Eastern Research Group, Inc.

Category 1 and 2 Commercial Marine Vessel 2022 Emissions Inventory

Prepared for:

U.S. Environmental Protection Agency
Office of Air Quality Planning and Standards
109 T.W. Alexander Drive
Research Triangle Park, NC 27711

Prepared by:

Eastern Research Group, Inc.
1600 Perimeter Park Drive, Suite 200
Morrisville, NC 27312

July 31, 2024

Table of Contents

List of Tables

List of Figures

List of Abbreviations

AIS	Automatic Identification Systems
C1	Category 1
C1C2	Category 1 and 2
C1C2CMV	Category 1 and 2 commercial marine vessel components
C2	Category 2
C3CMV	Category 3 Commercial Marine Vessel
CMV	Commercial Marine Vessel
CO_2	Carbon Dioxide
ECA	Emissions Control Area
EF	Emission factor
FCC	Federal Communications Commission
GFW	Global Fishing Watch
HAP	Hazardous air pollutant
g/kWhr	Grams/kilowatt hour
kWhrs	Kilowatt-hours
GPS	Global Positioning System
GT	Gross Tonnage
IMO	International Maritime Organization
Kn	Knot
kW	Kilowatts
LF	Load factor
LLAF	Low load adjustment factor
LNG	Liquified natural gas
MDO	Marine diesel oil
MGO	Marine gas oil
MMSI	Maritime Mobile Service Identifier
NEI	National Emission Inventory
Nm	Nautical miles
PM	Particulate matter
PM_{10}	Particulate matter less than 10 microns in diameter
$PM_{2.5}$	Particulate matter less than 2.5 microns in diameter
Reefer	Refrigerated vessels
Ro Ro	Roll on/Roll off
S-AIS	Satellite automatic identification systems
SO_2	Sulfur dioxide
SOLAS	Safety of Life at Sea
T-AIS	Terrestrial automatic identification systems
TEU	Twenty-foot equivalent units
USACE	US Army Corps of Engineers
USCG	United States Coast Guard
USEPA	U.S. Environmental Protection Agency
ITU	International Telecommunications Union
VHF	Very High Frequency

1.0 Introduction

The National Emission Inventory (NEI) assembles data that state, tribal, and local agencies need in order to evaluate and compare emissions trends within the United States. The NEI also serves as a basis for various U.S. Environmental Protection Agency (USEPA) modeling and regulatory analyses. The NEI compiles comprehensive emissions data for criteria pollutants, hazardous air pollutants, and greenhouse gases for mobile, point, and nonpoint sources.

ERG has developed the Category 1 and 2 commercial marine vessel components (C1C2CMV) of the 2022 modeling platform. Category 1 (C1) engines are defined as having displacement below 7 liters per cylinder while Category 2 (C2) engines are defined as having displacement below 30 liters per cylinder and greater than or equal to 7 liters per cylinder.

Note this 2022 modeling platform builds upon the 2020 NEI which used a similar approach. Improvements in surrogate value calculations within the 2022 inventory have increased emission estimates in comparison to the 2020 NEI. This report documents the development of the Automated Identification System (AIS) preprocessor for all CMV modeling data (C1, C2) and the application of the C1C2CMV model used for the 2022 modeling platform including the conceptual framework, equations, data sources, assumptions, and limitations.

AIS is a tracking system used by vessels to enhance navigation and avoid collision with other AIS transmitting vessels. This system integrates a vessel's Very High Frequency (VHF) radio transceiver with positioning systems such as a Global Positioning System (GPS) receiver and other electronic navigation sensors, such as gyrocompasses or rate of turn indicators. Each participating vessel transmits a signal that is picked up by onshore VHF towers, oil and gas platforms or offshore buoys equipped with AIS receivers, or satellites. VHF towers that receive these signals have a range of approximately 20-30 nautical miles, while a growing number of AIS satellites extend the range up to 2,000 miles from the coast.

The (IMO) International Convention for the Safety of Life at Sea requires AIS transmitters be fitted aboard all passenger ships as well as vessels with gross tonnage (GT) of 300 or more involved in international trips (IMO, 2002). As the cost of these transmitters have reduced over time, voluntary AIS usage has increased even for smaller vessels that do not trigger reporting requirements. In addition to the IMO requirements, the United States Coast Guard (USCG) has mandated that all commercial marine vessels continuously transmit AIS signals while transiting U.S. navigable waters.

The USEPA Office of Transportation and Air Quality received AIS data from USCG in order to quantify all ship activity which occurred between January 1 and December 31, 2022. The provided AIS data extends beyond 200 nautical miles from the U.S. coast. Data were received for the areas shaded in gray. For the 2022 modeling platform the boundary in the U.S. Exclusive Economic Zone was used (black line in Figure 1). This includes the continental U.S., Alaska, Hawaii, and U.S. protectorates in the Caribbean.

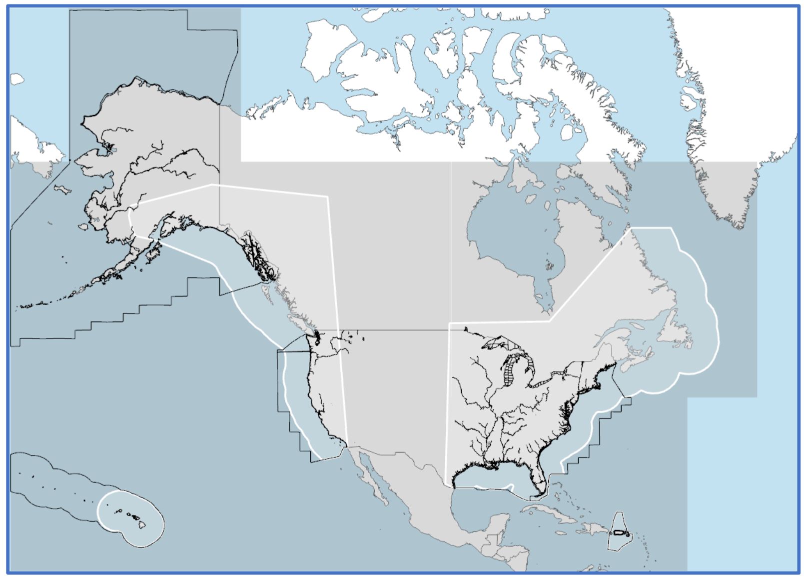

Figure 1. Entire AIS Area (Transparent Gray), 2022 Modeling Platform Geographical Extent (Black Outline), and U.S. ECA (White Outline)

The AIS data were compiled into five-minute intervals by the USCG, providing a reasonably refined assessment of a vessel's movement. For example, using a five-minute average, a vessel traveling at 25 knots (kn) would be captured every two nautical miles that the vessel travels. For slower moving vessels, the distance between transmissions would be less. The ability to track vessel movements through AIS data and link them to vessel attribute data, has allowed for the development of an inventory of very accurate emission estimates. These AIS data were used to define the locations of individual vessel movements, estimate hours of operation, and quantify propulsion engine loads. The compiled AIS data also included the vessel's IMO number and Maritime Mobile Service Identifier (MMSI); which allowed each vessel to be matched to their characteristics obtained from the Clarksons ship registry (Clarksons, 2021).

The engine bore and stroke data reported in Clarksons for all vessel included in the AIS dataset, were used to calculate cylinder volume. Any vessel that had a calculated cylinder volume greater than 30 liters was flagged as a C3 vessel and incorporated into the USEPA's new Marine Emissions Tools. The remaining records were assumed to represent C1C2 or non-ship activity. This report focuses on data processing for the C1C2 vessels.

2.0 AIS Data Processing

USCG AIS data is 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 3,066,040,708 records received from the USCG for the 2022 annual dataset were retained and standardized through this process, with the removal of just 13,701 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. 2,216,185,142 T-AIS and 849,841,865 S-AIS records were retained from the standardization process. Duplicate records were identified and removed within each dataset, with 1,108,127,188 duplicates removed from T-AIS files and 10,240 removed from S-AIS files.

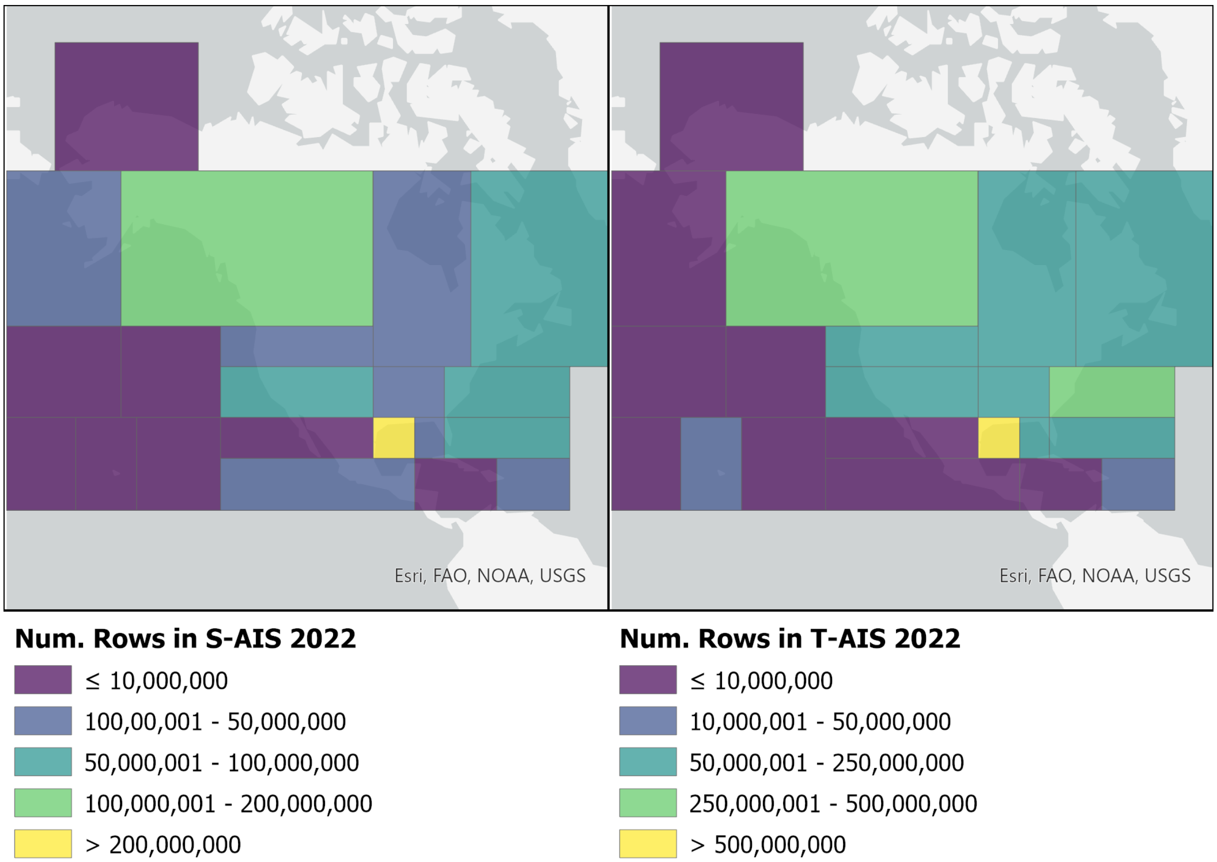

Figure 2. Distribution of Terrestrial and Satellite AIS Data

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. 553,948,321 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 were identified and removed from the AIS dataset. These miscellaneous entities were identified using USCGverified MMSI patterns, based on information obtained from the USCG Navigation center.[1] An additional, 2,209,516 records were removed from the dataset. These 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 MMSI patterns. Easily identifiable pleasure craft vessels were also removed, further reducing the dataset by 333,616,783 records. This data cleaning reduced the size of the dataset by 65.2%, with 1,068,114,959 records retained out of the total 3,066,040,708 read in for all vessel categories, as noted in Figure 3. Note that the data referenced here include information for C1, C2, and C3 vessels.

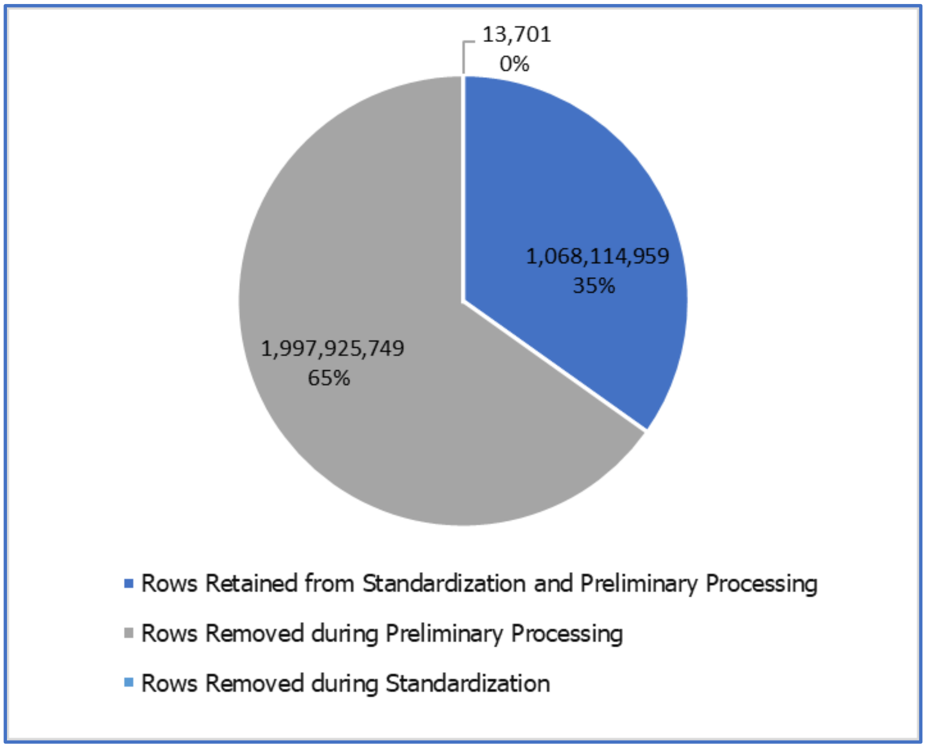

Figure 3. Comparison of Record Retention During Preliminary Processing

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 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 distances 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

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

haversine method. 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 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. 326,492,785 AIS records were retained after removal of single record filtering, hoteling aggregation, and erroneous speed calculations. This accounts for 10.6% of all 2022 AIS records.

Each remaining AIS record was assigned a state and county FIPS code for aggregation purposes. FIPS codes were assigned using three shapefiles: the Port Shapefile, the 2021 TIGER County Shapefile, and the Shipping Lane Shapefiles (Figure 4). If an AIS record reported from a location within a Port Shapefile, it would receive the FIPS code associated with that port polygon. In addition, these records with port polygons were assigned port source classification codes (SCCs), and all others were assigned underway SCCs. Otherwise, if an AIS message did not report from a port but did report from within a TIGER County shapefile, it would receive the FIPS code associated with that county shape. Finally, an AIS message reported from within the shipping lane shapefiles, but not within the TIGER County or port shapefiles (i.e., federal waters), would be assigned the FIPS associated with that specific federal waters shipping lane shape. All records reported outside United States territorial waters were assigned a FIPS of 98001. Additional codes were used to differentiate Canadian and Mexican waters.

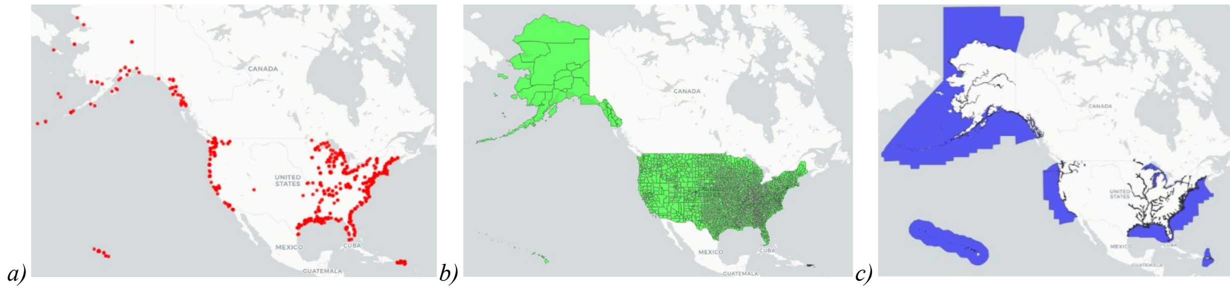

Figure 4. Shapefiles Used for Assigning FIPS including a) Port Shapefile; b) TIGER County Shapefile; c) Shipping Lane Shapefile

3.0 Emissions Calculation

This inventory represents emissions from each self-propelled, and non-pleasure-craft, marine vessel included in the cleaned AIS activity dataset. Emissions are calculated for each time interval between consecutive AIS messages for each vessel and allocated to the location of the message following the interval. Emissions are calculated according to Equation 1.

$$Emissions_{interval} = Time\ (hr)_{interval} \times\ Power(kW) \times EF(\frac{g}{kWh}) \times LLAF \qquad (1)$$

Power is calculated for the propulsive (main), auxiliary, and auxiliary boiler engines for each interval and emission factor (EF) reflects the assigned emission factors for each engine, as described below. LLAF represents the low load adjustment factor, a unitless factor which reflects increasing propulsive emissions during low load operations. Time indicates the activity duration time between consecutive intervals.

4.0 Vessel Identification

After the AIS dataset was cleaned, the MMSIs were compiled for vessel identification. Vessels must be identified to determine their vessel type, and thus their vessel group, power rating, and engine tier information which are required for emissions calculations. Ship characteristics information was compiled from Clarksons 2021 Ship Registry and Global Fishing Watch's (GFW) Version 2 Fishing Vessels dataset, with a preference for Clarksons reported data when the same vessels were reported across multiple datasets. GFW determines ship type information by analyzing processed 2012 to 2020 AIS data through machine learning classifiers, which identify activity patterns by ship and gear type.

Vessel-specific information was linked to AIS records by matching the AIS fleet MMSIs and IMOs with those in the compiled ship registry dataset. C3 vessels that could not be matched on both identifiers were matched on IMO and then MMSI, in that order. In contrast, C1C2 vessels were matched on MMSI before IMO if it could not match on both identifiers.

The received AIS data included ship and cargo type information, but because these data are entered by the user, there might be issues with regards to the accuracy of this field. The current version of the Marine Cadastre AIS data includes updated vessel type information that tries to address some of these quality issues (Marine Cadastre, 2018). The Marine Cadastre vessel types associated with the AIS ship and cargo type number were used for the remaining vessels unidentified by both the Clarksons and GFW datasets.

5.0 Vessel Group Assignments

Each vessel in the 2022 fleet was assigned a unique vessel type based on the combination of vessel types designated from Clarksons, Bureau of Ocean Energy Management (BOEM), and Marine Cadastre. Priority was given to Clarksons and BOEM when making vessel type assignments due to the data quality issues of AIS. In total, 246 different vessel types were assigned to C1C2 vessels (Table A-1, Appendix A). Surrogate vessel attribute data is not available for all vessel types, so vessel types were aggregated into 16 different vessel groups for which surrogate data were available (Table 1). Note that the number of vessels assigned to a vessel group has increased from 2017 to 2022. This indicates an increase in use of AIS transponders which enables more vessels to be included within the inventory. Vessels were assigned to the Miscellaneous vessel group if their vessel type did not fit into any of the other groups. The Miscellaneous vessel group represents 1.6% of the 2022 fleet which is a large improvement from 2017 when it accounted for 14.3% of the fleet. This decrease can be attributed to improvements in both vessel group assignments and Marine Cadastre vessel type codes.

Table 1. C1C2 Inventory Ship Counts in Entire AIS Data

Vessel Group	2017 Entire Area Ship Count	2020 Entire Area Ship Count	2021 Entire Area Ship Count	2022 Entire Area Ship Count
Bulk Carrier	45	44	46	47
Commercial Fishing	1,686	4,262	5,826	5,859
Container Ship	8	16	11	15
Ferry Excursion	482	724	849	997
General Cargo	1,555	3,451	3,190	3,122
Government	1,368	1,192	1,179	1,216
Miscellaneous	1,810	269	291	300
Offshore support	1,203	1,337	1,416	1,377
Pilot	NA	17	15	15
Reefer	15	13	12	28
Ro Ro	27	218	219	212
Tanker	144	555	591	677
Tug	4,203	5,661	5,299	5,289
Work Boat	83	151	162	168
Total in Inventory:	**12,629**	**17,910**	**19,106**	**19,322**

Table 2. C1C2 Vessels Removed

Vessel Group	Ship Count
Pleasure Craft (Removed)	16,890
Non-Propelled (Removed)	52
Total (Including Table 1 Inventory Ships)	**16,942**

The aggregated vessel counts were evaluated to ensure they were reasonable using publicly available data sources. For example, the US Army Corps of Engineers (USACE 2020) reported that there were 6,386 US flagged tugs operating in the US in 2020. This suggests that the 2022 AIS value of 5,289 tugs, though less than the USACE estimate, represents more of the fleet than was accounted for in the 2017 inventory.

The latest BOEM (2017) Gulf of Mexico emissions inventory identified 1,007 support vessels that provide services to oil and gas platforms in federal waters. The USACE reported 1,855[2] vessels in this category. The 2022 AIS C1C2 fleet included 1,377 offshore support vessels. Both

[2] US Army Corps of Engineers; 2022 Waterborne Transportation Lines of the United States (March 2024) https://usace.contentdm.oclc.org/utils/getfile/collection/p16021coll2/id/14463.

the USACE and the 2022 AIS estimates would include vessels that support offshore platforms located in federal and state waters in the Gulf of Mexico, California, and Alaska.

The USACE documented that there were 76 domestic flagged tankers. This stands in comparison to the 2022 AIS estimate of 677 tankers which includes non-US flagged vessels operating in the US, Canadian, or Mexican waters.

The 2022 AIS estimate of 997 ferry-excursion vessels is comparable to the USACE's 2020 estimate of 1,181 passenger-ferry vessels. AIS participation is not mandated for vessels with less than 150 passengers with fixed, limited, slow speed transits, suggesting that AIS may not be including the smaller vessels; conversely, some of the vessels included in the USACE may be Category 3 vessels; further study may be needed to better understand these vessel counts.

Other comparisons are more problematic. For example, the USACE estimates that there are 845 U.S flagged dry cargo vessels operating in the U.S., however 3,122 general cargo ships were identified in the 2022 AIS fleet is much larger than the USACE number as it includes foreign flagged vessels. It should be noted that the general cargo vessel type is vaguely defined, such that some of these vessels may be mapped to other vessel groups if more detailed data were available. Even accounting for foreign registered vessels, AIS indicates that the dry cargo fleet may be larger than what is reported by the USACE.

5,859 commercial fishing vessels were identified in the 2022 AIS dataset. The national fisherman trade association estimated that nearly 2,900 commercial fishing vessels are required to comply with the AIS reporting standard (National Fisherman, 2015). In addition, the estimated size of the U.S. commercial fishing vessel fleet is approximately 27,000 vessels (OECD, 2019), suggesting that 2022 inventory is still underreporting commercial fishing vessels. This underreporting may indicate that most of the fleet is composed of smaller vessels that do not trigger reporting requirements. The cost of AIS transmitter installation and the desire to keep fishing sites and activities secret may contribute to this underreporting of AIS data for commercial fishing vessels.

6.0 Power Assignments

6.1 Propulsive Power

Power ratings are required per vessel to calculate emissions. Propulsive power consumption is calculated using the Propeller Law, which requires each vessel's total installed propulsive power in addition to their optimal service speed, as shown in Equation 2.

$$P = \mathrm{LF} \times P_{ref} = \left(\frac{V}{V_{ref}}\right)^3 \times P_{ref} \tag{2}$$

Where:

P	=	Power per AIS message interval (kW)
LF	=	Load Factor
P_{ref}	=	Total Installed Propulsive Power (kW)
V	=	AIS reported speed (kn)
V_{ref}	=	Service Speed (kn)

Equation 2 is used to estimate the likely propulsive power applied for each vessel between consecutive AIS messages. The cubic ratio of the AIS reported speed following the message interval and the vessel's optimal service speed is calculated to estimate a load factor (LF). The load factor represents the percentage of the vessel's total installed propulsive power assumed to be used during that activity interval.

Vessel-specific installed propulsive power ratings and service speeds were pulled from Clarksons ship registry and adopted from GFW's dataset when available. However, as noted, there is limited vessel-specific attribute data for most of the C1C2 2022 platform fleet. This necessitated the use of surrogate engine power and vessel service speeds. Surrogate values are calculated for vessels missing attribute data by taking the 2022 activity time weighted average of vessels with attribute data that have the same ship category, vessel group, tier, and engine type. Table 3 shows the average surrogate power and vessel service speed assignments for each vessel group.

Table 3. C1C2 Propulsive Power and Load Factor Surrogates

Vessel Group	Average Surrogate Total Installed Propulsive Power (kW)	Number of Vessels from which Average Surrogate Total Installed Propulsive Power was Calculated	Average Surrogate Service Speed (kn)	Number of Vessels from which Average Surrogate Service Speed was Calculated
Bulk Carrier	3,341.28	34	14.48	33
Commercial Fishing	493.36	2,536	11.22	253
Container Ship	NA	NA	12.00	7
Ferry Excursion	4,692.47	164	23.46	154
General Cargo	1,034.59	196	9.38	115
Government	1,402.02	268	11.51	112
Miscellaneous	3,707.61	180	13.31	178
Offshore support	3,764.65	764	16.76	725
Reefer	893.16	15	10.04	14
Ro Ro	3,720.16	165	13.03	159
Tanker	2,761.43	101	19.09	91
Tug	2,616.27	1,781	11.39	864
Work Boat	1,696.91	147	12.05	133

Vessels missing service speed information adopted the surrogate service speed to calculate a surrogate LF to be used as described in Equation 2. Given this variation in sample sizes, the uncertainty surrounding the load factors which used surrogate service speed also varies. For this reason, vessel-group specific upper bounds provided by the EPA were used to cap all surrogate load factors. A lower bound of 2% was placed on all load factors, both surrogate and non-surrogate.

After data cleaning there was a small percentage of AIS messages missing AIS-reported speed. In these cases, vessels were assumed to be operating at a 20% load. This assumption is supported by the fact that the vast majority of C1C2 vessels have been shown to operate close to shore at lower than optimal loads. All vessels operating below 0.5 kn were assumed to be non-active, drifting vessels whose AIS-reported speed reflected the effect of the wind, wave actions, tides and currents which move the ship slightly. Thus, all vessels reporting speeds below 0.5 kn were assumed not to be in transit and assigned 0 propulsive power during these events. The percent of fleet vessel count associated with propulsive power and load factor surrogates can be seen in Figure 5. A comparison of Figure 5 and Figure 6, which displays the C1C2 platform AIS activity hours by vessel group, suggest the effect these surrogates have on the resulting C1C2 platform emission estimates. For example, tugs represent a large number of operating hours and are one of the categories that require extensive use of surrogates, compared to bulk carriers where vessel specific attributes are available but have considerably fewer operating hours.

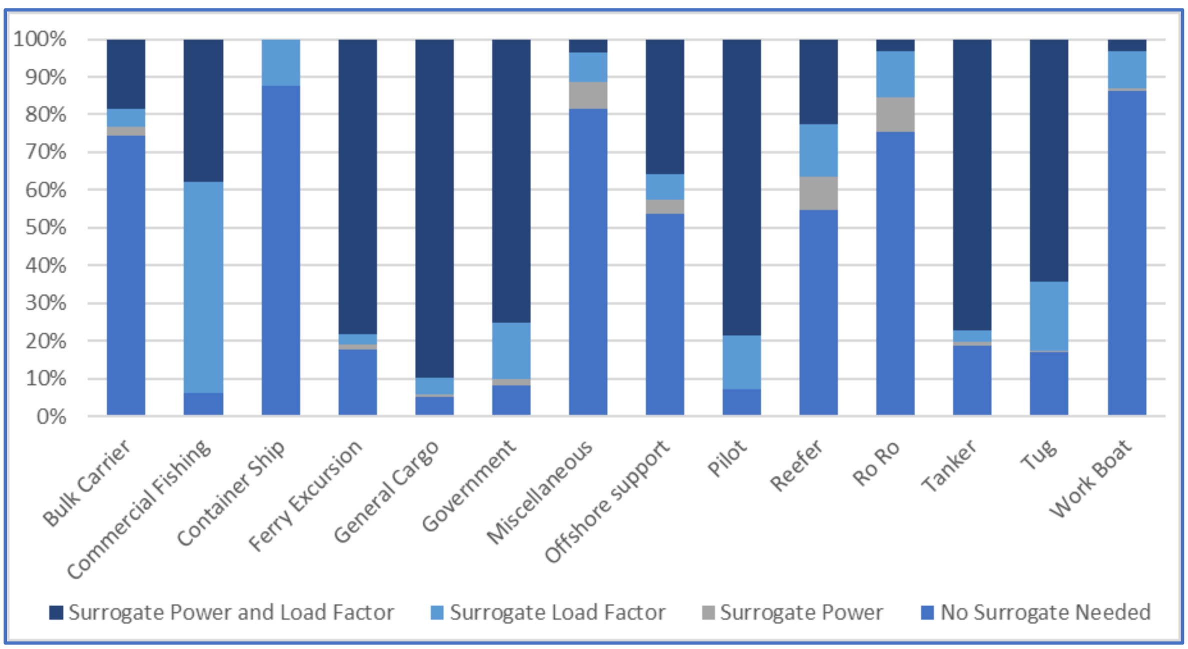

Figure 5. Use of Propulsion Surrogates for the 2022 Vessel Fleet (percent)

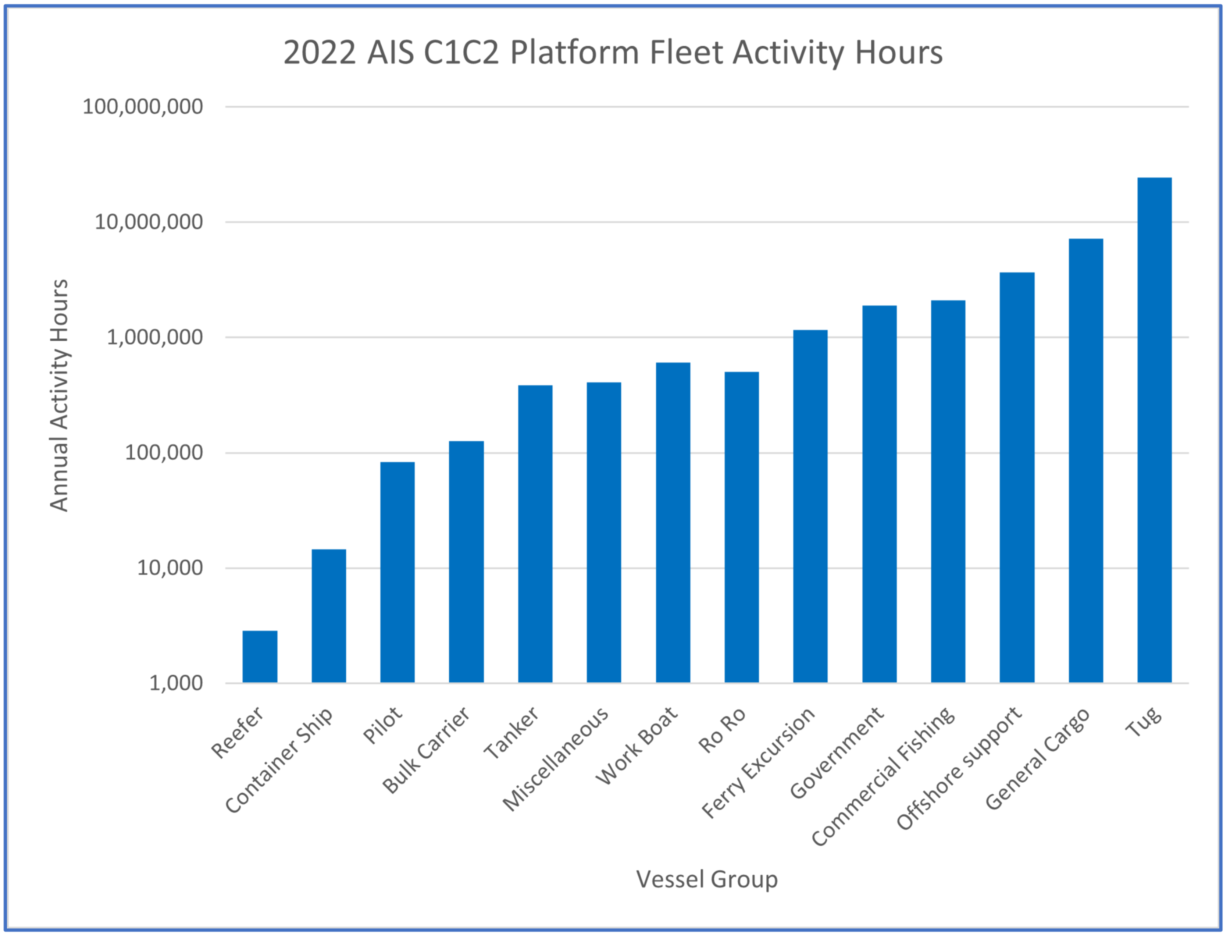

Figure 6. C1C2 Activity Hours by Vessel Group within 2022 Modeling Platform CMV Boundaries

6.2 Auxiliary and Boiler Power

Auxiliary engine power ratings are rarely documented in ship registry datasets, and auxiliary boiler power is not included at all. Therefore, to calculate auxiliary engine and boiler emissions, power surrogates are required, as shown in Table 4. Auxiliary power ratings were developed from analysis of C1C2 vessels with auxiliary data available in the Clarksons ship registry dataset. Similar to propulsive engines, auxiliary power is applied to each AIS observation by multiplying the auxiliary LF with the auxiliary total installed power rating. Surrogate auxiliary kWs were developed by adjusting the average auxiliary power rating by the load factors presented in Table 4. Additional auxiliary LFs were compiled from USEPA's (2009) *Current Methodologies in Preparing Mobile Source Port-Related Emission Inventories* in addition to EPA-provided values. The surrogate auxiliary kW values used in the 2022 inventory are the same values used in the 2020 and 2021 inventories.

Table 4. C1C2 Auxiliary and Boiler Power Surrogates

Vessel Group	Aux Operating Load Factor	Auxiliary Power Rated at Load (kW)	Boiler Power Rating at Load (kW)
Bulk Carrier	0.1	100.9	109
Commercial Fishing	0.43	243.7	0
Container Ship	0.19	112.9	506
Ferry Excursion	0.43	595.5	0
General Cargo	0.22	246.3	106
Government	0.43	994.4	0
Miscellaneous	0.43	459.8	0
Offshore support	0.56	605.2	0
Pilot	0.43	8.7	0
Reefer	0.32	913.3	464
Ro Ro	0.26	180.8	109
Tanker	0.26	623.7	346
Tug	0.43	69.5	0
Work Boat	0.43	641.6	0

Boilers are used on commercial marine vessels to provide hot water and steam for multiple applications. Previously, heat from boilers was used to elevate the temperature of storage tanks and fuel systems to allow residual fuels to flow, but with a requirement to use low sulfur residual blends that do not have the viscosity of residual fuels, this need for heat may be reduced. Boiler emissions were estimated for vessels that typically are equipped with boilers (e.g., bulk carriers, containerships, general cargo ships, Roll on/Roll off (Ro Ros), refrigerated vessels (Reefers), and tankers). The boiler power ratings reported in Table 4 were adopted from USEPA's (2009) *Current Methodologies in Preparing Mobile Source Port-Related Emission Inventories* and reflect boiler usages at common boiler engine loads. Therefore, a load factor is not needed for boiler power assignments and the values reported in Table 4 are used as-is.

7.0 Emission Factors

The emission factors used in this inventory take into consideration the EPA's marine vessel fuel regulations as well as exhaust standards based on the year that the vessel was manufactured appropriate regulatory tier. These values are reported as g/kWh in Table 5 and were developed using engine tier factors reported in Appendix H of the USEPA's (2020) Port Emissions Inventory Guidance (2020). To compile these emissions factors, population-weighted average emission factors were calculated by engine tier based on C1C2 population distributions grouped by engine displacement. Table 6 shows boiler emission factors that were obtained from an earlier

Entec study (Entec, 2002). The propulsive, auxiliary, and boiler emission factors used in the 2022 inventory were also used to compute the 2020 and 2021 inventories.

If the year of manufacture was unknown then it was assumed that the vessel was Tier 0, such that actual emissions may be less than those estimated in this inventory. Without more specific data, the magnitude of this emissions difference cannot be estimated.

Table 5. C1C2 Propulsive and Auxiliary Emission Factors

Tier	NO_x (g/kWhr)	PM_{10} (g/kWhr)	$PM_{2.5}$ (g/kWhr)	CO (g/kWhr)	CO_2 (g/kWhr)	SO_2 (g/kWhr)	VOC (g/kWhr)
Tier 0	10.28152	0.258902	0.251135	1.612632	679.47	0.006246	0.295615
Tier 1	9.624039	0.258902	0.251135	1.61	679.47	0.006246	0.295615
Tier 2	5.642273	0.148049	0.143608	0.918732	679.47	0.006246	0.295615
Tier 3	4.749214	0.082975	0.080486	0.918732	679.47	0.006246	0.124798
Tier 4	1.3	0.03	0.0291	0.918732	679.47	0.006246	0.124798

Table 6 reports the boiler engine emissions factors.

Table 6. C1C2 Auxiliary Boiler Emission Factors

NO_x (g/kWhr)	VOC (g/kWhr)	CO (g/kWhr)	SO_2 (g/kWhr)	CO_2 (g/kWhr)	PM_{10} (g/kWhr)	$PM_{2.5}$ (g/kWhr)
2	0.11	0.2	0.59	961.8	0.2	0.19

7.1 Low Load Adjustment Factor

Propulsive emissions from low-load operations were adjusted to account for elevated emission rates associated with activities outside the engines' optimal operating range. Table 7 below shows the emission factor adjustments by load and pollutant, based on the data compiled for the Port Everglades 2015 Emission Inventory (USEPA, 2018). The emission factor adjustments used in the 2022 inventory were also used to compute the 2020 and 2021 inventories. Adjustment to the criteria emissions were made using the following equation:

$$EF\_LLAF_{iy} = EF_{iy} \times LLAF_y \tag{3}$$

Where:

EF_LLAF_{iy}	=	Emission Factor adjusted for low load operation for vessel i and pollutant y (g/kWh)
EF_{iy}	=	Emission Factor of pollutant y for vessel i (g/kWh)
$LLAF_y$	=	Adjustment factor for a given AIS observation for pollutant y dependent on the load factor of vessel i during a given AIS activity interval (unitless)

Table 7. Low Load Adjustment Factors

Load	PM_{10}	NO_X	SO_2	VOC	CO_2	$PM_{2.5}$	CO
0.01	7.29	4.63	1	21.18	1	7.29	1
0.02	7.29	4.63	1	21.18	1	7.29	1
0.03	4.33	2.92	1	11.68	1	4.33	1
0.04	3.09	2.21	1	7.71	1	3.09	1
0.05	2.44	1.83	1	5.61	1	2.44	1
0.06	2.04	1.6	1	4.35	1	2.04	1
0.07	1.79	1.45	1	3.52	1	1.79	1
0.08	1.61	1.35	1	2.95	1	1.61	1
0.09	1.48	1.27	1	2.52	1	1.48	1
0.1	1.38	1.22	1	2.18	1	1.38	1
0.11	1.3	1.17	1	1.96	1	1.3	1
0.12	1.24	1.14	1	1.76	1	1.24	1
0.13	1.19	1.11	1	1.6	1	1.19	1
0.14	1.15	1.08	1	1.47	1	1.15	1
0.15	1.11	1.06	1	1.36	1	1.11	1
0.16	1.08	1.05	1	1.26	1	1.08	1
0.17	1.06	1.03	1	1.18	1	1.06	1
0.18	1.04	1.02	1	1.11	1	1.04	1
0.19	1.02	1.01	1	1.05	1	1.02	1
0.2	1	1	1	1	1	1	1

7.2 HAP Specific Profiles

The EPA developed hazardous air pollutant (HAP) profiles to calculate HAP emissions as speciations of criteria pollutants estimated by the above-described methodology. The fractions reported in Table 8 were multiplied by the emissions of their assigned basis pollutant to complete this calculation. The HAP Speciation Profiles used in the 2022 inventory were also used to compute the 2020 and 2021 inventories.

Table 8. HAP Speciation Profile

Pollutant	Pollutant Code	Basis	Fraction
1,3-Butadiene[a]	106990	VOC	0.001013
2,2,4-Trimethylpentane[b]	540841	VOC	0.00712
Acenaphthene[a]	83329	VOC	5.09E-05
Acenaphthylene[a]	208968	VOC	0.000118
Acetaldehyde[a]	75070	VOC	0.009783
Acrolein[a]	107028	VOC	0.001848

Pollutant	Pollutant Code	Basis	Fraction
Ammonia[c]	7664417	$PM_{2.5}$	0.019247
Anthracene[a]	120127	VOC	0.000344
Antimony[a]	7440360	$PM_{2.5}$	0.000615
Arsenic[c]	7440382	$PM_{2.5}$	2.59E-05
Benz[a]Anthracene[a]	56553	$PM_{2.5}$	8.82E-06
Benzene[a]	71432	VOC	0.004739
Benzo[a]Pyrene[c]	50328	$PM_{2.5}$	4.18E-06
Benzo[b]Fluoranthene[c]	205992	$PM_{2.5}$	8.35E-06
Benzo[k]Fluoranthene[c]	207089	$PM_{2.5}$	4.18E-06
Benzo(g,h,i)Fluoranthene[a]	203123	$PM_{2.5}$	0.000132
Cadmium[a]	7440439	$PM_{2.5}$	0.000236
Chrysene[a]	218019	$PM_{2.5}$	1.63E-05
Chromium (VI)[b]	18540299	$PM_{2.5}$	7.24E-09
Dibenzo[a,h]anthracene[a]	53703	$PM_{2.5}$	8.65E-06
Ethyl Benzene[a]	100414	VOC	0.000439
Fluoranthene[a]	206440	$PM_{2.5}$	8.97E-05
Fluorene[a]	86737	VOC	0.000164
Formaldehyde[a]	50000	VOC	0.042696
Indeno[1,2,3-c,d]Pyrene[c]	193395	$PM_{2.5}$	8.35E-06
Lead[c]	7439921	$PM_{2.5}$	0.000125
Manganese[b]	7439965	$PM_{2.5}$	3.22E-06
Mercury[c]	7439976	$PM_{2.5}$	4.18E-08
Naphthalene[a]	91203	VOC	0.031304
Hexane[b]	110543	VOC	0.00279
Nickel[c]	7440020	$PM_{2.5}$	0.000687
Polychlorinated Biphenyls[c]	1336363	$PM_{2.5}$	4.18E-07
Phenanthrene[a]	85018	VOC	0.001356
Propionaldehyde[a]	123386	VOC	0.001517
Pyrene[a]	129000	$PM_{2.5}$	3.37E-05
Selenium[c]	7782492	$PM_{2.5}$	4.38E-08
Toluene[a]	108883	VOC	0.002035
Xylenes (Mixed Isomers)[a]	1330207	VOC	0.001422
o-Xylene[a]	95476	VOC	0.000513

[a] Agrawal, Harshit, William A Welch, J Wayne Miller, and David R Cocker. 2008. 'Emission Measurements from a Crude Oil Tanker at Sea,' Environmental Science & Technology, 42, no. 19: 7098-103. DOI: 10.1021/es703102y. Used data for auxiliary engine which burned marine gas oil with 0.06 wt % sulfur and 0.01 wt,% ash content.

[b] Speciation Profiles and toxic Emission Factors for Nonroad Engines in MOVES2014b, EPA-420-R-18-011, July 2018.

[c] Swedish Environmental Protection Agency, Swedish Methodology for Environmental Data; Methodology for Calculating Emissions from Ships: 1. Update of Emission Factors, 2004.

8.0 Summary

Table 9 presents the total 2021 and 2022 emissions from C1C2 vessels in the 2022 modeling platform area. The summary tables and figures of the 2021 inventory documentation contain emission values that include international waters outside of the 2022 modeling platform area. These emissions have been removed for this comparison table.

Table 9. Total C1C2 2021 and 2022 Emissions for the 2022 Modeling Platform CMV area (tons)

Year	VOC	CO_2	CO	NO_X	$PM_{2.5}$	SO_2	PM_{10}	kWhrs
2021	6,473.44	12,324,916	25,575.14	170,966.28	4,480.55	711.53	4,623.37	1.61E+10
2022	6,506.23	12,367,738	25,590.97	171,251.73	4,499.13	737.01	4,642.70	1.61E+10

Table 10 presents the total 2022 emissions from C1C2 by vessel group and Figure 7 shows the relative distribution of NO_x emissions by vessel group within the 2022 modeling platform CMV region. Tanker vessels have a kWhrs increase of 70.4% from 2021 to 2022 even though the vessel fleet size only increased by 14.6%. This is attributed to a 107.3% increase in the total record count of Tanker vessels across these years. Changes in kWhrs of other vessel groups are not as extreme. Ferry Excursion vessels have a kWhrs increase of 25.7% from 2021 to 2022 but is largely attributed to the 17.4% increase in vessel fleet size. Pilot, Reefer, and Work Boat vessels had a 15.8%, 15.4%, and 10.6% increase in kWhrs from 2021 to 2022 respectively. The only notable decrease in kWhrs from 2021 to 2022 occurred for Bulk Carrier vessels at 12.6%. All other vessel groups have less than a 10 percent change in kWhrs from 2021 to 2022.

Table 10. 2022 C1C2 Emissions by Vessel Group (tons)

Vessel Group	VOC	CO_2	CO	NO_X	$PM_{2.5}$	SO_2	PM_{10}	kWhrs
Bulk Carrier	63.43	140,376.50	300.20	1,966.22	50.99	10.09	52.63	1.82e8
Commercial Fishing	203.63	425,255.23	1,001.81	6,483.75	160.46	3.91	165.42	5.68e8
Container Ship	3.48	14,690.62	15.54	90.20	3.36	4.86	3.50	1.65e7
Ferry Excursion	402.39	719,398.15	1,624.93	10,651.97	271.15	6.61	279.54	9.60e8
General Cargo	951.34	2,574,410.60	4,356.44	28,947.65	836.09	512.55	865.41	3.12e9
Government	672.52	1,503,657.64	3,551.52	22,728.77	557.30	13.82	574.54	2.01e9
Miscellaneous	80.81	182,337.75	326.95	1,966.53	48.11	1.68	49.60	2.43e8
Offshore support	1,033.89	2,106,223.36	4,367.52	28,203.49	700.64	19.36	722.31	2.81e9
Pilot	2.18	6,789.98	9.45	54.96	1.05	0.06	1.08	9.07e6
Reefer	1.03	5,048.35	5.89	34.00	0.88	0.89	0.92	6.19e6
Ro Ro	145.70	358,008.80	665.03	4,228.08	112.57	38.28	116.30	4.55e8
Tanker	145.13	413,119.28	654.17	4,325.07	127.49	88.86	132.04	4.96e8
Tug	2,633.66	3,582,878.52	7,983.50	56,923.13	1,510.52	32.94	1,557.23	4.78e9
Work Boat	167.05	335,544.14	728.08	4,647.91	118.51	3.08	122.18	4.48e8

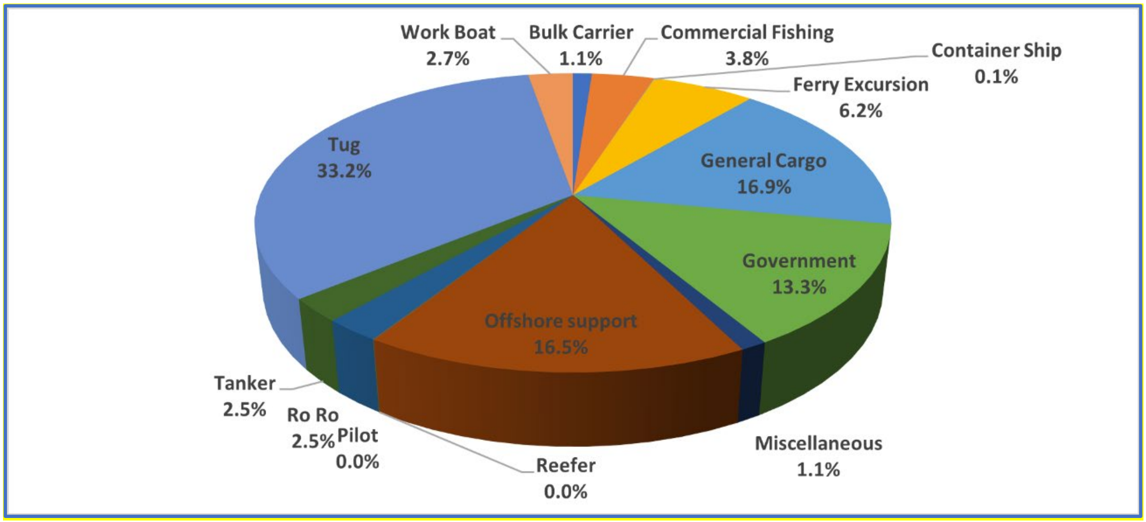

Figure 7. Relative Distribution of 2022 C1C2 NOx Emissions by Vessel Type

As noted earlier, kilowatt-hours (kWhrs) were calculated by multiplying the activity durations per AIS interval and the assigned power estimation based on AIS reported speed, and Clarksons or surrogate installed power ratings and load based on service speed. kWhrs were summed by vessel group as well as by engine and location. Each vessel group's total kWhrs were analyzed and presented as percentages for each SCC category (Figure 8).

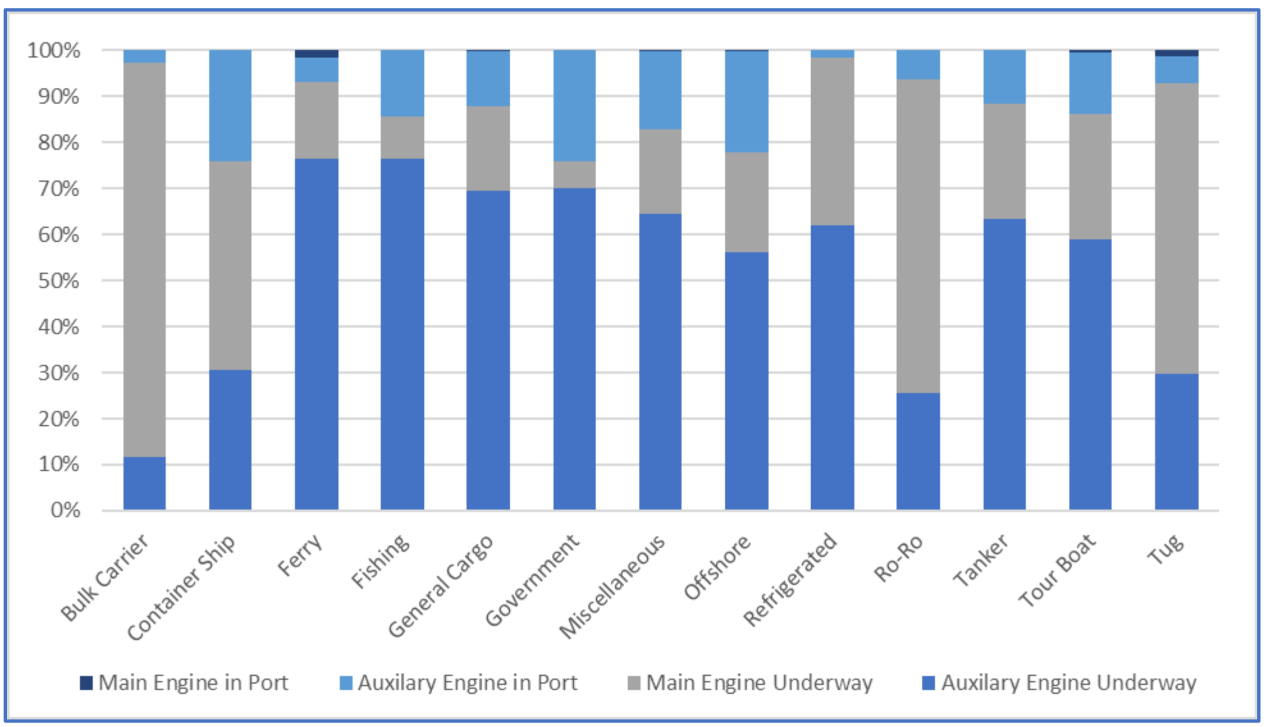

Figure 8. Vessel Group Kilowatt Hour Distribution by Engine and Location

Table 11. 2022 C1C2 Emissions (tons) by SCC

SCC	Vessel Type	Port/ Underway	Engine	VOC	CO_2	CO	NO_X	$PM_{2.5}$	SO_2	PM_{10}	kWhrs
2280202113	Offshore	Port	Main	9.53	2,267.90	4.43	72.30	2.51	0.02	2.59	3.03e6
2280202114	Offshore	Port	Auxiliary	162.91	413,316.19	780.80	4,814.80	118.06	9.25	121.76	5.48e8
2280202123	Offshore	Underway	Main	282.18	401,762.29	757.80	5,321.43	139.80	3.69	144.12	5.36e8
2280202124	Offshore	Underway	Auxiliary	427.14	1,057,714.41	2,114.63	13,192.89	328.87	34.25	339.21	1.40e9
2280203113	Bulk Carrier	Port	Main	0.45	64.62	0.15	3.60	0.13	0.00	0.14	8.63e4
2280203114	Bulk Carrier	Port	Auxiliary	1.11	4,605.72	4.87	32.96	1.22	1.73	1.27	5.06e6
2280203123	Bulk Carrier	Underway	Main	57.20	116,226.85	274.61	1,790.03	44.50	1.07	45.88	1.55e8
2280203124	Bulk Carrier	Underway	Auxiliary	4.67	19,479.31	20.57	139.63	5.14	7.30	5.35	2.14e7
2280204113	Fishing	Port	Main	0.34	87.59	0.21	3.19	0.11	0.00	0.11	1.17e5
2280204114	Fishing	Port	Auxiliary	26.35	60,684.08	143.80	915.77	22.36	0.56	23.06	8.10e7
2280204123	Fishing	Underway	Main	36.50	39,234.70	90.55	694.96	19.11	0.36	19.70	5.24e7
2280204124	Fishing	Underway	Auxiliary	140.44	325,248.85	767.25	4,869.83	118.87	2.99	122.55	4.34e8
2280205113	Container Ship	Port	Main	0.02	6.90	0.01	0.14	0.01	6.34e-5	0.01	9.21e3
2280205114	Container Ship	Port	Auxiliary	0.59	3,998.93	1.83	13.05	0.83	2.12	0.87	3.99e6
2280205123	Container Ship	Underway	Main	2.10	5,628.61	11.27	59.02	1.45	0.05	1.49	7.51e6
2280205124	Container Ship	Underway	Auxiliary	0.77	5,056.17	2.43	17.99	1.08	2.69	1.13	5.04e6
2280206113	Ferry	Port	Main	0.27	157.55	0.37	3.63	0.11	0.00	0.11	2.10e5
2280206114	Ferry	Port	Auxiliary	0.24	559.19	1.33	8.46	0.21	0.01	0.21	7.47e5
2280206123	Ferry	Underway	Main	1.38	1,689.28	4.01	29.57	0.79	0.02	0.82	2.26e6
2280206124	Ferry	Underway	Auxiliary	3.41	7,830.61	18.58	118.49	2.89	0.07	2.98	1.05e7
2280207113	General Cargo	Port	Main	8.02	5,094.89	12.09	113.36	3.42	0.05	3.53	6.80e6
2280207114	General Cargo	Port	Auxiliary	92.95	296,325.38	460.36	3,019.41	90.22	70.50	93.49	3.52e8
2280207123	General Cargo	Underway	Main	254.24	400,712.23	950.27	6,555.84	169.16	3.68	174.39	5.35e8
2280207124	General Cargo	Underway	Auxiliary	536.29	1,709,975.90	2,655.95	17,418.48	520.48	406.85	539.35	2.03e9
2280208113	Government	Port	Main	1.47	605.27	1.42	16.43	0.53	0.01	0.55	8.08e5
2280208114	Government	Port	Auxiliary	156.45	363,174.95	852.58	5,400.63	131.85	3.34	135.93	4.85e8
2280208123	Government	Underway	Main	58.89	87,412.83	203.82	1,411.42	36.43	0.80	37.56	1.17e8
2280208124	Government	Underway	Auxiliary	456.22	1,052,781.66	2,484.23	15,795.23	385.91	9.68	397.85	1.41e9
2280209113	Miscellaneous	Port	Main	5.48	1,372.40	3.18	50.51	1.77	0.01	1.82	1.83e6
2280209114	Miscellaneous	Port	Auxiliary	67.20	158,822.50	359.47	2,274.46	55.28	1.46	56.99	2.12e8
2280209123	Miscellaneous	Underway	Main	145.18	169,612.39	370.47	2,778.64	75.38	1.56	77.71	2.26e8
2280209124	Miscellaneous	Underway	Auxiliary	252.92	601,959.22	1,360.24	8,536.62	207.80	5.53	214.22	8.04e8
2280210113	Ro-Ro	Port	Main	1.29	211.33	0.48	10.22	0.38	0.00	0.39	2.82e5
2280210114	Ro-Ro	Port	Auxiliary	6.89	24,521.51	31.33	206.21	6.69	7.05	6.94	2.83e7
2280210123	Ro-Ro	Underway	Main	110.97	232,034.02	506.60	3,208.08	79.28	2.13	81.73	3.10e8
2280210124	Ro-Ro	Underway	Auxiliary	26.55	101,241.94	126.62	803.57	26.22	29.10	27.23	1.17e8
2280211113	Tanker	Port	Main	0.42	59.25	0.14	3.33	0.13	0.00	0.13	7.91e4

SCC	Vessel Type	Port/ Underway	Engine	VOC	CO_2	CO	NO_X	$PM_{2.5}$	SO_2	PM_{10}	kWhrs
2280211114	Tanker	Port	Auxiliary	14.47	49,817.64	69.98	459.16	14.42	13.70	14.96	5.79e7
2280211123	Tanker	Underway	Main	51.80	93,007.96	211.33	1,411.98	35.71	0.86	36.81	1.24e8
2280211124	Tanker	Underway	Auxiliary	78.44	270,234.43	372.73	2,450.60	77.24	74.31	80.14	3.14e8
2280212113	Tour Boat	Port	Main	11.21	2,751.27	6.25	100.44	3.55	0.03	3.66	3.67e6
2280212114	Tour Boat	Port	Auxiliary	39.01	95,330.32	212.99	1,296.27	31.65	0.88	32.63	1.27e8
2280212123	Tour Boat	Underway	Main	172.89	192,767.37	436.79	3,257.93	89.68	1.77	92.46	2.57e8
2280212124	Tour Boat	Underway	Auxiliary	172.33	414,976.33	936.70	5,785.41	140.98	3.81	145.34	5.54e8
2280213113	Tug	Port	Main	85.19	43,942.43	95.48	989.26	31.13	0.40	32.09	5.87e7
2280213114	Tug	Port	Auxiliary	87.75	211,207.50	468.85	2,924.32	71.13	1.94	73.33	2.82e8
2280213123	Tug	Underway	Main	2,002.75	2,258,433.07	4,955.66	37,436.49	1,028.48	20.76	1,060.28	3.02e9
2280213124	Tug	Underway	Auxiliary	449.61	1,057,192.32	2,436.04	15,378.57	374.72	9.72	386.31	1.41e9
2280214113	Refrigerated	Port	Main	0.00	0.14	0.00	0.00	6.92e-5	1.27e-6	7.13e-5	1.84e2
2280214114	Refrigerated	Port	Auxiliary	0.02	82.22	0.12	0.79	0.02	0.02	0.03	9.63e4
2280214123	Refrigerated	Underway	Main	0.41	1,695.56	2.56	14.21	0.28	0.02	0.28	2.26e6
2280214124	Refrigerated	Underway	Auxiliary	0.59	3,270.43	3.22	19.00	0.58	0.86	0.61	3.83e6

9.0 Limitations

Use of AIS data to develop emission inventories is a significant improvement over earlier 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 to its service speed, and other details related to vessel location and time stamp included in the AIS data stream.

These data are more complete and readily available for larger C3 vessels, but when it comes to smaller C1C2 vessels, many of the earlier assumptions about power and operating load are still required, as is the question about whether the dataset represent a complete inventory of these smaller vessels.

The AIS system continues to evolve and expand coverage, but there are still areas where the VHF signals are missing and there are vessels that do not have transponders or turn off their transponders. In processing the AIS data for 2022, record counts varied significantly from day to day indicating possible data gaps, suggesting that the AIS data may underestimate actual activities. For example, USCG confirmed substantial data gaps from mid-April to the end of June. There are no AIS records on 4/28, 6/3, and 6/5. These data gaps are not limited to a specific region and occur throughout the entire 2022 modeling platform area. While USCG investigated this issue, the decision was made to proceed with the data as-is to prevent delays in the inventory development process. Adjustments to data for this period will be implemented prior to using the data for air quality modeling.

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. Further study is needed to better understand these events.

In this version, records that have a timestamp prior to the preceding day were removed from AIS data processing. This implies that the maximum time in-between sequential records used in emissions calculations is 48 hours. However, a software bug resulted in some instances with sequential records beyond 48 hours being retained for emissions calculations. Future versions will address this issue and maximize the time in-between sequential records used in emissions calculations at 24 hours.

Though AIS has been instrumental in improving the overall quality of propulsion engine emission estimates, similar improvements are needed for auxiliary engines and boilers, specifically better methods to estimate auxiliary engine operating loads. Further study of dockside operations is needed to better understand when vessels shut off their engines dockside to reduce fuel consumption and emissions.

As use of shore power expands, it would be helpful to have ports provide information about utilization rates by vessel categories to enable adjustments of dockside emissions and avoid double counting with landside Electricity Generating Units (EGUs).

In 2020, states provided vessel specific information about strategic engine and vessel replacements targeted to improve local air quality – these data were retained in this 2022 inventory. This information was linked directly to the vessels' attribute data to account for emission reductions associated with the use of higher tiered engines. We encourage provision of such information.

Unlike Category 3 vessels, available vessel characteristics data for most Category 1 and 2 vessels is limited; often there is not vessel-specific data for main and auxiliary power, engine specifications, design max speed and vessels dimensions. It should be noted that these data gaps are filled by averaging data from a relatively small number of vessels for which data are available in a suitable format, such that there is considerable uncertainty associated with these default values. Further study is needed to expand Category 1 and 2 vessel attributes to allow for better matching of vessels to appropriate characteristics. It would also be helpful to develop a better understanding of the variance within the key surrogate data elements to help quantify uncertainty.

10.0 References

Agrawal, Harshit, William A Welch, J Wayne Miller, and David R Cocker. 2008. 'Emission Measurements from a Crude Oil Tanker at Sea,' Environmental Science & Technology, 42, no. 19: 7098-103. DOI: 10.1021/es703102y.

Clarksons (Accessed Jan. 2021). *World Fleet Register.*

Entec, UK, Quantification of Emissions from Ships Associated with Ship Movements between Ports in the European Community – Final Report, European Commission, 2002.

Global Fishing Watch. "Fishing Effort," 2020. https://globalfishingwatch.org/data-download/datasets/public-fishing-effort.

IMO (International Maritime Organization) (2002). *SOLAS Chapter V, Regulation 19—Carriage Requirements for Shipborne Navigational Systems and Equipment*. https://assets.publishing.service.gov.uk/media/5a7f0081ed915d74e33f3c6e/solas_v_on_safety_of_navigation.pdf.**Error! Hyperlink reference not valid.**

International Telecommunications Union. "Table of International Call Sign Series (Appendix 42 to the RR)," 2017. https://www.itu.int/en/ITU-R/terrestrial/fmd/Pages/call_sign_series.aspx.

"Table of Maritime Identification Digits," 2017. https://www.itu.int/en/ITU-R/terrestrial/fmd/Pages/mid.aspx.

Marine Cadastre. "AIS Vessel Type and Group Codes Used by the Marine Cadastre Project," May 23, 2018. https://coast.noaa.gov/data/marinecadastre/ais/VesselTypeCodes2018.pdf.

Organization of Economic Cooperation and Development (OECD) Fishing Fleet data, https://stats.oecd.org/Index.aspx?DataSetCode=FISH_FLEET (2019).

Swedish Environmental Protection Agency, Swedish Methodology for Environmental Data; Methodology for Calculating Emissions from Ships: 1. Update of Emission Factors, 2004.

U.S. Army Corps of Engineers (USACE) Waterway System Transportation Facts and Information. 2020, https://usace.contentdm.oclc.org/digital/collection/p16021coll2/id/1829.

U.S. Environmental Protection Agency (USEPA) (2010). *Designation of North American Emission Control Area to Reduce Emissions from Ships.* https://nepis.epa.gov/Exe/ZyPDF.cgi/P100AU0I.PDF?Dockey=P100AU0I.PDF.

USEPA, Current Methodologies in Preparing Mobile Source Port-Related Emission Inventories, April 2009.

USEPA, Port Emissions Inventory Guidance: Methodologies for Estimating Port-related and Goods Movement Mobile Source Emissions, EPA-420-B-20-04. September 2020.

USEPA. EPA and Port Everglades Partnership: Emission Inventories and Reduction Strategies. US Environmental Protection Agency, Office of Transportation and Air Quality, June 2018. https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100UKV8.pdf.

USEPA. "Regulatory Impact Analysis: Control of Emissions of Air Pollution from Locomotive Engines and Marine Compression-Ignition Engines Less than 30 Liters per Cylinder." Assessment and Standards Division Office of Transportation and Air Quality U.S. Environmental Protection Agency, May 2008.

USEPA. Speciation Profiles and toxic Emission Factors for Nonroad Engines in MOVES2014b, EPA-420-R-18-011, July 2018.

U.S. Coast Guard (Accessed September 2017). *Merchant Vessels of the United States.*

U.S. Coast Guard. *2017 Recreational Boating Statistics, 2018.* https://www.uscgboating.org/library/accident-statistics/Recreational-Boating-Statistics-2017.pdf.

U.S. Coast Guard (Accessed 2018). *U. S. Coast Guard Vessel Data.*

U.S. Department of Transportation (Accessed May 2017). *2016 National Census of Ferry Operator Database.*

National Fisherman, AIS Rule Becomes Effective March 2. February 24, 2015. https://www.nationalfisherman.com/viewpoints/boats-gear/ais-rule-becomes-effective-march-2/.

APPENDIX A

Vessel Type and Ship Group Bridge

Table A-1. Bridge Between Vessel Type and Ship Group

Ship Group	Vessel Type
Barge	Container Barge
	Covered Bulk Cargo Barge
	Crane Pontoon
	Dredging Pontoon
	Hopper Barge
	Pipe Laying Barge
	Pontoon (Function Unknown)
	Products Tank Barge
	Self Elevating Install. Barge
	Split Hopper Barge
Bulk Carrier	Aggregate Carrier
	Aggregates Carrier
	Bulk
	Bulk Carrier
	Cement Carrier
	Gravel/Stone Discharge
	Ore Carrier
	Palletised Cargo Carrier
	Replenishment Dry Cargo Vessel
Commercial Fishing	dredge_fishing
	drifting_longlines
	Factory Stern Trawler
	Fish Factory Ship
	Fishery Support Vessel
	Fishing
	Fishing
	Fishing Vessel
	Fishing; Passenger
	fixed_gear
	Gear
	Live Fish Carrier (Well Boat)
	other_fishing
	other_purse_seines
	other_seines
	pole_and_line
	pots_and_traps
	purse_seines
	set_gillnets
	set_longlines
	squid_jigger

Ship Group	Vessel Type
	Stern Trawler
	Trawler
	trawlers
	trollers
	tuna_purse_seines
Container Ship	Container Ship (Inland)
	Fully Cellular Container
Ferry Excursion	Cruise
	Cruise (Inland)
	Cruise Ship
	Ferry
	Pass./Car Catamaran Vessel
	Passenger
	Passenger (Inland)
	Passenger Catamaran Vessel
	Passenger Vessel
General Cargo	Cargo
	cargo
	Cargo and Passenger
	Cargo; Fishing
	Deck Cargo Carrier
	General Cargo
	General Cargo (Inland)
	General Cargo Barge, Propelled
	Merchant
	Merchant, Passenger Ship
	Miscellaneous Cargo
	Passenger/Cargo Vessel
	Product Carrier
	Small Commercial
	Transport (Heavy Lift)
Government	Buoy/Lighthouse Tender
	Cable Layer, Naval Auxiliary
	Coast Guard
	Crew Boat, Naval Auxiliary
	Destroyer
	ERRV
	Fire
	Fishery Patrol Vessel
	Frigate
	Government
	Icebreaker

Ship Group	Vessel Type
	Icebreaker AGB
	Landing Craft
	Military
	Military; Cargo
	Military; Fishing
	Naval
	Patrol Vessel
	Patrol Vessel, Naval
	Rescue
	Research Vessel, Naval Auxiliary
	Salvage Vessel, Naval Auxiliary
	SAR
	Standby Safety/Guard
	Tank Landing Craft
	Torpedo Recovery Vessel
	Training Ship
	Training Ship, Naval Auxiliary
	Tug, Naval Auxiliary
	USCG
Miscellaneous	Dredging (Inland)
	Electricity Generating Vessel
	Fishery Research Vessel
	Hospital Vessel
	Landing Ship (Dock Type)
	Maintenance
	Marine Research
	Multi-Purpose
	Multi-Purpose Support
	Other Activities (Inland)
	Research or Survey Ship
	Research Survey Vessel
	Research Vessel
	Special Purpose
	Waste Disposal Carrier
	Wine Carrier
	Yacht Support Vessel
Offshore support	Accommodation Barge
	Accommodation Unit - Semi Sub.
	Accommodation Vessel
	Anchor Handling Tug
	Anchor Handling Tug/Supply
	Anti-Pollution Vessel

Ship Group	Vessel Type
	Backhoe/Dipper/Grab Dredger
	Cable Layer (Fibre Optic)
	Cable, Umbilicals & FP/Flowline Lay
	Crew Boat
	Crew Tender
	Crew/Fast Supply Vessel
	Crewboat / Supply / Utility Vessel
	Cutter Suction/Bucket Wheel Dredger
	Diving Support
	Diving Support Vessel
	Dredge
	Dredger
	Dredgers (Stone Dumping, Fallpipe)
	Drilling
	Drilling Ship
	Drillship
	Extended Well Test Vessel
	Floating Production Unit
	FPSO
	FSO
	FSRU
	Geophysical Survey
	Heavy Lift/Crane Ship
	Hydrographic Survey
	Jack-up Drilling Rig
	Jack-up Production Unit
	LNG/FPSO
	Merchant, Barge
	Merchant, Cargo and Passenger
	Merchant, Pilot Tender
	Merchant, Research or Survey Ship
	Merchant, Supply Vessel
	Miscellaneous Offshore Service
	Oceanographic Survey
	Official Service Shp
	Official Service Shp, Auxiliary Ship
	Official Service Shp, Cargo and Passenger
	Official Service Shp, Supply Vessel
	Offshore Construction Vessel, jack up
	Offshore Oil and Gas Support
	Oil and Gas
	Oilfield Pollution Control

Ship Group	Vessel Type
	Other Dredger
	Pipe Layer
	Platform Supply
	Platform Supply Ship
	Pollution Control Vessel
	Rescue
	ROV/Submersible Support
	Salvage Vessel
	Seismic Support
	Seismic Survey
	seismic_vessel
	Semi-Submersible Drilling Rig
	Semi-Submersible Heavy Lift
	Semi-Submersible Production Unit
	Service
	Special Equipment Dredger
	Submarine Salvage Vessel
	Suction Dredger
	Supply
	Supply Tender
	Support Vessel
	Survey
	Tender
	Trailing Suction Hopper Dredger
	Tug, Anchor Hoy
	Well Stimulation
	Wind Turbine Installation
	Windfarm Crew/Supply Tender
Pilot	Pilot
	pilot
	Pilot Vessel
Pleasure Craft	Motor Yacht
	motor_passenger
	Pleasure Craft/Sailing
	Pleasure Craft/Sailing; Fishing
	Pleasure Craft/Sailing; Passenger
	sailing ship
	Sailing Vessel
	Yacht (Sailing)
	Yacht/Recreational
Reefer	Fruit Juice Carrier
	Reefer

Ship Group	Vessel Type
	Reefer Fish Carrier
	Reefer/Pallets Carrier
Ro Ro	Pass./Car Ferry
	Passenger/Ro-Ro (Inland)
	Pure Car Carrier
	Ro-Ro
	Ro-Ro Freight/Passenger
	Ro-Ro/Lo-Lo
Tanker	Asphalt & Bitumen Carrier
	Chemical & Oil Carrier
	Chemical Tanker (Inland)
	Chemical/Products Tanker (Inland)
	Edible Oil Carrier
	LNG Carrier
	LPG Carrier
	Oil Bunkering Tanker
	Oil Tanker (Inland)
	Replenishment Tanker
	Tanker
	tanker
	Tanker; Passenger
	Urea Carrier
Tug	Fire-fighting Tug
	Fishing; Tug Tow
	Maintenance Pontoon
	Merchant, Tug
	Ocean-going Salvage Tug
	Ocean-going Tug
	Pushboat
	Towing/Pushing (Inland)
	Tug
	tug
	Tug Tow
	Tug Tow; Passenger
Unknown	Miscellaneous
	Unknown
Work Boat	Utility/Workboat
	Work/Repair Vessel