS has been instrumental in improving the overall quality of propulsion engine emission estimates, similar improvements are needed for auxiliary engines, specifically better methods to estimate auxiliary engine operating loads.

As use of shore power expands it would be helpful to have ports provide information about utilization rates for all vessel categories to adjust dockside emissions to account for these initiatives and avoid double counting with land-side Electricity Generating Units (EGUs).

9.0 References

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APPENDIX A

Ship Type and Subtype Assignments

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
Bulk Carrier	Bulk carrier

Clarkson’s Vessel Type	**Ship Type**
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
Aggregate Carrier	General cargo

Clarkson's Vessel Type	Ship Type
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
Minelayer	Miscellaneous

Clarkson's Vessel Type	Ship Type
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
Standby Safety/Guard	Miscellaneous

Clarkson's Vessel Type	**Ship Type**
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
Cutter Suction/Bucket Wheel Dredger	Offshore

Clarkson’s Vessel Type	**Ship Type**
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
Buoy/Lighthouse Tender	Offshore

Clarkson's Vessel Type	Ship Type
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
Asphalt & Bitumen Carrier	Other tanker

Clarkson's Vessel Type	**Ship Type**
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
Water Tanker, Naval Auxiliary	Other tanker

Clarkson's Vessel Type	**Ship Type**
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

A-2 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
		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

ShipType	SizeUnits	SizeMin	SizeMax	SubType
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