Eastern Research Group, Inc.

CATEGORY 1 AND 2 COMMERCIAL MARINE VESSEL 2017 EMISSIONS INVENTORY

Prepared for:

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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
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 2017 NEI. Category 2 (C2) engines are defined as having displacement below 30 liters per cylinder and greater than or equal to 7 liters per cylinder. Category 1 (C1) engines are defined as having displacement below 7 liters per cylinder. This report documents the development of the C1C2CMV model used for the 2017 NEI, including the conceptual framework, equations, data sources, and assumptions. This document is a deliverable under USEPA contract EP-C-17-0411, Work Assignment 2-19.

2.0 AIS Dataset

Automated Identification System (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 (Nm), 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, 2017. The provided AIS data extends beyond 200 nautical miles from the U.S. coast (Figure 1). 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.

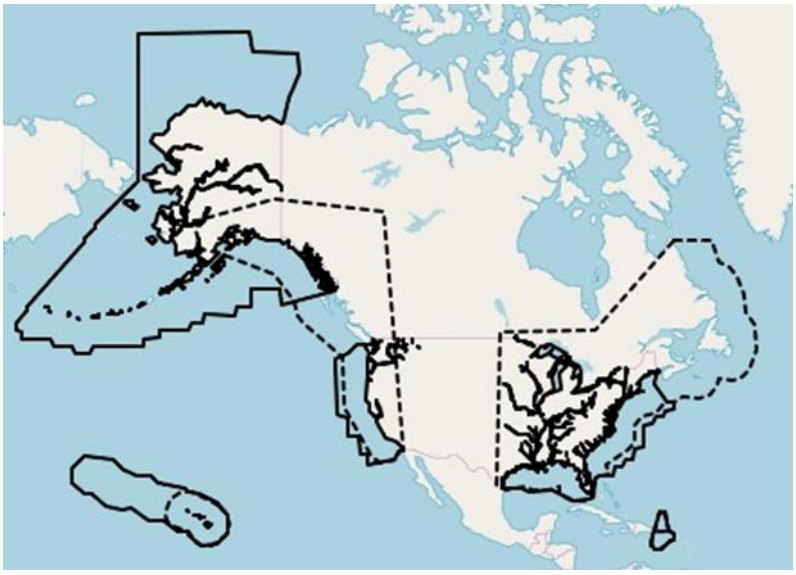

Figure 1. Geographic Boundary of Category 1/2 Study

The preprocessed data was 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 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 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, 2018).

USEPA used the engine bore and stroke data to calculate cylinder volume. Any vessel that had a calculated cylinder volume greater than 30 liters was incorporated into the USEPA's new Category 3 Commercial Marine Vessel (C3CMV) model. The remaining records were assumed to represent Category 1 and 2 (C1C2) or non-ship activity. This report focuses on data processing of the C1C2 vessels.

3.0 AIS Data Processing

AIS data are transmitted to both satellite (S-AIS) and terrestrial (T-AIS) receivers. 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. Given the close-to-shore nature of C1 and C2 activity, exclusively T-AIS data was used for the C1C2CMV inventory.

Duplicate messages were identified and removed which resulted in a total of 814 million AIS records. Additionally, AIS transmitters unrelated to marine vessel combustion sources, such as

non-self-propelled vessels, buoys, and helicopters, were identified and records removed from the dataset. These miscellaneous entities were identified base on the first 3 digits of their associated MMSI code (e.g. 111XXXXXX 970XXXXXX, 972XXXXXX, and 99XXXXXXX). This cleaning reduced the dataset to 607 million records. Easily identifiable pleasure craft vessels were removed, further reducing the dataset to 446 million records. Entities that reported only a single AIS records throughout the year of data were removed, because at minimum two records are needed per ship to calculate activity durations. Finally, consecutive hoteling activity of each ship were aggregated in the dataset in order to reduce size. With these last two steps, the AIS dataset was reduced to 422 million records. Throughout this process, the duration between AIS observations was calculated.

4.0 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 to 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.

5.0 Vessel Identification

After the AIS dataset was cleaned, the MMSIs were compiled for vessel identification. Vessels must be identified in order determine their vessel type, and thus their vessel group, power rating, and engine tier information which are required for emissions calculations. The different sources used to identify a vessel are presented in Figure 2. Vessel-specific information were compiled by matching the AIS fleet MMSIs with those in the Clarksons dataset. 9,278 vessels were identified through this method. However, it was assumed that the remaining vessels in the AIS dataset were still C1 C2 vessels, given that requirements for their registry in datasets such as Clarksons are not as stringent as C3 vessels. In order to further identify vessels MMSI codes and call signs reported by the International Telecommunications Union (ITU) (2017 a, b) were used to differentiated between U.S. and foreign flagged ships. According to the ITU, vessels with MMSIs beginning with 303, 379, 338, 366, 367, 368, or 369, and those with call signs beginning in W, K, N, and AA-AL were flagged as U.S. registered ships.

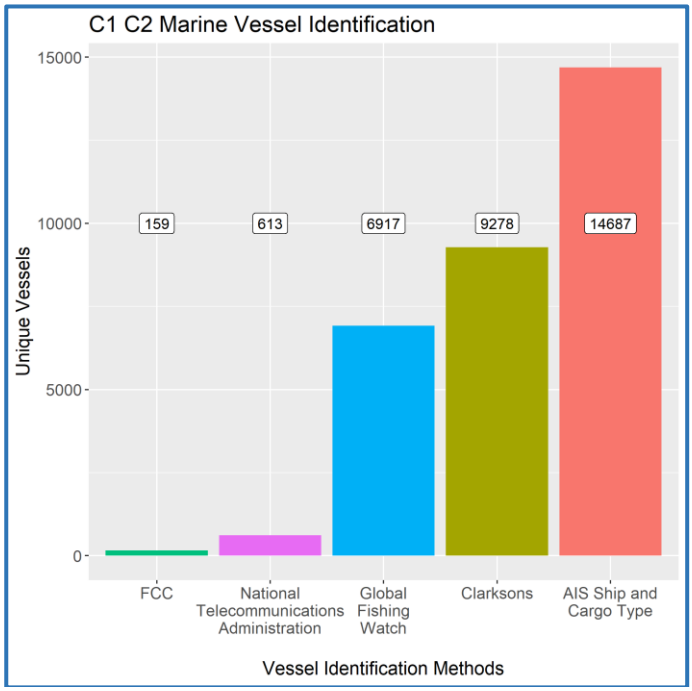

Figure 2. Ship Counts by Vessel Identification Methods

The Federal Communications Commission (FCC) issues MMSI codes as part of their authority regarding commercial marine vessel communications. Based on FCC guidance it was assumed that FCC vessels are those with US flags who MMSIs, identifying 1,852 vessels. Of these vessels, only 159 were discovered in an FCC provided dataset, which identifies vessels by Call Sign. FCC categorizes vessels according to whether they are “Compulsory” or “Non-Compulsory”. 65 of the vessels in the C1C2 fleet were flagged as the former and 94 were flagged as the latter. Compulsory vessels are larger, passenger or cargo ships which are involved in commercial activities and are legally required to be equipped with telecommunications instruments. Non-compulsory vessels are not required by law to have these communication

devices but have voluntarily opted to install this equipment and are likely large recreational boats. All 95 non-compulsory vessels in the C1C2 fleet were assumed to be pleasure craft and were later removed from the dataset.

U.S. vessels with MMSI codes containing a nine in the fourth digit were considered to be military vessels consistent with patterns from National Telecommunications Administration vessels.

The remaining ships were compared to publicly available data compiled by Global Fishing Watch (GFW). GFW determines ship type information by analyzing processed 2012 to 2016 AIS data through machine learning classifiers, which identify activity patterns by ship and gear type. C1and C2 vessels were matched to this dataset using MMSI, ship name, Call Sign and IMO numbers. When vessels could not be matched by all four, they were matched iteratively by three, two and one of these identifiers. Vessels were not matched on ship name exclusively. 6,917 vessels were matched through this method. Vessels that were missing power rating information and were identified by GFW adopted the inferred engine power field from the GFW dataset.

The received AIS data included ship and cargo type information, but because these data are entered by the user, there are issues with regards to the accuracy of this field. The current version 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 the methods explained above.

6.0 Vessel Group Assignments

In combining these different data sources, 108 different vessel types were matched to the C1 C2 vessels (Table A-1, Appendix A). Surrogate vessel attribute data is not available for all these vessel types, so the vessel types were aggregated into 16 different vessel groups for which surrogate data were available (Table 1). Note Table 2 provides a list of vessels types removed. To determine these groups, the vessel types identified in the above-described datasets were compared to the Marine Cadastre ship types associated with each of the vessels' Ship and Cargo Type number. Additionally, all vessels with Ship and Cargo Type numbers associated with the "Tug Tow" Vessel Group were assigned "Tug" vessel types. Between the non-tug vessels who adopted vessel types from the Marine Cadastre assignments out of necessity and the tug vessels who were specified to adopt these, 14,687 vessels were directly identified by their ship and cargo number. The miscellaneous group represent 14 percent of the AIS vessels (excluding recreational vessels) for which a specific vessel type could not be assigned.

Table 1. C1C2 Inventory Ship Counts in Entire AIS and NEI Regions

Vessel Group	Entire Area Ship Count	NEI Area Ship Count
Bulk Carrier	45	37
Commercial Fishing	1,686	1,147
Container Ship	8	7
Ferry Excursion	482	441

Table 1. C1C2 Inventory Ship Counts in Entire AIS and NEI Regions

Vessel Group	Entire Area Ship Count	NEI Area Ship Count
General Cargo	1,555	1,498
Government	1,368	1,338
Miscellaneous	1,810	1,475
Offshore support	1,203	1,149
Reefer	15	13
Ro Ro	27	26
Tanker	144	100
Tug	4,203	3,994
Work Boat	83	77
Total in Inventory:	**12,629**	**11,302**

Table 2. Removed Ships

Vessel Group	Ship Count
Pleasure Craft (Removed)	18,002
Non-Propelled (Removed)	1,023
Total (Including Table 1 Inventory Ships)	**31,654**

The aggregated vessel counts were evaluated to ensure they were reasonable using publicly available data sources. For example, the American Waterways Operators and the US Army Corps of Engineers (USACE) report that there are between 5,500 and 5,599 tugs operating in the US. This suggests that the 2017 AIS value of 4,203 across the region, and only 3,994 within the NEI area, underestimates the actual number of work tugs (America Waterways Operators, 2017).

The BOEM 2017 Gulf of Mexico emission inventory identified 1,007 support vessels that provide services to oil and gas platforms in federal waters. The USACE reported 1,713 vessels in this category. The 2017 AIS C1C2 fleet included 1,203 offshore support vessels which would include vessels that support offshore platforms located in federal and state waters in the Gulf of Mexico, as well as California, Alaska and possibly Canada.

The USACE documented that there were 70 domestic flagged tankers (USACE 2016). This stands in comparison to the 2017 AIS estimate of 144 tankers, of which approximately 20% (or 28 vessels) were registered in the US. Some of the 70 U.S. registered tankers identified by USACE may be larger Category 3 vessels which were not properly registered in Clarksons or are operating outside of U.S. waters.

Other comparisons are more problematic. For example, the USACE estimates that there are 794 U.S flagged dry cargo vessels operating in the U.S., however the 1,555 general cargo ships identified in the 2017 AIS fleet dwarfs this number. 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.

The 2017 AIS estimate of 482 ferry-excursion vessels is compared with USACE's 2016 estimate of 797 passenger-ferry vessels. The threshold for required participation in AIS for excursion ferries is 150 passengers, 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.

Though the AIS dataset included 18,002 recreational vessels, the U.S. Coast Guard estimated that there are approximately 12 million registered recreational vessels in the U.S. (USCG, 2018); such that AIS is capturing a very small fraction of this fleet. For the purpose of the 2017 NEI, recreational vessels were excluded from this inventory.

1,686 commercial fishing vessels were identified in the 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). Therefore the 2017 AIS inventory is under reporting commercial fishing vessels. This under reporting 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 secrete may contribute to this lack of AIS data on commercial fishing vessels.

The majority (9,428 or 75%) of C1C2 vessels included in this assessment are domestic, U.S. flagged vessels. The remaining 3,201 vessels are foreign flagged. Registration varies by vessel type; the percentages of each ship group representing foreign and domestic flagged vessels are presented in Figure 3.

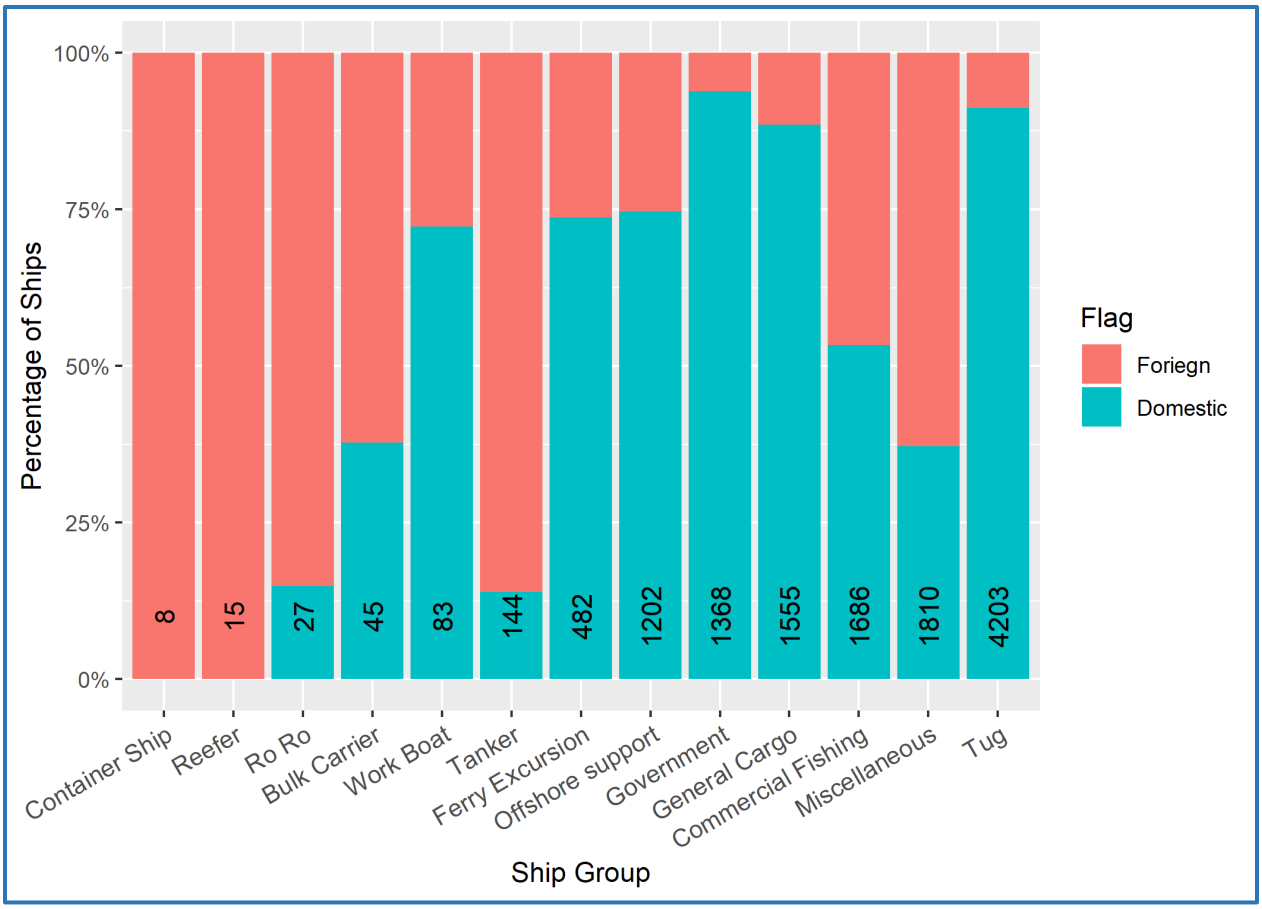

Figure 3. Ship Distribution by Flag

7.0 Power Assignments

7.1 Propulsive Power

Power ratings are required per vessel in order 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.

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

Where:

P = Power per AIS message interval
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 each of its 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 Clarkson's 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 2017 NEI fleet. This necessitated the use of surrogate engine power and load values. Propulsive surrogate power and load factors values are reported in Table 3. Surrogate total installed propulsive power values were compiled through analysis of C1C2 vessels with propulsive power data reported in Clarksons. ERG assessed these values in comparison to those documented in USEPA's (2009) *Current Methodologies in Preparing Mobile Source Port-Related Emission Inventories*. Vessels missing propulsive power data adopted the surrogate values associated with their vessel group.

Table 3. Propulsive Power and Load Factor Surrogates

Vessel Group	Surrogate Total Installed Propulsive Power (kW)	Surrogate Service Speed (kn)	Number of Vessels from which Average Service Speed was Calculated
Bulk Carrier	7,505.32	14.37765	22
Commercial Fishing	519.67	12.18724	31
Container Ship	2,700	15.01095	2
Ferry Excursion	5,322.14	19.79121	102
General Cargo	2,395.58	12.00845	35
Government	2,124.82	15.88268	27
Miscellaneous	2,336.58	12.60714	77
Offshore support	3,949.33	13.54577	557
Reefer	5,876.7	12.50963	4
Ro Ro	3,792.7	13.63689	24
Tanker	6,577.66	13.73031	58
Tug	2,395.11	11.45347	485
Work Boat	3,546.08	12.24971	44

Vessels missing service speed information adopted the surrogate service speed reported in Table 3 in order to calculate a surrogate LF to be used as described in Equation 2. Surrogate service speed was compiled by calculating the time-weighted, ship type average service speed information of vessels with this data reported in the 2017 AIS C1C2 fleet. The number of vessels

with service speed data used to calculate these averages varied by vessel group and are reported in Table 3. 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 (USEPA, 2009).

A very small percentage of AIS messages after data cleaning were 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 activity time associated with propulsive power and load factor surrogates can be seen in Figure 4. A comparison of Figure 4 and Figure 5, which displays the C1C2 AIS NEI activity hours by vessel group, shows the effect of these surrogates have on the resulting C1C2 NEI emission estimates.

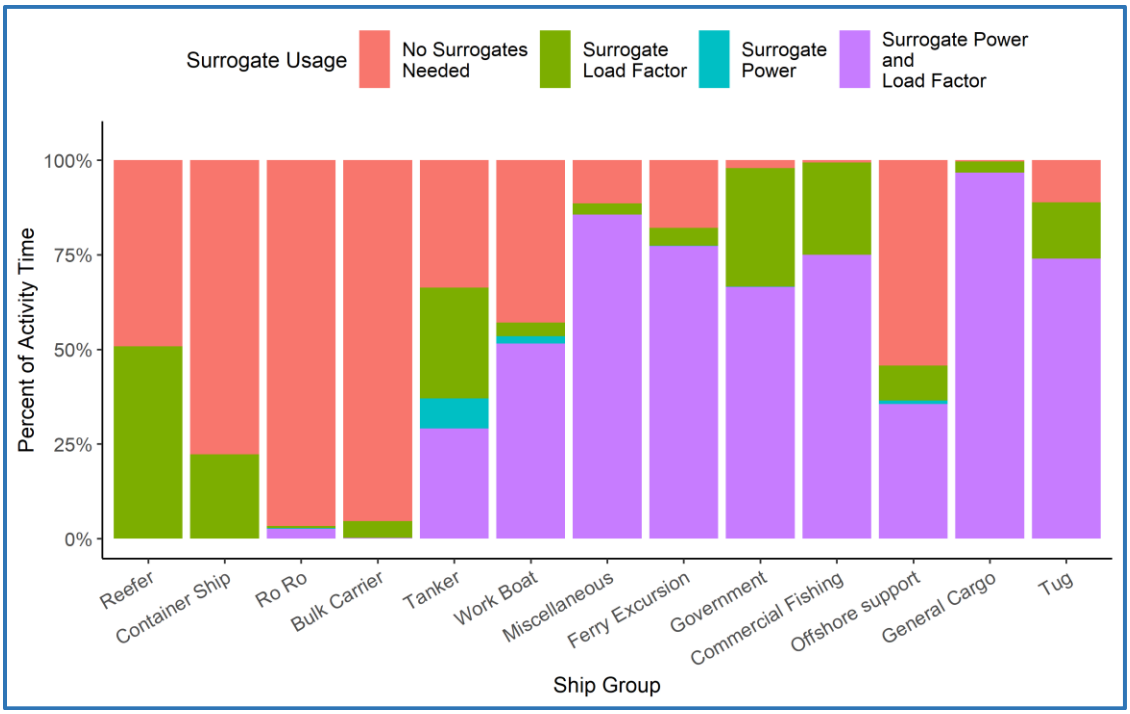

Figure 4. Percent of NEI Activity Time associated with Propulsive Surrogates

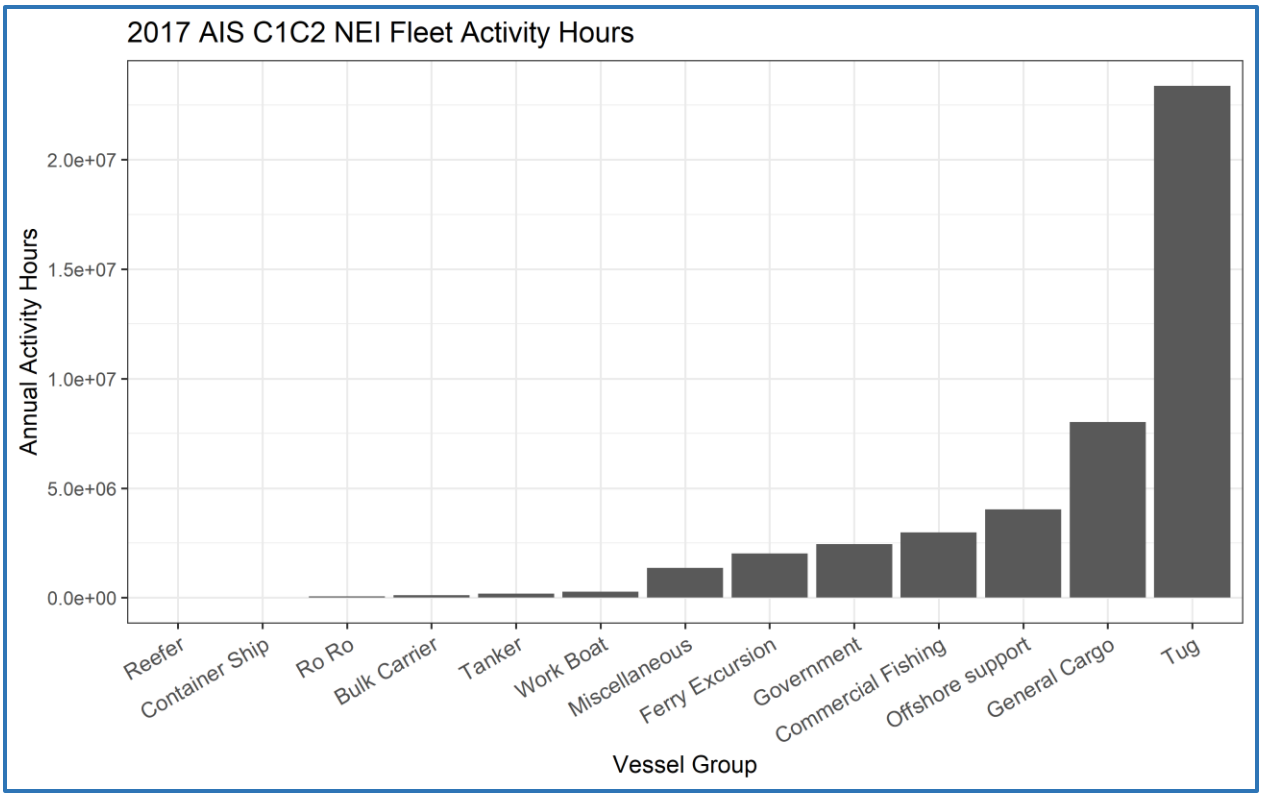

Figure 5. C1C2 NEI AIS Activity Hours by Vessel Group

7.2 Auxiliary and Boiler Power

Auxiliary engine power ratings are rarely documented in the ship registry datasets, and auxiliary boiler power is not included at all. Therefore, in order 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 to the auxiliary total installed power rating. Auxiliary LFs were compiled from USEPA's (2009) *Current Methodologies in Preparing Mobile Source Port-Related Emission Inventories* in addition to EPA provided values.

Table 4. Auxiliary and Boiler Power Surrogates

Vessel Group	Aux Operating Load Factor	Auxiliary Total Installed Power Rating (kW)	Boiler Power Rating at Load (kW)
Bulk Carrier	0.1	1,008.76	109
Commercial Fishing	0.43	566.82	0
Container Ship	0.19	594	506
Ferry Excursion	0.43	1,384.85	0

Table 4. Auxiliary and Boiler Power Surrogates

Vessel Group	Aux Operating Load Factor	Auxiliary Total Installed Power Rating (kW)	Boiler Power Rating at Load (kW)
General Cargo	0.22	1,119.67	106
Government	0.43	2,312.53	0
Miscellaneous	0.43	1,069.33	0
Offshore support	0.56	1,080.78	0
Pilot	0.43	20.19	0
Reefer	0.32	2,854.1	464
Ro Ro	0.26	695.24	109
Tanker	0.26	2,398.96	346
Tug	0.43	161.56	0
Work Boat	0.43	1,492.02	0

Boilers are used on commercial marine vessels to provide hot water and steam for different applications. Previously heat from boilers was used to elevate the temperature of storage tanks and fuel system 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.

8.0 Emission Factors

The emission factors used in this inventory take into consideration the EPA's marine vessel fuel regulations as well as exhaust standards that are based on the year that the vessel was manufactured to determine the appropriate regulatory tier. These values are reported as g/kWh in Table 5 and were developed using Tables 3-7 through 3-10 in USEPA's (2008) Regulatory Impact Analysis on engines less than 30 liters per cylinder. To compile these emissions factors, population-weighted average emission factor were calculated per tier based on C1C2 population distributions grouped by engine displacement. Boiler emission factors were obtained from an earlier Entec study (Entec, 2004).

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. However without more specific data, the magnitude of this emissions difference cannot be estimated.

Table 5. 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. 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

8.1 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). Adjustment to the criteria emissions were made using the following equation:

$$EF\_LLAF_{iy} = EF_{iy} \times LLAF_y \quad (2)$$

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

Table 7. Low Load Adjustment Factors

Load	PM_{10}	NO_X	SO_2	VOC	CO_2	$PM_{2.5}$	CO
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

8.2 HAP Specific Profiles

The EPA recently developed updated HAP speciation profiles in order to calculate HAPs from the 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.

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
Ammonia[c]	NH_3	$PM_{2.5}$	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

Table 8. HAP Speciation Profile

Pollutant	Pollutant Code	Basis	Fraction
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)Perylene[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	0.00273
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.

9.0 Rasterization

In order to include the results of the inventory in the national air quality modeling platform, ERG developed daily rasters from the C1C2CMV estimated emissions. After emissions were calculated and allocated to the latitude and longitude coordinates of the message following their associated activity interval, they were split into daily files and read into the rasterization function. Throughout the function's processing, these emissions were then additionally split by hour and SCC category. After this, the R rasterize function was used to overlay the points with a grid cell box and sum emissions per grid cell to create a raster. An example of this process can be seen in Figure 6.

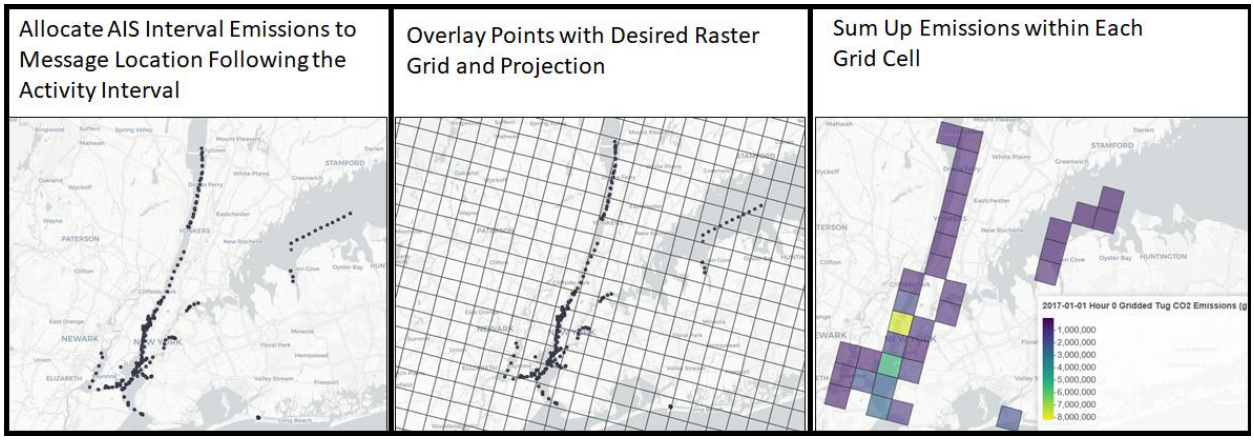

Figure 6. C1C2 NEI AIS Activity Hours by Vessel Group

In order to rasterize the data as needed, multiple rasterization grids were developed to cover the continental US (CONUS) and give more granular depictions of Alaska, Hawaii, Puerto Rico, the Great Lakes and the Long Island regions. These grids were created with an R script which was written to output rectangular polygon shapefiles which outline the extent of the raster grid and are imbedded with the necessary projection for that area. For each desired raster, these polygons and the desired grid resolution were used as inputs for the rasterization function.

The resulting rasters were outputted as netCDF files, each of which represent a single day and SCC combination. Each netCDF file has 24 layers and seven variables, with the first layer representing the first hour of the day (00:00:00 – 01:00:00 UTC), and each variable representing one of the modelled pollutants (VOC, CO_2, CO, NO_X, $PM_{2.5}$, SO_2, PM_{10}). In comparison to the C3 model, no masking raster was needed for the C1C2 results. This is because the C1C2CMV model did not interpolate activity between non-hotelling messages with intervals greater than five minutes, as the C3CMV model did. Thus, the geographic distribution of the entire resulting C1C2 dataset was assumed to be correct. That being said, it is possible that a small portion of the geographic data associated with these emissions are in incorrect locations. These geographically incorrect data points, otherwise known as rogue messages, are a known issue in raw AIS data. They are often the result of blips in the AIS triangulation system and can result in a vessel message showing up in an unlikely location.

ERG also adjusted the resulting raster to estimate emissions for the 2016 air quality modeling platform. For this process, the geographic distribution of the emissions was assumed to be equivalent to that of 2017, but the quantity of emissions was adjusted by a multiplier of 0.98. ERG developed this multiplier by analyzing the ratio of total inbound USACE Entrance and Clearance calls between 2016 and 2017 (USACE, 2018).

10.0 Summary

Table 9 presents the total estimated emissions due to Category 1 and 2 marine vessels in the NEI area throughout 2017 and Figure 7 shows the geographic distribution of NO_x emissions in U.S. waters.

Table 9. Total NEI Emissions by Category 1 and 2 Marine Vessels

Category	VOC	CO_2	CO	NO_X	$PM_{2.5}$	SO_2	PM_{10}	kWhrs	Time (hr)
C1/C2	8,348.18	14,628,561	31,290.04	213,636.7	5,628.328	737.7914	5,806.681	1.91E+10	4,489,8527

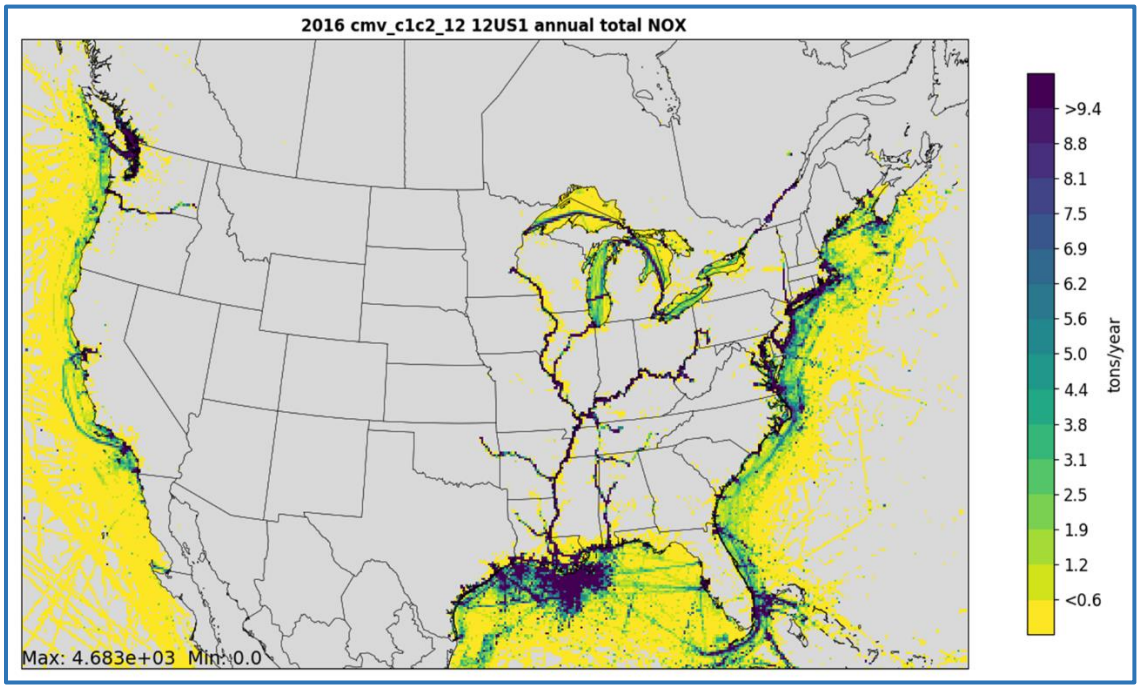

Figure 7. Geographic Distribution of NO_X Emissions in U.S. Waters

Table 10 presents the total C1C2 NEI emissions by ship type in 2017 and Figure 8 shows the relative distribution of NO_x emissions by vessel type.

Table 10. C1C2 NEI Emissions by Vessel Group

Category	Ship Type	VOC	CO_2	CO	NO_X	$PM_{2.5}$	SO_2	PM_{10}	kWhrs	Time (hr)
C1/C2	Bulk Carrier	75.92	164,920.85	362.95	2,375.79	60.92	9.46	62.86	2.15E+08	113,770.9
C1/C2	Commercial Fishing	320.62	631,013.56	1,493.72	9,811.47	244.74	5.80	252.31	8.42E+08	2,981,577
C1/C2	Container Ship	13.42	31,779.84	62.15	410.62	11.11	4.00	11.48	40027444	11,429.23
C1/C2	Ferry Excursion	844.48	1,433,040.09	3,322.79	22,497.87	574.66	13.17	592.43	1.91E+09	2,022,104
C1/C2	General Cargo	1469.51	3,133,513.09	5,483.10	38,111.76	1,107.79	573.92	1,145.92	3.83E+09	8,027,597
C1/C2	Government	957.66	2,013,195.03	4,758.06	30,835.82	762.44	18.51	786.02	2.69E+09	2,444,442
C1/C2	Miscellaneous	382.44	608,593.78	1,427.24	9,825.25	253.39	5.59	261.23	8.13E+08	1,367,106
C1/C2	Offshore support	1353.16	2,600,501.65	5,427.47	35,481.30	892.97	23.91	920.59	3.47E+09	4,030,182
C1/C2	Reefer	5.69	14,913.58	29.28	189.45	5.05	1.84	5.22	18804644	5,741.911
C1/C2	Ro Ro	17.85	42,857.80	86.22	564.02	14.99	4.68	15.48	54443179	61,333.58
C1/C2	Tanker	91.74	240,484.03	403.84	2,644.87	76.16	42.77	78.80	2.95E+08	182,964.5
C1/C2	Tug	2705.55	3,523,258.00	7,991.97	57,923.71	1,548.32	32.39	1,596.20	4.7E+09	23,371,881
C1/C2	Work Boat	110.15	190,490.01	441.26	2,964.80	75.80	1.75	78.14	2.54E+08	278,397.8

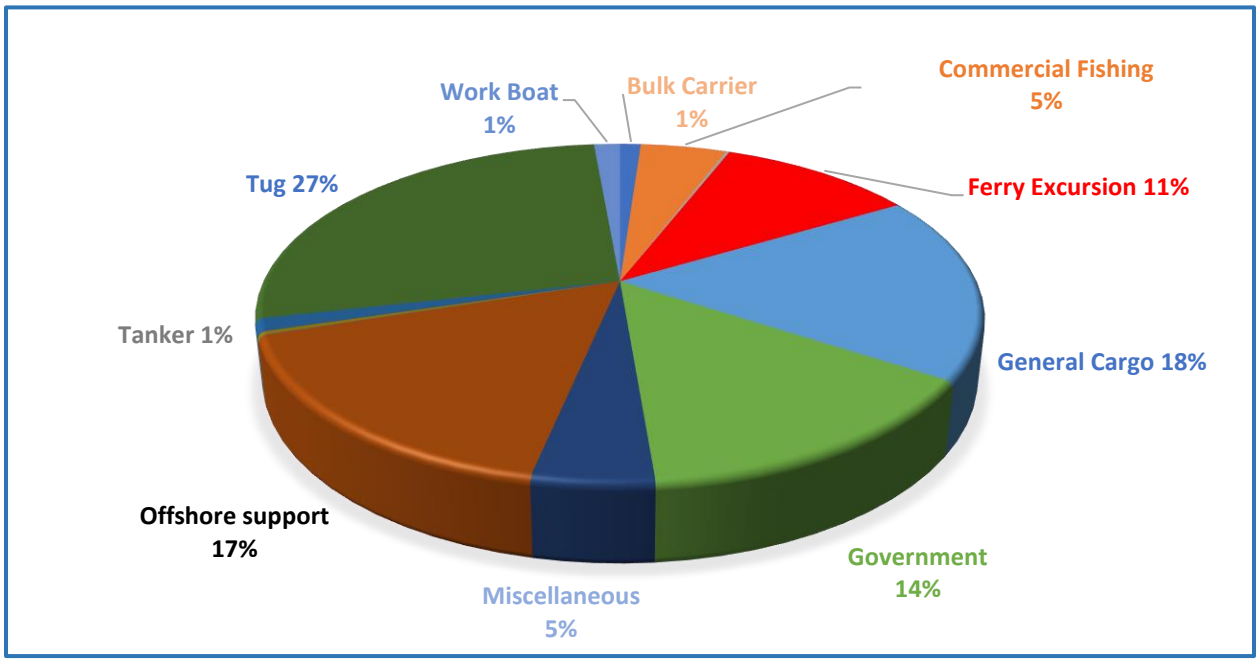

Figure 8. Relative Distribution of C1C2 NO_X Emissions by Vessel Type

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 service speed. kWhrs were summed by ship type as well as by SCC. Each ship type's total kWhrs were analyzed by the percentages allotted to each SCC category (Figure 9).

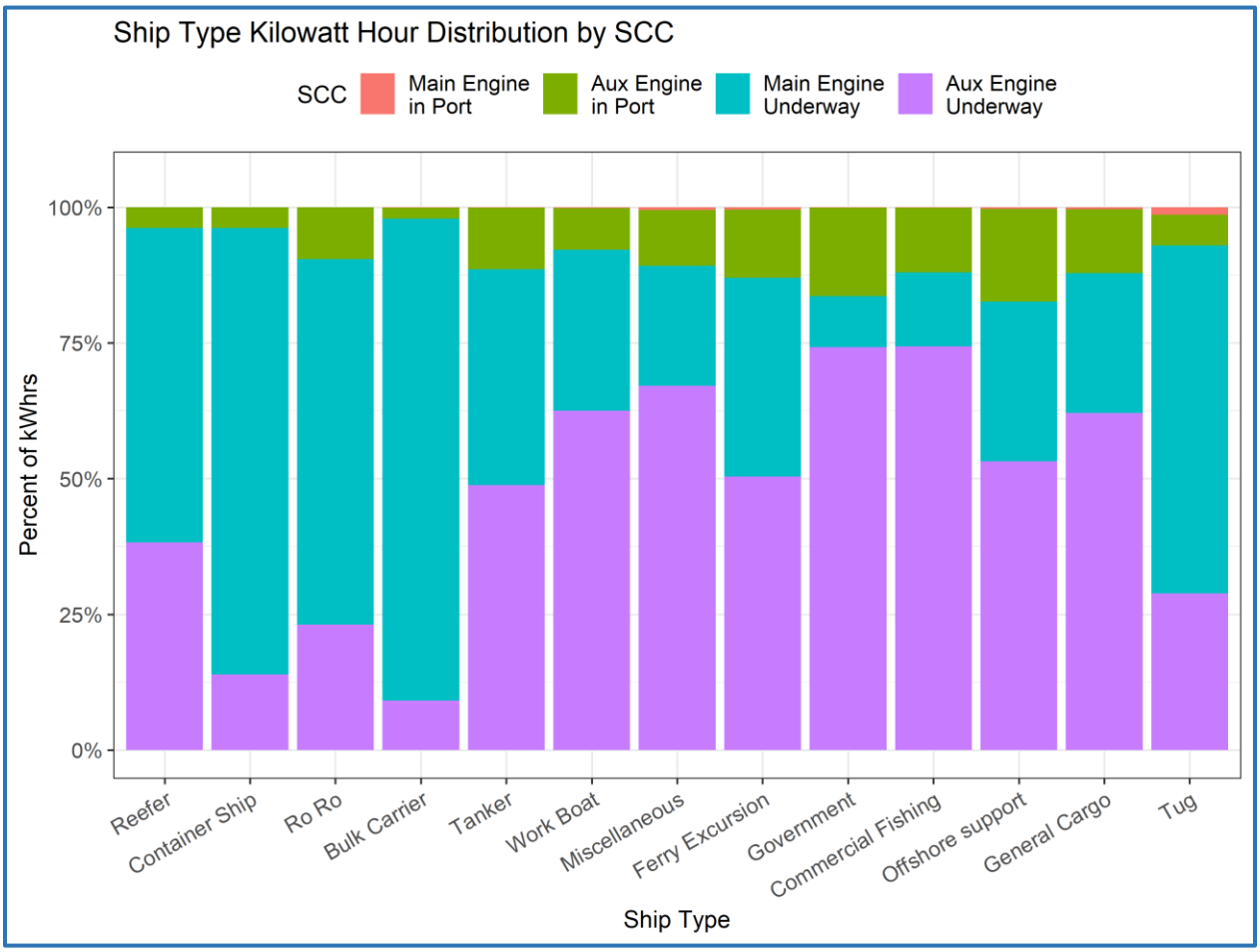

Figure 9. Ship Type Kilowatt Hour Distribution by SCC

Total emissions, activity durations, and kWhrs can be see per SCC in Table 11.

Table 11. NEI Emissions by SCC

SCC	FuelType	Port/ Underway	Engine	VOC	CO_2	CO	NO_X	$PM_{2.5}$	SO_2	PM_{10}	kWhrs	Time (hr)
2280002201	MGO/MDO	Underway	Main	4,368.0	5,045,668	11,347.7	85,303	2,328.0	46.4	2,400.0	37,263,038	6.74E+09
2280002202	MGO/MDO	Underway	Aux	3,091.9	7,778,098	16,247.2	103,836.2	2,659.7	576.5	2,745.6	74,526,076	1.01E+10
2280002101	MGO/MDO	Port	Main	204.6	81,712	183.6	2,187.1	71.7	0.75	74.0	7,635,489	1.09E+08
2280002101	MGO/MDO	Port	Aux	683.6	1,723,083	3,511.5	22,310.5	568.82	114.1	587.1	15,270,978	2.24E+09

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 factors related to vessel location and time stamp included in the AIS data stream. These data are more complete and readily available for larger Category 3 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. This 2017 NEI inventory should likely be seen as a first step in improving the C1C2 emission inventory and improvements are anticipated as more vessels are equipped with AIS transmitters and more vessel-specific attribute data become available.

11.0 References

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APPENDIX A

Vessel Type and Ship Group Bridge

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

Vessel Type	Marine Cadastre Vessel Group from Ship and Cargo Number	Vessel Group
Bulk	Not Available	Bulk Carrier
Bulk Carrier		Bulk Carrier
Bulk Carrier	Cargo	Bulk Carrier
Cement Carrier	Cargo	Bulk Carrier
Drifting_longlines	Fishing	Commercial Fishing
Drifting_longlines	Not Available	Commercial Fishing
Drifting_longlines	Pleasure Craft/Sailing	Commercial Fishing
Drifting_longlines		Commercial Fishing
Drifting_longlines	Other	Commercial Fishing
Fishing	Fishing	Commercial Fishing
Fishing	Pleasure Craft/Sailing	Commercial Fishing
Fishing	Passenger	Commercial Fishing
Fishing	Not Available	Commercial Fishing
Fishing		Commercial Fishing
Fishing	Other	Commercial Fishing
Fishing	Military	Commercial Fishing
Fishing	Cargo	Commercial Fishing
Fishing Vessel	Fishing	Commercial Fishing
Fishing Vessel	Other	Commercial Fishing
Gear	Pleasure Craft/Sailing	Commercial Fishing
Gear	Fishing	Commercial Fishing
Gear	Not Available	Commercial Fishing
Other_fishing	Fishing	Commercial Fishing
Other_fishing	Other	Commercial Fishing
Other_fishing	Pleasure Craft/Sailing	Commercial Fishing
Pole_and_line	Fishing	Commercial Fishing
Pole_and_line	Pleasure Craft/Sailing	Commercial Fishing
Pole_and_line	Other	Commercial Fishing
Pots_and_traps	Fishing	Commercial Fishing
Pots_and_traps	Pleasure Craft/Sailing	Commercial Fishing

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

Vessel Type	Marine Cadastre Vessel Group from Ship and Cargo Number	Vessel Group
Pots_and_traps	Not Available	Commercial Fishing
Purse_seines	Fishing	Commercial Fishing
Purse_seines	Not Available	Commercial Fishing
Purse_seines	Other	Commercial Fishing
Purse_seines		Commercial Fishing
Purse_seines	Passenger	Commercial Fishing
Purse_seines	Tanker	Commercial Fishing
Purse_seines	Pleasure Craft/Sailing	Commercial Fishing
Purse_seines	Cargo	Commercial Fishing
Set_gillnets	Fishing	Commercial Fishing
Set_gillnets	Pleasure Craft/Sailing	Commercial Fishing
Set_gillnets	Other	Commercial Fishing
Set_gillnets	Not Available	Commercial Fishing
Set_longlines	Fishing	Commercial Fishing
Set_longlines		Commercial Fishing
Set_longlines	Other	Commercial Fishing
Set_longlines	Not Available	Commercial Fishing
Set_longlines	Pleasure Craft/Sailing	Commercial Fishing
Squid_jigger	Not Available	Commercial Fishing
Trawler	Fishing	Commercial Fishing
Trawlers	Not Available	Commercial Fishing
Trawlers	Other	Commercial Fishing
Trawlers	Pleasure Craft/Sailing	Commercial Fishing
Trawlers		Commercial Fishing
Trawlers	Fishing	Commercial Fishing
Trawlers	Military	Commercial Fishing
Trollers	Fishing	Commercial Fishing
Trollers	Other	Commercial Fishing
Merchant	Fishing	Commercial Fishing
Miscellaneous	Fishing	Commercial Fishing
Container		Container Ship

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

Vessel Type	Marine Cadastre Vessel Group from Ship and Cargo Number	Vessel Group
Container Ship (Fully Cellular)		Container Ship
Container Ship (Fully Cellular)	Cargo	Container Ship
Containership		Container Ship
Official Service Shp	Pleasure Craft/Sailing	Offshore support
Official Service Shp	Other	Offshore support
Official Service Shp	Passenger	Offshore support
Official Service Shp	Cargo	Offshore support
Official Service Shp	Not Available	Offshore support
Official Service Shp	Fishing	Offshore support
Official Service Shp	Military	Offshore support
Official Service Shp	Tanker	Offshore support
Tender	Pleasure Craft/Sailing	Offshore support
Tender	Passenger	Offshore support
Tender	Other	Offshore support
Tender		Offshore support
Tender	Not Available	Offshore support
Tender	Fishing	Offshore support
Cruise		Ferry Excursion
Ferry	Pleasure Craft/Sailing	Ferry Excursion
Ferry		Ferry Excursion
Ferry	Other	Ferry Excursion
High Speed	Other	Ferry Excursion
Passenger	Passenger	Ferry Excursion
Passenger	Pleasure Craft/Sailing	Ferry Excursion
Merchant	Passenger	Ferry Excursion
Merchant	Pleasure Craft/Sailing	Ferry Excursion
Small Commercial	Fishing	Commercial Fishing
Auto Carrier	Cargo	General Cargo
Cargo	Cargo	General Cargo

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

Vessel Type	Marine Cadastre Vessel Group from Ship and Cargo Number	Vessel Group
Cargo	Other	General Cargo
Cargo	Pleasure Craft/Sailing	General Cargo
Cargo		General Cargo
Cargo	Cargo	General Cargo
Cargo	Military	General Cargo
Cargo	Not Available	General Cargo
Cargo	Fishing	General Cargo
Cargo	Tanker	General Cargo
Cargo and Passenger	Other	General Cargo
General Cargo	Fishing	General Cargo
General Cargo		General Cargo
General Cargo	Pleasure Craft/Sailing	General Cargo
General Cargo	Other	General Cargo
General Cargo Ship		General Cargo
General Cargo Ship	Not Available	General Cargo
General Cargo Ship	Cargo	General Cargo
General Cargo Ship	Pleasure Craft/Sailing	General Cargo
Merchant	Other	General Cargo
Merchant	Military	General Cargo
Merchant	Not Available	General Cargo
Merchant	Cargo	General Cargo
Merchant		General Cargo
Multi-Purpose/Heavy Lift Cargo		General Cargo
Small Commercial	Other	General Cargo
Small Commercial	Not Available	General Cargo
Small Commercial	Cargo	General Cargo
Coast Guard	Pleasure Craft/Sailing	Government
Coast Guard	Not Available	Government
Government	Not Available	Government
Government	Military	Government

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

Vessel Type	Marine Cadastre Vessel Group from Ship and Cargo Number	Vessel Group
Government	Pleasure Craft/Sailing	Government
Military	Military	Government
Military	Not Available	Government
Military	Other	Government
Military	Pleasure Craft/Sailing	Government
Military	Fishing	Government
Military		Government
Military	Tanker	Government
Military	Passenger	Government
Military	Cargo	Government
Naval		Government
USCG	Other	Government
USCG	Not Available	Government
USCG	Military	Government
USCG	Pleasure Craft/Sailing	Government
Motor_passenger	Military	Government
Buoy Tender		Government
Fire	Other	Government
Icebreaker		Government
Landing Ship (Dock Type)	Military	Government
Rescue	Other	Government
Rescue	Passenger	Government
Rescue	Not Available	Government
Rescue	Cargo	Government
Rescue	Pleasure Craft/Sailing	Government
Rescue	Fishing	Government
SAR	Other	Government
SAR	Pleasure Craft/Sailing	Government
Miscellaneous	Not Available	Miscellaneous
Miscellaneous		Miscellaneous
Miscellaneous	Other	Miscellaneous

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

Vessel Type	Marine Cadastre Vessel Group from Ship and Cargo Number	Vessel Group
Not Available	Not Available	Miscellaneous
Other	Other	Miscellaneous
Unknown	Other	Miscellaneous
Unknown	Not Available	Miscellaneous
Unknown	Fishing	Miscellaneous
		Miscellaneous
Pilot	Not Available	Pilot
Pilot	Other	Pilot
Pilot	Other	Pilot
Crew Boat		Offshore support
Crew/Supply Vessel		Offshore support
Crew/Supply Vessel	Passenger	Offshore support
Offshore Oil and Gas Support	Pleasure Craft/Sailing	Offshore support
Offshore Oil and Gas Support	Fishing	Offshore support
Offshore Oil and Gas Support	Other	Offshore support
Offshore Oil and Gas Support	Not Available	Offshore support
Offshore Oil and Gas Support	Tanker	Offshore support
Offshore Tug/Supply Ship	Other	Offshore support
Oil and Gas		Offshore support
Platform Supply	Not Available	Offshore support
Platform Supply	Other	Offshore support
Platform Supply Ship	Other	Offshore support
Platform Supply Ship	Cargo	Offshore support
Service	Other	Offshore support
Support Vessel		Offshore support
Drilling		Offshore support
Drilling	Other	Offshore support
Pipe Layer	Other	Offshore support
Seismic_vessel	Other	Offshore support
Seismic_vessel	Fishing	Offshore support

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

Vessel Type	Marine Cadastre Vessel Group from Ship and Cargo Number	Vessel Group
Seismic_vessel	Pleasure Craft/Sailing	Offshore support
Survey		Offshore support
Survey	Other	Offshore support
Survey	Military	Offshore support
Small Commercial	Passenger	Miscellaneous
Unknown	Pleasure Craft/Sailing	Pleasure Craft
Barge		Pleasure Craft
Sailing	Pleasure Craft/Sailing	Pleasure Craft
Sailing	Other	Pleasure Craft
Sailing		Pleasure Craft
Sailing	Pleasure Craft/Sailing	Pleasure Craft
Sailing	Military	Pleasure Craft
Sailing	Not Available	Pleasure Craft
Sailing	Passenger	Pleasure Craft
Sailing	Cargo	Pleasure Craft
Sailing Ship	Pleasure Craft/Sailing	Pleasure Craft
Motor_passenger	Pleasure Craft/Sailing	Pleasure Craft
Motor_passenger	Passenger	Pleasure Craft
Motor_passenger	Not Available	Pleasure Craft
Motor_passenger	Other	Pleasure Craft
Motor_passenger		Pleasure Craft
Motor_passenger	Fishing	Pleasure Craft
Motor_passenger	Cargo	Pleasure Craft
PC	Pleasure Craft/Sailing	Pleasure Craft
Pleasure	Pleasure Craft/Sailing	Pleasure Craft
Pleasure	Fishing	Pleasure Craft
Pleasure	Passenger	Pleasure Craft
Pleasure	Other	Pleasure Craft

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

Vessel Type	Marine Cadastre Vessel Group from Ship and Cargo Number	Vessel Group
Pleasure	Not Available	Pleasure Craft
Pleasure	Cargo	Pleasure Craft
Pleasure		Pleasure Craft
Pleasure Craft	Pleasure Craft/Sailing	Pleasure Craft
Pleasure Craft	Fishing	Pleasure Craft
Pleasure Craft	Not Available	Pleasure Craft
Pleasure Craft	Other	Pleasure Craft
Pleasure Craft	Passenger	Pleasure Craft
Pleasure Craft/Sailing	Pleasure Craft/Sailing	Pleasure Craft
Recreational	Pleasure Craft/Sailing	Pleasure Craft
Recreational	Other	Pleasure Craft
Yacht	Pleasure Craft/Sailing	Pleasure Craft
Yacht/Recreational		Pleasure Craft
Reefer		Reefer
Reefer	Cargo	Reefer
Reefer	Other	Reefer
Reefer		Reefer
Refrigerated Cargo Ship	Cargo	Reefer
Vehicles Carrier		Ro Ro
RORO	Cargo	Ro Ro
RORO		Ro Ro
Chemical & Oil Carrier		Tanker
Merchant	Tanker	Tanker
Chemical Tanker		Tanker
Chemical/Products Tanker	Pleasure Craft/Sailing	Tanker
Chemical/Products Tanker		Tanker
Crude Oil Tanker		Tanker
Crude Oil Tanker	Tanker	Tanker
Crude/Oil Products Tanker	Tanker	Tanker
LNG Carrier		Tanker
LNG Tanker		Tanker

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

Vessel Type	Marine Cadastre Vessel Group from Ship and Cargo Number	Vessel Group
LPG Tanker		Tanker
LPG Tanker	Cargo	Tanker
Products Tanker		Tanker
Tanker		Tanker
Tanker		Tanker
Tanker	Other	Tanker
Tanker	Tanker	Tanker
Tanker	Not Available	Tanker
Tanker	Tanker	Tanker
Tanker	Pleasure Craft/Sailing	Tanker
Tanker	Fishing	Tanker
Tanker	Military	Tanker
Tanker	Cargo	Tanker
Tanker, LNG/LPG	Not Available	Tanker
Tanker, Miscellaneous	Tanker	Tanker
Anchor Handling Tug Supply	Other	Tug
Tug		Tug
Tug	Not Available	Tug
Tug	Pleasure Craft/Sailing	Tug
Tug	Other	Tug
Tug	Military	Tug
Tug	Other	Tug
Tug	Cargo	Tug
Tug	Pleasure Craft/Sailing	Tug
Tug	Not Available	Tug
Tug	Fishing	Tug
Tug	Passenger	Tug
Tug		Tug
Tug	Military	Tug
Tug Tow	Tug Tow	Tug
Exhibition Vessel	Other	Work Boat
Research		Work Boat

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

Vessel Type	Marine Cadastre Vessel Group from Ship and Cargo Number	Vessel Group
Research	Pleasure Craft/Sailing	Work Boat
Research or Survey Ship	Other	Work Boat
Research Survey Vessel	Other	Work Boat
Cable/Pipe Layer		Work Boat
Dredge	Other	Work Boat
Dredge	Fishing	Work Boat
Dredge	Not Available	Work Boat
Dredger		Work Boat
Trailing Suction Hopper Dredger	Other	Work Boat