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Commercial Marine Emissions Inventory for EPA Category 2 and 3 Compression Ignition Marine Engines in the United States Continental and Inland Waterways

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Commercial Marine Emissions Inventory for EPA Category 2 and 3 Compression Ignition Marine Engines in the United States Continental and Inland Waterways

Engine Programs and Compliance Division
Office of Mobile Sources
U.S. Environmental Protection Agency

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NOTICE

This technical report does not necessarily represent final EPA decisions or positions. It is intended to present technical analysis of issues using data which are currently available. The purpose in the release of such reports is to facilitate the exchange of technical information and to inform the public of technical developments which may form the basis for a final EPA decision, position, or regulatory action.

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EXECUTIVE SUMMARY

The U.S. Environmental Protection Agency (EPA) is currently developing the first national emission regulations applicable to compression ignition (CI) marine engines above 37 kilowatts (kW). As part of the proposed rulemaking, EPA must develop an estimate of the current (i.e., baseline) CI marine engine emissions inventory. EPA has defined three categories for CI marine engines, according to cylinder displacement. These categories are shown in Table E1.

Table E1. EPA Categories for CI Marine Engines

EPA Category	Propulsion Engine Displacement per Cylinder (liters)
1	Less than 5
2	Equal to 5, less than 20
3	Equal to or greater than 20

Calculations for Category 2 and 3 engines are presented in this report. This report provides estimates of oxides of nitrogen (NOx), particulate matter (PM), hydrocarbons (HC), and carbon monoxide (CO) from all ships (domestic and foreign) operating in U.S. navigable waterways (i.e., within approximately 200 miles of U.S. coastlines, inland waterways, and the Great Lakes). Emissions are estimated using ship characteristics from 1996 fleet registry data [*LMIS*, 1996], which include vessels 100 gross registered tons (GRT) and greater. Two analytical methods were used to estimate the emissions: Method A is based on general ship operations, and Method B is based on cargo transportation profiles. Method A estimates emissions for the U.S. flag fleet (excluding those operating outside U.S. waters) directly from main engine data, and these emissions are characterized by engine category. Method B estimates emissions from foreign vessels operating in U.S. waters from information about foreign cargo transported on foreign vessels into U.S. ports; they were then characterized by engine category. Method B also estimates regional emissions for ships involved in trade (not including fishing vessels, passenger vessels, tugs, and utility ships) using 1996 fleet registry data, and 1993 data describing waterway transport and trade [*USACE*, 1995].

Total nationwide emissions equal the sum of emissions from U.S. flag vessels operating in U.S. waters, and emissions from foreign flag vessels carrying cargo on U.S. navigable waterways. Total nationwide emissions from main propulsion CI marine engines on commercial ships (100 GRT and greater) operating in U.S. waters are shown in Table E2.

Table E2. Total Nationwide Ship Emissions From Main Engines in U.S. Waters[a]

10^3 Metric tons	Engine Category 2	Engine Category 3	Total
U.S. Flag			
NOx	220.5	118.8	339.3
PM	4.6	9.6	14.2
HC	9.3	3.4	12.7
CO	28.6	10.6	39.2
Foreign Flag			
NOx	9.9	116.9	126.9
PM	0.7	8.7	9.4
HC	0.3	3.6	3.9
CO	0.9	11.0	11.9
Grand Total			
NOx	230.4	235.7	466.1
PM	5.4	18.3	23.7
HC	9.6	7.0	16.6
CO	29.6	21.6	51.2

a. There may be some differences in totals due to rounding.

This report considers emissions only from main propulsion engines, and does not consider auxiliary engine emissions. For CI marine engines used in main propulsion, available engine-specific data is provided, including engine manufacturer and model number.

1. INTRODUCTION

The U.S. Environmental Protection Agency (EPA) is currently developing the first national emission regulations applicable to compression ignition (CI) marine engines above 37 kilowatts (kW). As part of the proposed rulemaking, EPA must develop an estimate of the current (i.e., baseline) CI marine engine emissions inventory. EPA is considering dividing CI marine engines into three categories, each with unique emission regulations. Under the most likely approach to be taken by EPA, these categories would be defined by engine cylinder displacement, as shown in Table 1.

Table 1. EPA Categories for CI Marine Engines

EPA Category	Propulsion Engine Displacement per Cylinder (liters)
1	Less than 5
2	Equal to 5, less than 20
3	Equal to or greater than 20

Calculations for Category 2 and 3 engines are presented in this report. This report provides estimates of oxides of nitrogen (NOx), particulate matter (PM), hydrocarbons (HC), and carbon monoxide (CO) from all ships (domestic and foreign) operating in U.S. navigable waterways (i.e., within approximately 200 miles of U.S. coastlines, inland waterways, and the Great Lakes). Emissions are estimated for the U.S. flag fleet directly from main engine data, and these emissions are characterized by engine category. Emissions from foreign vessels operating in U.S. waters were estimated from information about foreign cargo transported on foreign vessels into U.S. ports; they were then characterized by engine category.

2. ESTIMATION AND METHODOLOGY FOR SHIP EMISSIONS

No single approach with currently available data can produce a comprehensive inventory of ship emissions in U.S. waters.[1] Therefore, this analysis developed and applied two different methods to estimate baseline emissions from commercial CI marine engines from 1996 ship inventory data [*LMIS*, 1996]. Method A produces an inventory of emissions from commercial

[1] EPA is developing a marine module for its NONROAD emissions model that may ultimately provide such a comprehensive estimate.

U.S. flag vessels with CI marine engines by considering engine types, duty cycles, and other operational factors. Method B estimates emissions from foreign and domestic ships transporting cargo in U.S. waters by estimating the emissions per ton-mile of cargo moved, and deriving the pollution emitted from cargo transport in U.S. waters. Since foreign shipping carries significant volumes of cargo to and from U.S. ports, this method provides an estimate of emissions from foreign shipping in U.S. waterways; additionally, regional characteristics of ship emissions are identified by this method.

By combining the inventory of emissions from U.S. flag vessels (Method A) with the estimated emissions from foreign cargo ships in Method B, an estimate of the total nationwide emissions from commercial ships in U.S. waters results. Method A captures emissions from U.S. flag vessels, and Method B captures emissions from foreign cargo vessels. This analysis integrates these distinct estimation methods to develop total nationwide emissions from CI marine engines used in main propulsion systems for commercial shipping. Table 2 presents the summary estimate for total nationwide emissions for EPA Categories 2 and 3.

Table 2. Total Nationwide Emissions from Ship Main Engines in U.S. Waters[a]

10^3 Metric tons	Engine Category 2	Engine Category 3	Total Categories 2 and 3 Engines
U.S. Flag			
NOx	220.5	118.8	339.3
PM	4.6	9.6	14.2
HC	9.3	3.4	12.7
CO	28.6	10.6	39.2
Foreign Flag			
NOx	9.9	116.9	126.9
PM	0.7	8.7	9.4
HC	0.3	3.6	3.9
CO	0.9	11.0	11.9
Grand Total			
NOx	230.4	235.7	466.1
PM	5.4	18.3	23.7
HC	9.6	7.0	16.6
CO	29.6	21.6	51.2

a. There may be some differences in totals due to rounding.

Table 3 shows regional detail, derived from Method B, for each pollutant to be addressed by EPA regulations. Total nationwide Category 2 and 3 emissions reported in Table 2 are simply the sum of the emissions from U.S. flag CI engines in Method A (e.g., 339.3 thousand metric tons NOx) and total emissions from foreign CI engines estimated by Method B (e.g., 126.9 thousand metric tons for NOx). A notable regional insight is that emissions from Category 2 and 3 CI marine engines on the inland rivers (e.g., 106.5 thousand metric tons NOx) equal nearly 70% of the combined emissions from oceangoing (foreign) and coastwise (domestic) shipping (e.g., 156.3 thousand metric tons NOx). The primary reason for this is that the ton-miles of cargo moved over inland rivers equal approximately 65% of the ton-miles of cargo transported in U.S. coastal waters. Moreover, since the navigable miles on the inland rivers equal only about one third of the navigable ocean miles, emissions from these cargo movements occur in a much smaller area.

Table 3. Regional Annual Emissions from CI Marine Engines from Cargo Transport Using Method B (EPA Categories 2 and 3)

U.S. Region	**NOx Emissions** (10^3 metric tons NOx/year)	**PM Emissions** (10^3 metric tons PM/year)	**HC Emissions** (10^3 metric tons HC/year)	**CO Emissions** (10^3 metric tons CO/year)
Oceangoing (foreign cargo)				
US Flag CI Engines	8.0	0.4	0.2	0.7
Category 2 CI Engines	4.9	0.1	0.15	0.5
Category 3 CI Engines	3.1	0.3	0.07	0.2
Foreign CI Engines	96.3	7.8	2.8	8.6
Category 2 CI Engines	7.5	0.6	0.2	0.7
Category 3 CI Engines	88.8	7.2	2.6	7.9
Total	104.3	8.2	3.0	9.3
Coastwise (domestic cargo)	52.0	2.6	1.4	4.6
Category 2 CI Engines	31.7	0.8	1.0	3.2
Category 3 CI Engines	20.3	1.8	0.4	1.4
Inland Rivers				
US Flag CI Engines	76.8	2.4	2.6	8.4
Category 2 CI Engines	46.8	0.7	1.8	5.8
Category 3 CI Engines	30.0	1.7	0.8	2.6
Foreign CI Engines	29.7	1.5	1.1	3.3
Category 2 CI Engines	2.3	0.1	0.1	0.3
Category 3 CI Engines	27.4	1.4	1.0	3.0
Total	106.5	3.9	3.6	11.6

U.S. Region	NOx Emissions (10^3 metric tons NOx/year)	PM Emissions (10^3 metric tons PM/year)	HC Emissions (10^3 metric tons HC/year)	CO Emissions (10^3 metric tons CO/year)
Great Lakes				
US Flag Engines	9.4	0.5	0.3	0.8
Category 2 CI Engines	5.7	0.1	0.2	0.6
Category 3 CI Engines	3.7	0.4	0.1	0.2
Foreign CI Engines	0.8	0.1	0.02	0.1
Category 2 CI Engines	0.06	0.005	0.002	0.005
Category 3 CI Engines	0.77	0.060	0.022	0.060
Total	10.2	0.5	0.3	0.9
Total U.S. Emissions[a,b]				
US Flag Engines	146.1	5.8	4.4	14,5
Category 2 CI Engines	89.0	1.7	3.1	10.0
Category 3 CI Engines	57.1	4.1	1.3	4.4
Foreign CI Engines	126.9	9.4	3.9	11.9
Category 2 CI Engines	9.9	0.7	0.3	0.9
Category 3 CI Engines	117.0	8.7	3.6	11.0
Grand Total for Cargo	**273.0**	**15.2**	**8.3**	**26.4**
Category 2 CI Engines	**99.0**	**2.4**	**3.4**	**11.0**
Category 3 CI Engines	**174.0**	**12.8**	**4.9**	**15.4**

a. There may be some differences in totals due to rounding of numbers.
b. Emissions estimated to a distance of 200 miles from shore; this is approximately the distance from shore as most of the major shipping lanes.

These methods rely on a common database of registered ships containing such information as propulsion type, brake horsepower, and engine data [*LMIS*, 1996]. In addition, both methods used marine diesel emission factors reported by Lloyd's Register Engineering Services in the Marine Exhaust Emissions Research Programme [*Carlton et al.*, 1995]. These provide the most current emissions factors for large CI marine engines in commercial use today. These emission factors are similar to currently available EPA emission factors in AP-42 [*EPA*, 1997] for similar CI engines, as shown in Table 4. (The units of the AP-42 factors (lb/MMBtu) were converted to match the fuel-based units (kg/tonne fuel) reported by Lloyds.)

Aside from these two common databases, the estimation methods are quite different. The methodologies are explained in detail in the next sections.

Table 4. Comparison of CI Marine Engine Emission Factors with AP-42

Pollutant	Emission Factor (fuel-based) (kg pollutant/tonne fuel)
Oxides of Nitrogen (NOx) as NO_2	
Lloyds: Slow Speed	87
Lloyds: Medium Speed	57
AP-42 Emission Factors:	
Large Stationary Diesel	53
Uncontrolled Diesel Industrial Engine	73
Non-Road CI Engine (steady state)	50
Particulate Matter (PM)	
Lloyds: Slow Speed	7.6
Lloyds: Medium Speed	1.2
AP-42 Emission Factors:	
Large Stationary Diesel	2.0
Uncontrolled Diesel Industrial Engine	5.0
Non-Road CI Engine (steady state)	1.0
Hydrocarbons (HC)	
Lloyds: All CI Marine Engines	2.4
AP-42 Emission Factors:	
Large Stationary Diesel	1.0
Uncontrolled Diesel Industrial Engine	6.0
Non-Road CI Engine (steady state)	4.0
Carbon Monoxide (CO) as CO	
Lloyds: All CI Marine Engines	7.4
AP-42 Emission Factors:	
Large Stationary Diesel	14.0
Uncontrolled Diesel Industrial Engine	16.0
Non-Road CI Engine (steady state)	16.0

2.1 Method A: U.S. Emissions Estimated Using Ship Registry Data

Method A (Ship Operations Method) is a theoretical approach using estimates of daily fuel consumption calculated from ship brake horsepower (BHP) and engine brake-specific fuel consumption (BSFC). Fuel-based emission factors were applied to get emissions per day, making adjustments for usage using marine duty cycles from ISO [*ISO*, 1996], estimated time in service, and time underway per year. This approach allows for a direct estimate of emissions for all types of vessels, including fishing vessels, tugs, and utility ships.

The numbers of ships in the U.S. commercial fleet with engines in each category were estimated. This estimate was based on engine manufacturer and model data gathered for commercial ships greater than 100 gross registered tons (GRT) and listed in Lloyds Maritime Information System database of registered vessels [*LMIS*, 1996]. Engine data, particularly cylinder displacement, was available for 42% of the ships with CI engines in the data set. A statistical test (chi-squared test) showed that the distribution of unassigned engines was not different from the distribution of categorized engines.[2] Based on this information, the remaining engines were distributed by EPA category proportionally, as shown in Table 5.

Table 5. Estimated Number of U.S. Flag Ships by Type and EPA Category

	Category				
Vessel Service	**1**	**2**	**3**	**Not Diesel**	**Grand Total**
Container	-	1	49	37	87
Fishing	2,498	241	40	-	2,778
Passenger	8	-	6	27	41
RoRo[a]	6	21	39	32	97
Transport	6	17	49	347	419
Tug	244	975	42	7	1,269
Utility	420	171	12	47	650
Grand Total	**3,182**	**1,426**	**236**	**498**	**5,341**

a. RoRo: Roll-on, Roll-off vessel; this includes ships carrying vehicles and other large, non-containerized items.

This study does not include ships less than 100 GRT, because the Lloyds database does not contain smaller vessels and it was not possible to find comparable data for these vessels. One source for smaller vessels may be the US Coast Guard vessel data collected by the Waterborne Commerce Statistics Center (WCSC) [*USACE*, 1995]. This data indicates 8,319 U.S. flag vessels (ships and boats) are available for service, compared to the 5,341 ships in the Lloyds registry; fishing vessels appear to be excluded from the WCSC data. However, engine data is not provided for these ships. Another alternate source for information on smaller vessels may be the Merchant Vessels of the United States CD-ROM [*DOT*, 1998]. This is a data file of merchant and recreational vessels documented under the laws of the United States by the U.S. Coast Guard. The file contains the vessel name, official number, managing owner name, particulars such as tonnage and length, port of documentation (homeport), and authorized trade endorsements. Once again, engine-specific data is not provided. This analysis does not use this source in estimating emissions for this report, although some 63,809 vessels (boats and ships) are listed that may be used in commerce (171,663 recreational vessels are listed as well). A significant number may not be powered by CI marine engines at all. Of the remainder, most, if not all, of these vessels would likely fall into EPA Category 1, and would not be included in this study.

Brake horsepower for nearly all of these engines is reported in the Lloyds registry data. The BHP for each engine was multiplied by a typical brake-specific-fuel-consumption (BSFC) factor for the horsepower range indicated. Generalized fuel-consumption characteristics for direct-drive, geared, and diesel-electric CI marine engines illustrate the relationship between fuel-consumption and engine rating for these propulsion-plant configurations [*Harrington*, 1992]. These fuel-consumption characteristics were confirmed by comparison with other sources [*Heywood*, 1988; *Osbourne*, 1943; *Turpin and McEwen*, 1965]. Units were converted to tons-fuel per day (tpd). The rated BHP values used in the fuel-consumption estimates were adjusted downward, in consideration of the fact that ship engines generally operate at maximum loads no higher than 80% of rated load. Then marine duty-cycle load factors were applied, to make the fuel-consumption estimates more realistic. The E3 duty cycle for heavy-duty marine engines was used [*ISO*, 1996; *Markle and Brown*, 1996]. This duty cycle was developed to represent typical overall engine loads for exhaust emission measurement; no better duty cycle representing actual operations is avaible. A summary of the U.S. flag fleet fuel consumption in tpd is presented in Table 6. These estimates are not unreasonable when compared with fuel consumption reported by other sources [*Evans and Marlow*, 1990; *Ewart*, 1982].

Category 3 engines were divided into two subcategories by cylinder displacement; engines with cylinder displacements greater than 20 liters but less than 60 liters were assigned to subcategory 3A. Those greater than 60 liters were assigned to subcategory 3B. The reason for this is that emission factors for NOx and PM are different for medium speed and slow speed

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[2] This is without including the U.S. flag container ships, of which only three ships out of 87 were in the unassigned category; a chi-squared test for the world fleet – including container ships – showed similar results.

engines [*Carlton et al.*, 1995] (see Table 4). All Category 2 engines are assumed to be medium-speed engines. The larger engines in Category 3 are assumed to be slow-speed engines, but this is not true of the smaller engine sizes. In the absence of better information characterizing these engines, this analysis assumed that 50% of the engines in subcategory 3A were medium-speed engines, and half were slow-speed engines. Therefore, the fuel-consumption estimates shown in Table 6 estimate fuel usage for subcategories 3A and 3B separately. The fuel-based emission factors for CI marine engines were then multiplied by the estimated fuel-consumption to obtain an estimate for the daily emissions for each pollutant in kg per day.

Table 6. Estimated Fuel-Consumption for CI Engines in the U.S. Fleet (tpd)

	Category		
Vessel Service	**2**	**3A**	**3B**
Container	5	-	56
Fishing	5	13	10
Passenger	-	10	20
RoRo	6	48	40
Transport	6	31	29
Tug	5	24	31
Utility	4	20	12

The daily emissions per ship were multiplied by the number of ships, and by the number of days per year to estimate annual emissions. However, this estimate represented the unrealistic scenario where vessels were underway 100% of the time during the year. This study assumed a conservatively high underway factor of 80% to obtain a final estimate of annual emissions from U.S. flag ships, based on the authors' knowledge of and experience with oceangoing ships. An informal telephone survey of several commercial tug and barge operators (Crowley Maritime Corporation, Foss Maritime Company, American Commercial Barge Lines Company, National Marine Inc., and the Port of Pittsburgh) confirmed that this assumption was also reasonable for tugs and utility vessels.

In estimating total nationwide emissions by Method A, two errors are present. This inventory only includes U.S. flag vessels, and does not address foreign vessels operating in and around U.S. waterways. This also includes U.S. flag vessels operating anywhere in the world. The problem of including foreign shipping is addressed through Method B, described in the next section. Analysis of vessels arriving in U.S. ports carrying foreign cargo [*USACE*, 1995] showed that 410 U.S. cargo ships (68% of the 597 cargo ships in the U.S. fleet – nearly all of which have Category 2 and 3 engines) made approximately 13,500 visits from foreign ports (15% of the ship visits reported by U.S. Customs). This represents an average of 33 visits per ship-year (about 1 every 10 days). The problem of removing U.S. flag vessels that are not operating within U.S. waterways was corrected by assuming that these U.S. flag vessels spend approximately 30% of their operating time in U.S. waters (about one day inbound in U.S. waters, one day in harbor, and one day outbound in U.S. waters). Therefore, estimated emissions were reduced by approximately 48% (68% - [68% * 30%] = 48%) to "back out" these emissions occurring outside of U.S. waters. This represents a reasonable upper bound for the number of U.S. vessels operating outside of U.S. waters, especially for ships that transport both foreign and domestic cargoes. Estimates for each pollutant, by type of vessel and by EPA Category are presented for U.S. flag vessels that operate in U.S. waters in Table 7.

2.2 Method B: Foreign and Domestic Cargo Transport Fleet Inventory

Method B (Cargo Method) used cargo movements and waterway data to calculate the total tons and ton-miles moved by ships annually in and around the U.S. Then the numbers of "average" cargo ships needed to carry these volumes were estimated and emissions per ton-mile derived for these hypothetical cargo ships. The annual emissions estimated by this approach are directly applicable to U.S. trade regions (for both foreign and domestic cargo) and national shipping lanes, which include the Great Lakes, inland waterways, and coastal shipping lanes extending to approximately 200 miles from the coasts. Most navigable U.S. waterways are inventoried in the U.S. Army Corps of Engineers (USACE) Waterway Link Network. Shipping lanes and open water passage lanes are represented by over 5,000 line segments, or "links." The 1993 National Waterway Network (NWN) geographic database, developed by the Oak Ridge National Laboratory, Vanderbilt University, and the National Waterway GIS Design Committee, includes physical and location information about each of these links [*USACE*, 1995]. Ocean shipping lanes (waterway links) in the NWN data were within 200 miles of U.S. coastlines. The USACE Waterborne Commerce Statistics Center (WCSC) tracks commodity movements across these links by conducting on-going surveys of companies and government agencies [*USACE*, 1995]. For this report, 1993 NWN data on the USACE waterway links were merged with 1993 WCSC shipment data to create a comprehensive picture of cargo movement in and around the

Table 7. Estimated Annual Pollution for CI Engines in the U.S. Fleet (metric tons)

Vessel Service	Category		Categories
Pollutant	**2**	**3**	**2 and 3 Total**
Container			
NOx (as NOx)	92	36,085	36,177
PM	2	3,152	3,154
HC	4	995	999
CO (as CO)	12	3,069	3,081
Fishing			
NOx (as NOx)	37,193	9,937	47,129
PM	783	823	1,606
HC	1,566	284	1,850
CO (as CO)	4,828	876	5,704
Passenger			
NOx (as NOx)	-	2,362	2,362
PM		196	196
HC		67	67
CO (as CO)		208	208
RoRo			
NOx (as NOx)	2,255	20,912	23,167
PM	47	1,621	1,668
HC	95	622	717
CO (as CO)	293	1,918	2,211
Transport			
NOx (as NOx)	1,823	18,019	19,842
PM	38	1,442	1,480
HC	77	526	603
CO (as CO)	237	1,622	1,859
Tug			
NOx (as NOx)	154,898	26,921	181,820
PM	3,261	2,052	5,313
HC	6,522	808	7,330
CO (as CO)	20,110	2,492	22,602
Utility			
NOx (as NOx)	24,247	4,521	28,768
PM	510	319	829
HC	1,021	141	1,162
CO (as CO)	3,148	436	3,583
Total			
NOx (as NOx)	220,507	118,759	339,266
PM	4,642	9,604	14,247
HC	9,285	3,445	12,729
CO (as CO)	28,627	10,621	39,248

U.S. The cargo movements in ton-miles for each region were then calculated by summing the product of the number of tons shipped along each link in a region by the length of that link, as shown below:

$$C_G = \sum_{i=1}^{5,000} L_{Gi} * T_{Gi} \qquad \textbf{Equation 1}$$

Where

C	=	Cargo movement in ton-miles
G	=	Geographic Region (Ocean, Inland, Great Lakes)
L	=	Length (in miles) of link *i*
T	=	Tonnage (total tons shipped in 1993) of link *i*
i	=	Each link in the NWN and WCSC data for a given geographic region

A summary of these calculations is shown in Table 8. Interestingly, the number of tons moved on the inland river systems in the U.S. exceeds the number moved on the other waterways, including the oceans bordering the U.S. (by a factor of 2). Alternatively, the distances described by waterway links for the oceans exceed the distances on the inland rivers by nearly a factor of 3. The fact that the ton-miles of cargo moved over inland rivers equal approximately 65% of the ton-miles of cargo transported in U.S. coastal waters implies that emissions on the inland waters may be significant. Moreover, since the navigable miles on the inland rivers equal only about one third of the navigable ocean miles, emissions from these cargo movements occur in a much smaller area.

Table 8 . Summary of Cargo Movements in 1993 By Major Waterway

Region	Distance (miles)[a]	10^6 Tons moved[b]	10^9 Ton-miles
Ocean	116,411	15,968.6	764.9
Great Lakes	8,382	7,662.2	85.3
Inland Rivers	43,566	33,055.5	494.4
Unassigned	120	91.9	2.3
Total	168,478	56,778.2	1,346.9

a. From NWN data [*USACE*, 1995].
b. From WCSC data [*USACE*, 1995]. Note that tonnage moved is not the same as tons received or sent by a given port; the same tons may move across several links, and therefore can be counted in the ton-miles more than once.

To estimate emissions per ton-mile from commercial marine vessels, the estimated daily emissions per ship from Method A were used, along with vessel average deadweight tonnage (DWT) and speed data from Lloyds registry. Deadweight tonnage is a measurement of total contents of a ship including cargo, fuel, crew, passengers, food, and water aside from boiler water. Because DWT describes more than the cargo carrying capacity of a ship, the DWT reported in Lloyds was multiplied by 80% to obtain an estimate of the maximum cargo tons that could be carried; this is consistent with typical voyage estimating factors [*Packard*, 1991]. Average DWT for cargo vessels (i.e., containers, roll-on-roll-off ships (RoRo's), and other transport ships (including dry bulk, tankers, etc.) was computed for all vessels in Lloyds registry (including U.S. flag) and separately for U.S. flag vessels. The average DWT for cargo ships in the world fleet is 34,387 DWT; the average DWT for cargo ships in the U.S. flag fleet is 15,454 DWT.

However, ships do not typically operate fully loaded with cargo. Many ships, particularly tankers, may carry cargo in one direction and return empty (or with ballast only). Other ships carry cargo both directions, but rarely carry their full capacity. Most ships carry cargo loads that average 50% to 65% capacity; when cargo capacities exceed 70%, it can be indication that too few ships are available for the route [*Abrams*, 1997]. This analysis applied a cargo capacity factor of 50% to vessels operating on ocean routes, and a 60% cargo capacity factor to inland rivers and Great Lakes vessels. This is consistent with reported statistics [*Wilde Mathews*, 1998a]. The higher capacity factor for inland river cargo transport follows from the understanding that inland vessels are smaller, with shallower drafts and smaller total capacities per vessel. This fact, combined with the large tonnages moved on inland rivers, implies that these vessels are loaded to higher capacities than oceangoing and coastwise transport. Moreover, barges can be added or removed from a group of as many as 35 barges [*Wilde Mathews*, 1998b], and therefore barge towboats/pushboats may also transport higher average capacities.

Speed data reported in Lloyds represents the rated design speed of the vessel, similar to the BHP data. Therefore, marine duty-cycle load factors were applied to speed, in the same way as for BHP in Section 2.1. The E3 duty cycle was used for heavy-duty marine engines for all engines [*ISO*, 1996; *Markle and Brown*, 1996]. To be consistent with adjustments made to the maximum BHP load to be 80% of rated BHP, the maximum speed was adjusted by employing the relationship between horsepower and the cube of the speed [*Laurence*, 1984]. This resulted in a maximum speed that is 93% of the rated design speed of the vessel. Average speeds for cargo ships in the U.S. flag fleet are shown in Table 9. Average speeds for the world fleet are presented in Table 10.

From this information, the emissions per ton-mile and emissions per year can be calculated, according to the following equations:

$$E_{TM} = E_d \div (DWT * CCF * V * 24) \qquad \textbf{Equation 2}$$

Where

E_{TM}	=	Emissions per ton-mile
E_d	=	Emissions per day (from Method A)
DWT	=	Average DWT per ship
CCF	=	Cargo capacity factor (0.5 for oceans, 0.6 for inland rivers and Great Lakes)
V	=	Average speed of vessel across duty cycle (adjusted for max BHP)
24	=	Hours per day to convert ship speed to ship miles per day

$$E_Y = E_{TM} * TM_Y \qquad \textbf{Equation 3}$$

Where

E_Y	=	Emissions per year
TM_Y	=	Ton-miles per year (from Table 8)

Table 9. Average Speed (in knots) of U.S. Fleet Cargo Ships (adjusted for duty cycle)[a]

	Category				Weighted
Vessel Service	**1**	**2**	**3A**	**3B**	**Average**
Container	-	5	-	10	10
RoRo	6	8	10	10	9
Transport	5	7	8	8	7
Weighted Average	5	7	9	9	9

a. The average speed of tugs moving barges on inland waters equals 79% of the speed of U.S. cargo vessels; this is taken as the average speed on the inland rivers.

Table 10. Average Speed (in knots) of World Fleet Cargo Ships (adjusted for duty cycle)

	Category				Weighted
Vessel Service	**1**	**2**	**3A**	**3B**	**Average**
Container	-	6	13	16	16
RoRo	6	8	14	14	12
Transport	5	6	12	12	11
Weighted Average	5	6	12	12	11

To distinguish between domestic and foreign trade, port data indicating the amount of domestic and foreign cargo was taken from the WCSC data on the US Waterways CD-ROM [*USACE*, 1995]. Here, the cargo tons delivered or shipped from the 179 ports reported in the data was used, rather than the tons moved along the waterway links. In 1993, 49% of the cargo delivered to ports in U.S. ocean regions (Atlantic, Pacific, and Gulf Coasts) was domestic. In Great Lakes, 80% of the trade was domestic; 70% of trade shipped on the inland rivers was domestic.

To estimate the number of U.S. ships engaged in foreign trade, this analysis used U.S. Census Bureau data indicating the number of port visits for foreign commerce (i.e., that involved U.S. Customs) in 1993 [*USACE*, 1995]. Some 90,000 ship visits nationwide were reported. Approximately 15% of these vessels making port visits were registered as U.S. flag ships; this factor was applied to separate foreign trade into foreign trade carried by U.S. ships and foreign trade carried by foreign ships. (While 15% of the vessels making visits with foreign cargo were U.S. flag vessels, this amounted to 68% of the cargo ships in U.S. registered fleet as discussed in Section 2.1.)

This emission estimate assumes CI marine engines propel all vessels. This assumption is generally valid for non-U.S.-flag cargo vessels (which are nearly all diesel-propelled), but it is not true for U.S. flag cargo ships. While ships with steam-turbine engines only account for 6% of the U.S. flag fleet, they equal 52% of the U.S. flag cargo-carrying vessels. Marine steam-turbine engines emit significantly less NOx, HC, and CO, and about the same PM as CI marine engines [*Booz Allen & Hamilton*, 1991]. This analysis corrected the raw calculations to account for U.S. steam ships. This was done by taking 52% of the raw estimate and multiplying it by the ratio of steam-engine-emission factor to diesel-engine-emission factor for each pollutant.

Lastly, these emissions were characterized by engine category. World fleet characteristics for cargo vessels were assumed to apply to foreign flag vessels transporting cargo in U.S. waters. Emissions estimated for foreign ships by Method B were distributed according to the percent of foreign cargo vessels with engines in EPA Categories 1, 2 and 3. Estimates for emissions from cargo transport are shown by region, domestic versus foreign, in Table 11. Steam engines are shown separately from diesel engines, and diesel engines in Categories 2 and 3 are shown as a subset of diesel engines.

Table 11. Emissions from Maritime Transport of Cargo in U.S. Waterways [a]

U.S. Region	NOx (metric tons NOx/year)	PM (metric tons PM/year)	HC (metric tons HC/year)	CO (metric tons CO/year)
Oceangoing (foreign cargo)				
US Ship Engines	**9,836**	**801**	**284**	**876**
All US CI Engines	8,695	414	238	775
US Cat. 2 and 3	7,993	397	217	705
US Steam/other	1,141	387	46	101
Foreign Ship Engines	**103,803**	**8,448**	**2,999**	**9,248**
Foreign Cat. 2 and 3	96,325	7,840	2,783	8,581
Oceangoing Total	**113,639**	**9,249**	**3,283**	**10,124**
All Cat. 2 and 3	104,318	8,237	3,000	9,286
Coastwise (domestic cargo)				
All US CI Engines	56,535	2,690	1,550	5,041
US Cat. 2 and 3	51,971	2,582	1,409	4,583
US Steam/other	7,417	2,515	298	656
Coastwise Total	**63,952**	**5,205**	**1,848**	**5,697**
Inland Rivers				
US Ship Engines	**94,499**	**4,777**	**3,368**	**10,386**
All US CI Engines	83,539	2,468	2,826	9,190
US Cat. 2 and 3	76,795	2,370	2,569	8,354
US Steam/other	10,960	2,308	543	1,196
Foreign Ship Engines	**32,020**	**1,619**	**1,141**	**3,519**
Foreign Cat. 2 and 3	29,713	1,502	1,059	3,266
Inland Rivers Total	**126,518**	**6,395**	**4,510**	**13,906**
All Cat. 2 and 3	106,508	3,872	3,628	11,620
Great Lakes				
US Ship Engines	**11,556**	**940**	**334**	**1,029**
All US CI Engines	10,216	486	280	911
US Cat. 2 and 3	9,391	467	255	828
US Steam/other	1,340	454	54	119
Foreign Ship Engines	**901**	**73**	**26**	**80**
Foreign Cat. 2 and 3	836	68	24	74
Great Lakes Total	**12,457**	**1,014**	**360**	**1,110**
All Cat. 2 and 3	10,227	535	279	903

U.S. Region	NOx (metric tons NOx/year)	PM (metric tons PM/year)	HC (metric tons HC/year)	CO (metric tons CO/year)
Total U.S. Emissions[a,b]				
US Ship Engines	**179,842**	**11,723**	**5,834**	**17,989**
All US CI Engines	158,984	6,058	4,895	15,917
US Cat. 2 and 3	146,151	5,816	4,405	14,470
US Steam/other	20,858	5,665	940	2,072
Foreign Ship Engines	**136,723**	**10,140**	**4,167**	**12,847**
Foreign Cat. 2 and 3[a]	126,874	9,410	3,866	11,922
Grand Total (All Ships)	**316,566**	**21,863**	**10,001**	**30,836**
All Cat. 2 and 3	273,025	15,226	8,316	26,392

a. Foreign ship Category 2 and 3 numbers appear in Tables E2 and Table 2 as the estimates of total foreign flag emissions in U.S. waters.
b. There may be some differences in totals due to rounding of numbers.
c. Emissions estimated to a distance of 200 miles from shore; this is approximately the distance from shore as most of the major shipping lanes.

By assuming that all foreign flag vessels operating in U.S. waters are cargo vessels, the emissions estimated for foreign flag cargo vessels can be added to the emissions estimated for U.S. flag vessels (calculated in Section 2.1) to provide a single nationwide estimate for emissions from commercial shipping. This relies on the understanding that fishing vessels, tugs, utility vessels, and most passenger/ferry vessels operating in U.S. waters are U.S. flag vessels. The possible exception to this understanding would be foreign passenger cruise ships. Emissions from these relatively few ships are not expected to change the nationwide inventory of ship emissions.[3] In fact, emissions from these ships may only impact port emissions inventories that are dominated by tourism-related vessel activity.

2.3 Comparing the U.S. Emissions Inventory with a Global Inventory

Previous work can be used to verify that the estimate of nationwide emissions from ships in U.S. waters provide is reasonable. A global inventory of ship emissions that was developed independent of the analysis for this report [*Corbett and Fischbeck*, 1997] can provide a point of comparison. Because this method derives the traffic densities for ships from the Comprehensive Ocean-Atmosphere Data Set (COADS), this approach estimates only the coastal emissions (both oceangoing and some coastwise domestic); it cannot reliably estimate emissions on the Great

[3] This analysis estimates that less than 2% of the world fleet of passenger ships are propelled by EPA Category 2 and/or 3 CI marine engines. There are far more passenger ferries than passenger cruise ships in the world fleet.

Lakes, or the inland waterway emissions. In addition, this method was not intended to include detailed coastwise domestic operations very near the coastlines. Also, the COADS data filtered out reports from large fishing fleets. Therefore, this provides only a rough check of the sum of oceangoing and coastwise emissions estimated by Method B.

Global emissions calculations used the following equation to obtain the total emissions from international shipping:

$$P = \sum_{i=1}^{n} E_i * (F * A_i) \quad \textbf{Equation 4}$$

Where:
P = Total propulsion emissions.
E_I = Fuel-based pollutant emission factor based on engine type.
F = Annual marine fuel (bunkers) used.
A_i = Percent of all vessels with each engine type.
i = Engine type (1 = slow-speed, 2 = medium-speed, and 3 = steam/other.
n = 3 engine types for NOx calculation.

Emission rates from Lloyd's were applied to diesel engines (see Table 4). A steam-turbine emission rate of 8.8 kg NOx/tonne fuel was derived from data in a 1991 study by TRC Environmental Consultants, Inc. [*Hottenstein*, 1991]. Since more than 95% of ships in the world fleet use CI marine engines and the emission rates are higher for CI engines than for boilers, the resulting estimates reasonably represent CI emission estimates for practical purposes. The annual estimates for global NOx emissions were calculated by weighting the yearly marine-fuel use by the actual percent of marine engines of each type (slow-speed diesel, medium-speed diesel, and steam turbine). The average estimate for annual NOx emissions is simply the average of the estimates for each year: 10.12 million metric tons of NOx/yr. Global emissions (average estimates) were divided by the total annual COADS ship observations to get the average emissions per observation. This value was then multiplied by the number of observations in each 2^o x 2^o grid location to map the distribution of global marine emissions. (More discussion of this method is available [*Corbett and Fischbeck*, 1997; *Corbett et al.*, 1998].)

U.S. coastal emissions are simply the sum of the emissions estimated in each grid cell adjoining the coasts in the Atlantic, Pacific, and Gulf regions. Table 12 illustrates this approach for NOx emissions, including approximate distances from the U.S. coastlines in kilometers and miles. Shipping links described in Method B generally correspond to a distance between 1 and 1½ grid cells of the U.S. coastline. Table 13 shows all pollutants considered. If 1½ grid cells are used, these estimates are within 13% to 25% of the overall coastal emissions (the sum of oceangoing and coastwise emissions for all engine types) from cargo ships in U.S. waters presented in Table 11.

Table 12. Summary of NOx Emissions Near U.S. Coastlines From Previous Work

Number of Cells from U.S. Coasts	NOx Emissions (10^3 tons NOx/yr)	Approximate Distance (km)	Approximate Distance (mi)	Emissions as a % of Global
3 Grid Cells	516.2	667	414	5%
2 Grid Cells	319.0	444	276	3%
1½ Grid Cells	203.9	333	207	2%
1 Grid Cell	88.7	222	138	1%

Table 13. Emissions Within Approximately 200 Miles of U.S. Coastline

	10^3 kg NOx/yr	10^3 kg PM/yr	10^3 kg HC/yr	10^3 kg CO/yr
Oceangoing/Coastwise	203.9	17.2	6.9	21.2

3. ENGINE TYPES IN EPA CATEGORIES

Engine manufacturer and model data were available for some of the U.S. flag vessels in the Lloyds register data [*LMIS*, 1996]. Appendix 7.3 presents this data by vessel type and EPA Category. Ships with engines in EPA Category 2 are listed in Table 16. Those with engines in EPA Category 3 (shown as Category 3A, corresponding to cylinder displacements equal to 20 liters and less than 60 liters, and as Category 3B, corresponding to cylinder displacements equal to and greater than 60 liters) in Table 17. It should be noted that these tables show the number of vessels with each engine type; the number of engines per vessel was not reported in the data available. No other engine-specific data is provided in the Lloyds data fields that we use in our research, although Lloyds Registry may have that information. Engine-specific information, such as bore, stroke, rpm, etc., was obtained from manufacturer sources such as websites, and telephone conversations with manufacturer representatives. Some engine manufacturers were not located, perhaps because the engines are foreign, or no longer manufactured; in some cases engine manufacturers have consolidated or split into separate corporations. Engines that were not categorized are presented in Table 18. This analysis focused on defining cylinder displacement so that engines could be classified by EPA Category. Other data (e.g., turbocharging, aftercooling, etc.) were not consistently available and are not reported.

4. ENGINE REPLACEMENT RATES

Important considerations in developing regulations for CI marine engines include how quickly ships and/or their engines are replaced, and how fast the fleet may be growing. If emissions regulations apply primarily to new engines, then the impact on actual emissions depends on the rate at which emission controls are introduced through engine replacements. Engine replacement is a function of two primary factors: 1) The number of ships retired from service and scrapped; and 2) The number of new vessels built and placed in service. (A secondary factor in estimating engine replacement rates is replacement of engines on existing vessels without scrapping the ship itself. As of now, we have no direct information on engine replacement rates of this sort.) In recent years, approximately 1% of the world fleet greater than 1,000 GRT was demolished (broken-up) annually while new ships in this group accounted for approximately 3% of the world fleet [*UNCTAD*, 1995]; therefore the net growth of the world fleet is currently about 2% per year.

Moreover, the U.S. fleet has not been building at the same rate as the world fleet (see Figure 1). The U.S. flag fleet has lagged the pace of the world fleet in both of these aspects during the last decade, at least. From data shown in Figure 1, it can be seen that the U.S. fleet construction rate has been less than 15 ships per year since 1983, whereas world fleet construction has averaged about 1,500 ships per year. In other words, U.S. fleet construction has equaled ~0.5% of the approximately 5,300 ships in the U.S. fleet compared to world fleet construction of ~2% of the approximately 86,000 ships in the world fleet.

The world-fleet average age of a vessel when demolished is shown for recent years in Table 14 [*UNCTAD*, 1995]. The average age of the U.S. Fleet, by vessel type, is shown in Table 15; it is clear that the U.S. fleet is significantly older than the world average. It is reasonable to believe the U.S. flag fleet may increase its rate of fleet replacement in coming years, to stay competitive with the world fleet vessel construction. However, there is insufficient evidence to expect the U.S. fleet replacement rate to exceed the world fleet replacement rate of approximately 2% per year. Under current market and policy conditions (e.g., U.S. versus foreign labor rates for merchant vessel crews, and the Jones Act), there are limited economic incentives to modernize the U.S. flag fleet at the world fleet replacement rate. Therefore, the 2% per year world fleet replacement rate assumption would imply at most the construction of 1,000 additional ships of 100 GRT or greater over a ten-year period (2000-2010). However, only 503 ships have been built in the U.S. during the twenty-two year period of 1975 to 1996 (see Figure 1). Therefore, a more realistic upper bound might be 250 ships (100 GRT or greater) built over a ten-year period (2000-2010).

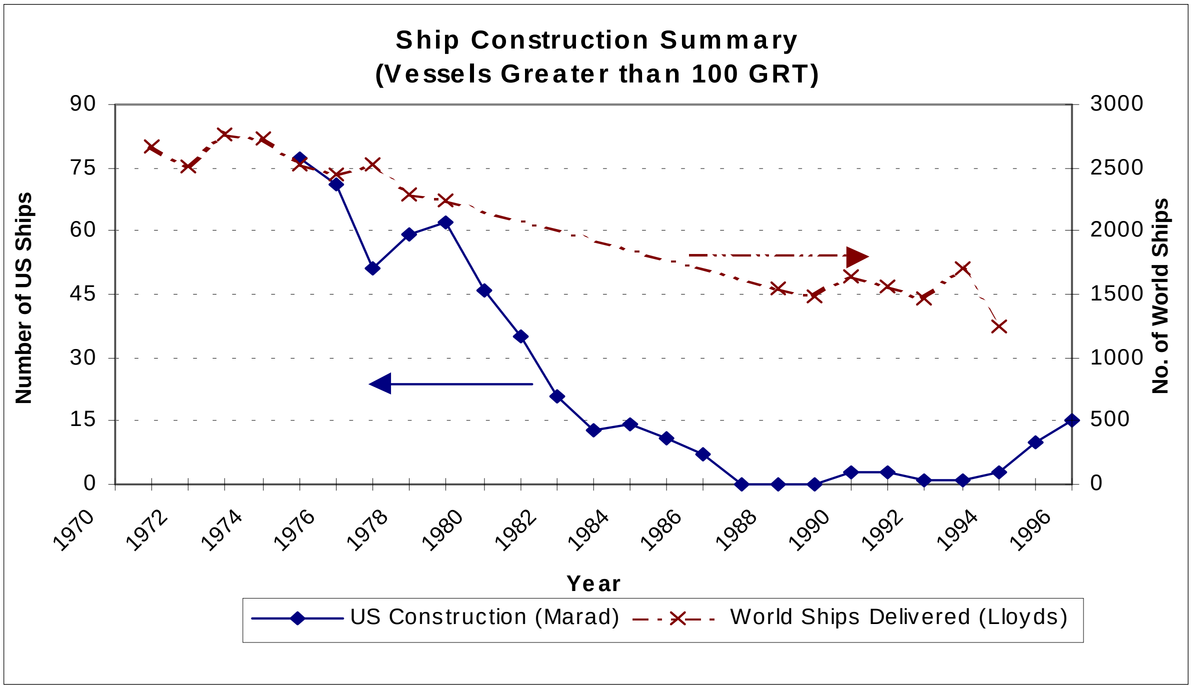

Figure 1. Comparison of New Shipbuilding in U.S. Flag and World Fleets [*Lloyd's_Register*, 1970-1994; *MARAD*, 1996]

Table 14. Average Age of Broken-up Ships Greater Than 1,000 GRT by Vessel Type During 1986-1994

Year	Tankers	Dry Bulk	Containers	General Cargo
1986	21.3	19.4	21.7	23.6
1987	24.4	19.8	24.9	23.8
1988	24.6	22.4	25.1	24.2
1989	24.9	23.1	27.2	25.5
1990	26.4	21.7	19.5	25.1
1991	25.3	22.0	19.0	24.8
1992	25.8	22.9	19.1	25.7
1993	24.7	24.0	22.9	26.4
1994	24.6	24.1	24.0	27.1

Table 15. Average Year Built for the 1996 U.S. Fleet Greater Than 100 GRT [*LMIS,* 1996]

Vessel Service	Average Year Built	Average Age in 1996
Container	1978	18
Fishing	1975	21
Passenger	1959	37
RoRo	1974	22
Transport	1964	32
Tug	1969	27
Utility	1976	20
U.S. Fleet Average	1973	23

5. SUMMARY

A commercial marine emissions inventory was developed that estimates the emissions of NOx, PM, HC, and CO from U.S. flag and foreign flag vessels operating in U.S. waters. This inventory is characterized by vessel service type and by EPA Category (representing engine cylinder displacement). Emissions from commercial vessels that carry cargo were estimated by region, including oceangoing (international), coastwise (domestic), inland river system, and Great Lakes. Emissions from cargo transport on the U.S. inland rivers equals nearly 70% of the total emissions from oceangoing and coastwise cargo transportation on all three coastlines. Oceangoing and coastal emissions estimated for cargo ships were compared with emission derived from previous work estimating global shipping emissions. Auxiliary engine emissions were not considered in this analysis. Engine-specific data available from the Lloyds dataset is provided, including engine manufacturer and model number. The U.S. fleet replacement rate is lower than the rate of replacement in the world fleet, and is not expected to increase construction beyond the world fleet replacement rate of approximately 2% per year under current market and policy conditions.

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7. APPENDICES

7.1 METHOD A: Ship Operations Method

1996 U.S. Flag Fleet CI Marine Engines, By EPA Category

Count of Ships	Category						
Vessel Service	Uncategorized	1	2	3A	3B	Not Diesel	Grand Total
CONTAINER	3		1		47	36	87
FISHING	1926	766	74	2	10		2778
PASSENGER	20	4		1	2	14	41
RORO	45	3	11	8	13	17	97
TRANSPORT	82	5	14	12	27	279	419
TUG	760	98	391	9	8	3	1269
UTILITY	277	241	98	4	3	27	650
Grand Total	3113	1117	589	36	110	376	5341
	58%	21%	11%	1%	2%	7%	

Expected distribution of uncategorized vessels with CI Marine Engines by EPA Category

Count of Ships	Category				
Vessel Service	1	2	3A	3B	Count of ships
CONTAINER	-	1	-	49	50
FISHING	2,498	241	7	33	2,778
PASSENGER	8	-	2	4	14
RORO	6	21	15	24	65
TRANSPORT	6	17	15	34	72
TUG	244	975	22	20	1,262
UTILITY	420	171	7	5	603
Count of ships	3,182	1,426	68	168	4,843

Category 3A engines are equal to or greater than 20 liters per cylinder and less than 60 liters per cylinder; Category 3B engines are greater than or equal to 60 liters per cylinder.

1996 U.S. Flag Fleet Fuel-Consumption Estimates (from BHP in metric tons per day)

Average of tpd	Category					
Vessel Service	Uncategorized	1	2	3A	3B	Weighted Ave
CONTAINER	36		19		101	96
FISHING	12	9	17	23	18	14
PASSENGER	36	17		18	36	32
RORO	45		23	87	74	53
TRANSPORT	33	15	22	56	53	40
TUG	14	10	17	44	56	16
UTILITY	15	10	16	36	22	13
Weighted Ave	17	10	17	55	72	20

fuel use per day-ship (adjusted for max load)		Category					Weighted Average	Max load = 80% max power
Vessel Service	Average of tpd		1	2	3A	3B		
CONTAINER			-	15	-	81	77	80%
FISHING			7	13	18	14	11	80%
PASSENGER			13	-	14	29	25	80%
RORO			-	18	69	59	42	80%
TRANSPORT			12	17	45	42	32	80%
TUG			8	14	35	44	13	80%
UTILITY			8	12	29	18	10	80%

fuel use per day-ship (with marine duty cycle)		Category	E5 Cycle	E5 Cycle	E3 Cycle	E3 Cycle	Weighted Average
Vessel Service	Average of tpd		1	2	3A	3B	
CONTAINER			-	10	-	56	55
FISHING			5	9	13	10	5
PASSENGER			9	-	10	20	12
RORO			-	13	48	40	30
TRANSPORT			8	12	31	29	23
TUG			6	10	24	31	9
UTILITY			5	9	20	12	7
Weighted Ave			5	9	29	34	8

1996 World Fleet CI Marine Engines, by EPA Category

World Ships Emission Inventory

Number of ships	Category				
Vessel Service	?	1	2	3A	3B	Grand Total
CONTAINER	983		2	38	800	1,823
FISHING	19,895	2,511	619	320	145	23,490
PASSENGER	2,824	544	35	230	39	3,672
RORO	2,116	92	87	210	191	2,696
TRANSPORT	30,685	371	378	1,018	3,594	36,046
TUG	7,004	847	1,170	180	115	9,316
UTILITY	5,603	1,190	322	110	67	7,292
Grand Total	69,110	5,555	2,613	2,106	4,951	84,335

Statistical distribution of world fleet by engine category

Number of ships	Category					
Vessel Service	?	1	2	3A	3B	Grand Total
CONTAINER		-	4	82	1,736	1,823
FISHING		16,407	4,045	2,091	947	23,490
PASSENGER		2,356	152	996	169	3,672
RORO		428	404	976	888	2,696
TRANSPORT		2,495	2,542	6,845	24,165	36,046
TUG		3,413	4,714	725	463	9,316
UTILITY		5,138	1,390	475	289	7,292
Grand Total		30,235	13,251	12,190	28,658	84,335

1996 NOx Emission Estimates (fuel-based)

(kg NOx/tonne fuel)

87 Slow Speed emission factor

57 Medium Speed emission factor

All Category 1, 2 use Medium-speed emission factors
half 3A use Medium-speed, half use Slow-speed factors
currently upper bound emissions factors
similar to AP-42 factors

68% ships in U.S. fleet involved in foreign trade, assume they spend 30% time in U.S. waters (from Census data on Waterways CD)

kg NOx per day-ship	Category				Weighted Average	U.S. Fleet in U.S. Waters
Vessel Service	1	2	3A	3B		
CONTAINER	-	304	-	2,539	2,492	52%
FISHING	286	528	906	863	315	100%
PASSENGER	521	-	709	1,717	890	100%
RORO	-	376	1,802	1,844	1,215	52%
TRANSPORT	247	359	1,158	1,324	964	52%
TUG	315	544	1,744	2,660	555	100%
UTILITY	312	486	1,414	1,075	381	100%
Weighted column average	291	530	1,483	1,821	431	

Assume 80% of the time underway

Estimated annual emissions	Category				Total	Percent underway
Vessel Service kg NOx/yr	1	2	3A	3B		
CONTAINER	-	92,007	-	36,085,495	36,177,501	80%
FISHING	208,365,719	37,192,614	1,725,533	8,211,745	255,495,611	80%
PASSENGER	1,188,750	-	404,118	1,958,047	3,550,915	80%
RORO	-	2,254,833	7,851,187	13,060,875	23,166,895	80%
TRANSPORT	448,424	1,822,588	5,043,205	12,976,166	20,290,383	80%
TUG	22,470,502	154,898,115	11,429,244	15,492,259	204,290,119	80%
UTILITY	38,240,282	24,246,987	2,878,947	1,641,764	67,007,980	80%
Total	270,713,677	220,507,144	29,332,232	89,426,350	609,979,403	

1996 PM Emission Estimates (fuel-based)

(kg PM/tonne fuel)

7.6 Slow Speed emission factor

1.2 Medium Speed emission factor

All Category 1, 2 use Medium-speed emission factors
half 3A use Medium-speed, half use Slow-speed factors
currently upper bound emissions factors
similar to AP-42 factors

68% ships in U.S. fleet involved in foreign trade, assume they spend 30% time in U.S. waters (from Census data)

kg PM per day-ship		Category				Weighted Average	U.S. Fleet in U.S. Waters
Vessel Service	Data	1	2	3A	3B		
CONTAINER		-	6	-	222	217	52%
FISHING		6	11	55	75	7	100%
PASSENGER		11	-	43	150	55	100%
RORO		-	8	110	161	88	52%
TRANSPORT		5	8	71	116	71	52%
TUG		7	11	107	232	16	100%
UTILITY		7	10	86	94	9	100%
Weighted column average		6	11	91	159	14	

Assume 80% of the time underway

Estimated annual emissions		Category				Total	Percent underway
Vessel Service	kg PM/yr	1	2	3A	3B		
CONTAINER		-	1,937	-	3,152,296	3,154,233	80%
FISHING		4,386,647	783,002	105,449	717,348	5,992,446	80%
PASSENGER		25,026	-	24,696	171,048	220,770	80%
RORO		-	47,470	479,795	1,140,950	1,668,215	80%
TRANSPORT		9,441	38,370	308,196	1,133,550	1,489,557	80%
TUG		473,063	3,261,013	698,454	1,353,347	5,785,877	80%
UTILITY		805,059	510,463	175,936	143,418	1,634,876	80%
Total		5,699,235	4,642,256	1,792,525	7,811,957	19,945,973	

1996 HC Emission Estimates (fuel-based)

(kg HC/tonne fuel)

2.4	Slow Speed emission factor	All Category 1, 2 use Medium-speed emission factors half 3A use Medium-speed, half use Slow-speed factors
2.4	Medium Speed emission factor	currently upper bound emissions factors similar to AP-42 factors

68% ships in U.S. fleet involved in foreign trade, assume they spend 30% time in U.S. waters (from Census data)

kg HC per day-ship		Category					Weighted Average	U.S. Fleet in U.S. Waters
Vessel Service	Data		1	2	3A	3B		
CONTAINER			-	13	-	70	69	52%
FISHING			12	22	30	24	13	100%
PASSENGER			22	-	24	47	29	100%
RORO			-	16	60	51	38	52%
TRANSPORT			10	15	39	37	30	52%
TUG			13	23	58	73	22	100%
UTILITY			13	20	47	30	16	100%
Weighted column average			12	22	49	50	17	

Assume 80% of the time underway

Estimated annual emissions		Category					Total	Percent underway
Vessel Service	kg HC/yr		1	2	3A	3B		
CONTAINER			-	3,874	-	995,462	999,336	80%
FISHING			8,773,293	1,566,005	57,518	226,531	10,623,347	80%
PASSENGER			50,053	-	13,471	54,015	117,538	80%
RORO			-	94,940	261,706	360,300	716,947	80%
TRANSPORT			18,881	76,741	168,107	357,963	621,692	80%
TUG			946,126	6,522,026	380,975	427,373	8,276,500	80%
UTILITY			1,610,117	1,020,926	95,965	45,290	2,772,298	80%
Total			11,398,471	9,284,511	977,741	2,466,934	24,127,657	

1996 CO Emission Estimates

(kg CO/tonne fuel)

7.4 Slow Speed emission factor

7.4 Medium Speed emission factor

All Category 1, 2 use Medium-speed emission factors
half 3A use Medium-speed, half use Slow-speed factors
currently upper bound emissions factors
similar to AP-42 factors

68% ships in U.S. fleet involved in foreign trade, assume they spend 30% time in U.S. waters (from Census data)

kg CO per day-ship		Category				Weighted Average	U.S. Fleet in U.S. Waters
Vessel Service	Data	1	2	3A	3B		
CONTAINER		-	39	-	216	212	52%
FISHING		37	69	93	73	40	100%
PASSENGER		68	-	73	146	91	100%
RORO		-	49	185	157	116	52%
TRANSPORT		32	47	119	113	91	52%
TUG		41	71	179	226	69	100%
UTILITY		40	63	145	91	49	100%
Weighted column average		38	69	152	155	53	

Assume 80% of the time underway

Estimated annual emissions	Category					Percent underway
Vessel Service kg CO/yr	1	2	3A	3B	Total	
CONTAINER	-	11,945	-	3,069,341	3,081,286	80%
FISHING	27,050,988	4,828,515	177,346	698,470	32,755,320	80%
PASSENGER	154,329	-	41,534	166,547	362,410	80%
RORO	-	292,733	806,928	1,110,925	2,210,585	80%
TRANSPORT	58,216	236,617	518,329	1,103,720	1,916,882	80%
TUG	2,917,223	20,109,580	1,174,672	1,317,732	25,519,208	80%
UTILITY	4,964,528	3,147,854	295,892	139,644	8,547,918	80%
Total Average	35,145,284	28,627,243	3,014,702	7,606,379	74,393,608	

7.2 Method B: Cargo Method using 1993 Cargo Trade Data

NOx Emissions (as NOx) Before Adjustments for Steam (non-CI) Engines in U.S. Fleet

Oceans (Foreign and Domestic)	
1,691	kg NOx per day-cargo-ship
34,837	Ave DWT per ship
0.5	cargo capacity factor
308	miles per day
0.00031	kg emissions per ton-mile
764,927,137,344	ton-miles on ocean/coastwise
240,949,607	kg emissions per year
49%	Coastwise (domestic tons)
51%	Oceangoing (foreign tons)
Great Lakes	
1,691	kg NOx per day-cargo-ship
34,837	Ave DWT per ship
0.6	cargo capacity factor
308	miles per day
0.00026	kg emissions per ton-mile
85,256,307,371	ton-miles on Great Lakes
22,379,554	kg emissions per year
81%	domestic tons
19%	foreign tons
Inland Rivers (Uses U.S. Fleet Emissions for Category 1, 2, 3A Engines)	
744	kg NOx per day-cargo-ship
15,454	Ave DWT per ship
0.6	cargo capacity factor
191	miles per day
0.00042	kg emissions per ton-mile
494,368,733,957	ton-miles on Inland Rivers
207,661,859	kg emissions per year
70%	domestic tons
30%	foreign tons
470,991,020	total national
281,435,600	total domestic
189,555,420	foreign

Miles per day were converted from nautical miles to statute miles for these calculations.

PM Emissions Before Adjustments for Steam (non-CI) Engines in U.S. Fleet

Oceans (Foreign and Domestic)	
138	kg PM per day-cargo-ship
34,837	Ave DWT per ship
0.5	cargo capacity factor
308	miles per day
0.00003	kg emissions per ton-mile
764,927,137,344	ton-miles on ocean/coastwise
19,610,143	kg emissions per year
49%	Coastwise (domestic tons)
51%	Oceangoing (foreign tons)
Great Lakes	
138	kg PM per day-cargo-ship
34,837	Ave DWT per ship
0.6	cargo capacity factor
308	miles per day
0.00002	kg emissions per ton-mile
85,256,307,371	ton-miles on Great Lakes
1,821,403	kg emissions per year
81%	domestic tons
19%	foreign tons
Inland Rivers (Uses U.S. Fleet Emissions for Category 1, 2, 3A Engines)	
38	kg PM per day-cargo-ship
15,454	Ave DWT per ship
0.6	cargo capacity factor
191	miles per day
0.00002	kg emissions per ton-mile
494,368,733,957	ton-miles on Inland Rivers
10,496,888	kg emissions per year
70%	domestic tons
30%	foreign tons
31,928,433	total national
18,447,527	total domestic
13,480,906	foreign

Miles per day were converted from nautical miles to statute miles for these calculations.

HC Emissions Before Adjustments for Steam (non-CI) Engines in U.S. Fleet

Oceans (Foreign and Domestic)	
49	kg HC per day-cargo-ship
34,837	Ave DWT per ship
0.5	cargo capacity factor
308	miles per day
0.00001	kg emissions per ton-mile
764,927,137,344	ton-miles on ocean/coastwise
6,961,848	kg emissions per year
49%	Coastwise (domestic tons)
51%	Oceangoing (foreign tons)
Great Lakes	
49	kg HC per day-cargo-ship
34,837	Ave DWT per ship
0.6	cargo capacity factor
308	miles per day
0.00001	kg emissions per ton-mile
85,256,307,371	ton-miles on Great Lakes
646,621	kg emissions per year
81%	domestic tons
19%	foreign tons
Inland Rivers (Uses U.S. Fleet Emissions for Category 1, 2, 3A Engines)	
27	kg HC per day-cargo-ship
15,454	Ave DWT per ship
0.6	cargo capacity factor
191	miles per day
0.00001	kg emissions per ton-mile
494,368,733,957	ton-miles on Inland Rivers
7,402,403	kg emissions per year
70%	domestic tons
30%	foreign tons
15,010,872	total national
9,107,752	total domestic
5,903,120	foreign

Miles per day were converted from nautical miles to statute miles for these calculations.

CO Emissions (as CO) Before Adjustments for Steam (non-CI) Engines in U.S. Fleet

Oceans (Foreign and Domestic)	
151	kg CO per day-cargo-ship
34,837	Ave DWT per ship
0.5	cargo capacity factor
308	miles per day
0.00003	kg emissions per ton-mile
764,927,137,344	ton-miles on ocean/coastwise
21,465,698	kg emissions per year
49%	Coastwise (domestic tons)
51%	Oceangoing (foreign tons)
Great Lakes	
151	kg CO per day-cargo-ship
34,837	Ave DWT per ship
0.6	cargo capacity factor
308	miles per day
0.00002	kg emissions per ton-mile
85,256,307,371	ton-miles on Great Lakes
1,993,748	kg emissions per year
81%	domestic tons
19%	foreign tons
Inland Rivers (Uses U.S. Fleet Emissions for Category 1, 2, 3A Engines)	
82	kg CO per day-cargo-ship
15,454	Ave DWT per ship
0.6	cargo capacity factor
191	miles per day
0.00005	kg emissions per ton-mile
494,368,733,957	ton-miles on Inland Rivers
22,824,077	kg emissions per year
70%	domestic tons
30%	foreign tons
46,283,524	total national
28,082,236	total domestic
18,201,288	foreign

Miles per day were converted from nautical miles to statute miles for these calculations.

Rough Emissions using Cargo Method (assumes all cargo carried by CI Engines)

	kg NOx per year	kg PM per year	kg HC per year	kg CO per year
Region	NOx	PM	HC	CO
Oceangoing (foreign tons)	122,084,298	9,936,063	3,527,428	10,876,236
US Flag CI Engines	18,281,433	1,487,869	528,212	1,628,655
Foreign Flag CI Engines	103,802,866	8,448,194	2,999,215	9,247,581
Coastwise (domestic tons)	118,865,309	9,674,080	3,434,420	10,589,463
Inland Rivers	207,661,859	10,496,888	7,402,403	22,824,077
US Flag CI Engines	175,642,270	8,878,362	6,261,019	19,304,810
Foreign Flag CI Engines	32,019,589	1,618,526	1,141,384	3,519,267
Great Lakes	22,379,554	1,821,403	646,621	1,993,748
US Flag CI Engines	21,478,650	1,748,081	620,591	1,913,488
Foreign Flag CI Engines	900,904	73,322	26,030	80,260
Total Nationwide Emissions	470,991,020	31,928,433	15,010,872	46,283,524
US Flag CI Engines	334,267,661	21,788,392	10,844,243	33,436,416
Foreign Flag CI Engines	136,723,359	10,140,041	4,166,630	12,847,108

Estimated number of cargo ships in world fleet

Number of cargo ships					
Vessel Service	1	2	3A	3B	Grand Total
CONTAINER	-	3	58	1,215	1,276
RORO	299	283	683	621	1,887
TRANSPORT	1,746	1,779	4,791	16,916	25,232
Grand Total	2,046	2,065	5,532	18,752	28,396
	7%	7%	19%	66%	

Foreign emissions in U.S. estimated by
EPA Category

Kg NOx per year					
Vessel Service	1	2	3A	3B	Grand Total
CONTAINER	-	14,629	277,960	5,851,788	6,144,378
RORO	1,441,355	1,363,020	3,290,049	2,992,378	9,086,803
TRANSPORT	8,407,685	8,566,320	23,070,143	81,448,030	15,231,181
Grand Total	9,849,040	9,943,970	26,638,152	90,292,196	136,723,359

Without Category 1 engines

Kg NOx per year					
Vessel Service	1	2	3A	3B	Grand Total
CONTAINER		14,629	277,960	5,851,788	6,144,378
RORO		1,363,020	3,290,049	2,992,378	7,645,448
TRANSPORT		8,566,320	23,070,143	81,448,030	13,789,826
Grand Total	-	9,943,970	26,638,152	90,292,196	126,874,319

Note: There is a potential error due to differences in emission rates for different engine types. This error (which would increase the estimates for Category 3 engine emissions and decrease the estimates for Category 2 engine emissions) is assumed to be offsetting and/or small because of the few numbers of category 1 and 2 engines involved in cargo transport.

Estimated number of cargo ships in world fleet

Number of cargo ships					
Vessel Service	1	2	3A	3B	Grand Total
CONTAINER	-	3	58	1,215	1,276
RORO	299	283	683	621	1,887
TRANSPORT	1,746	1,779	4,791	16,916	25,232
Grand Total	2,046	2,065	5,532	18,752	28,396

Foreign emissions in U.S. estimated by
EPA Category

Kg PM per year					
Vessel Service	1	2	3A	3B	Grand Total
CONTAINER	-	1,085	20,615	433,996	455,696
RORO	106,898	101,088	244,005	221,929	673,920
TRANSPORT	623,553	635,318	1,710,989	6,040,565	1,129,615
Grand Total	730,451	737,491	1,975,610	6,696,490	10,140,041

Without Category 1 engines

Kg PM per year					
Vessel Service	1	2	3A	3B	Grand Total
CONTAINER		1,085	20,615	433,996	455,696
RORO		101,088	244,005	221,929	567,022
TRANSPORT		635,318	1,710,989	6,040,565	1,022,718
Grand Total	-	737,491	1,975,610	6,696,490	9,409,591

Note: There is a potential error due to differences in emission rates for different engine types. This error (which would increase the estimates for Category 3 engine emissions and decrease the estimates for Category 2 engine emissions) is assumed to be offsetting and/or small because of the few numbers of category 1 and 2 engines involved in cargo transport.

Estimated number of cargo ships in world fleet

Number of cargo ships					
Vessel Service	1	2	3A	3B	Grand Total
CONTAINER	-	3	58	1,215	1,276
RORO	299	283	683	621	1,887
TRANSPORT	1,746	1,779	4,791	16,916	25,232
Grand Total	2,046	2,065	5,532	18,752	28,396

Foreign emissions in U.S. estimated by
EPA Category

Kg HC per year					
Vessel Service	1	2	3A	3B	Grand Total
CONTAINER	-	446	8,471	178,333	187,249
RORO	43,925	41,538	100,264	91,192	276,919
TRANSPORT	256,223	261,058	703,060	2,482,120	464,169
Grand Total	300,148	303,041	811,795	2,751,645	4,166,630

Without Category 1 engines

Kg HC per year					
Vessel Service	1	2	3A	3B	Grand Total
CONTAINER		446	8,471	178,333	187,249
RORO		41,538	100,264	91,192	232,994
TRANSPORT		261,058	703,060	2,482,120	420,243
Grand Total	-	303,041	811,795	2,751,645	3,866,481

Note: The potential error described on the previous worksheets does not apply here because calculations for all engines use the same emission factor for this pollutant.

Estimated number of cargo ships in world fleet

Number of cargo ships					
Vessel Service	1	2	3A	3B	Grand Total
CONTAINER	-	3	58	1,215	1,276
RORO	299	283	683	621	1,887
TRANSPORT	1,746	1,779	4,791	16,916	25,232
Grand Total	2,046	2,065	5,532	18,752	28,396

Foreign emissions in U.S. estimated by
EPA Category

Kg CO per year					
Vessel Service	1	2	3A	3B	Grand Total
CONTAINER	-	1,375	26,118	549,859	577,352
RORO	135,436	128,075	309,147	281,177	853,835
TRANSPORT	790,022	804,928	2,167,769	7,653,203	1,431,187
Grand Total	925,458	934,378	2,503,034	8,484,239	12,847,108

Without Category 1 engines

Kg CO per year					
Vessel Service	1	2	3A	3B	Grand Total
CONTAINER		1,375	26,118	549,859	577,352
RORO		128,075	309,147	281,177	718,399
TRANSPORT		804,928	2,167,769	7,653,203	1,295,751
Grand Total	-	934,378	2,503,034	8,484,239	11,921,650

Note: The potential error described on the previous worksheets does not apply here because calculations for all engines use the same emission factor for this pollutant.

Cargo Method emissions adjustments: Previous calculations are adjusted to account for steam plants in U.S. fleet and to highlight Category 2 and 3 engines. See text for calculation details.

Region	NOx	PM	HC	CO
Oceangoing	113,638,624	9,248,696	3,283,404	10,123,828
Categories 2 and 3 only	104,318,416	8,236,776	2,999,898	9,286,246
US Cargo Ships all engines	9,835,758	800,502	284,188	876,247
Diesel Engines	8,694,997	413,656	238,410	775,313
Categories 2 and 3 only	7,993,121	397,158	216,735	704,826
Steam Engines	1,140,761	386,846	45,778	100,934
Foreign Vessels	103,802,866	8,448,194	2,999,215	9,247,581
Categories 2 and 3 only	96,325,295	7,839,618	2,783,163	8,581,420
Coastwise (domestic)	63,951,794	5,204,839	1,847,783	5,697,332
Diesel Engines	56,534,599	2,689,578	1,550,134	5,041,063
Categories 2 and 3 only	51,971,025	2,582,309	1,409,204	4,582,758
Steam Engines	7,417,195	2,515,261	297,650	656,269
Inland Rivers	126,518,467	6,395,253	4,509,931	13,905,622
Categories 2 and 3 only	106,508,416	3,871,840	3,628,172	11,620,216
US Cargo Ships all engines	94,498,878	4,776,727	3,368,547	10,386,355
Diesel Engines	83,538,800	2,468,353	2,825,926	9,189,963
Categories 2 and 3 only	76,795,399	2,369,907	2,569,009	8,354,464
Steam Engines	10,960,078	2,308,374	542,622	1,196,392
Foreign Vessels	32,019,589	1,618,526	1,141,384	3,519,267
Categories 2 and 3 only	29,713,018	1,501,933	1,059,163	3,265,752
Great Lakes	12,456,826	1,013,822	359,920	1,109,753
Categories 2 and 3 only	10,227,034	534,656	278,795	902,570
US Cargo Ships all engines	11,555,922	940,501	333,890	1,029,493
Diesel Engines	10,215,654	486,000	280,105	910,907
Categories 2 and 3 only	9,391,028	466,616	254,640	828,092
Steam Engines	1,340,268	454,501	53,785	118,586
Foreign Vessels	900,904	73,322	26,030	80,260
Categories 2 and 3 only	836,006	68,040	24,155	74,478
Total Nationwide Emissions	316,565,710	21,862,610	10,001,038	30,836,535
Categories 2 and 3 only	273,024,892	15,225,581	8,316,069	26,391,791
US Cargo Ships all engines	179,842,352	11,722,569	5,834,409	17,989,427
Diesel Engines	158,984,050	6,057,587	4,894,574	15,917,246
Categories 2 and 3 only	146,150,573	5,815,990	4,449,588	14,470,141
Steam Engines	20,858,302	5,664,982	939,834	2,072,181
Foreign Vessels	136,723,359	10,140,041	4,166,630	12,847,108
Categories 2 and 3 only	126,874,319	9,409,591	3,866,481	11,921,650

7.3 Engine Manufactures and Engine Models in the U.S. Flag

Table 16. Category 2 Engine Manufacturer Data, by Vessel Service

Count of Engine			Category	
Vessel Service	Engine Design	Engine	2	Grand Total
CONTAINER	Alco	12V251C	1	1
	Alco Total		1	1
CONTAINER Total			1	1

Count of Engine			Category	
Vessel Service	Engine Design	Engine	2	Grand Total
FISHING	Alco	16V251F	2	2
		18V251F	2	2
	Alco Total		4	4
	Caterpillar	3608TA	1	1
		3612TA	1	1
	Caterpillar Total		2	2
	Deutz	SBV6M628	1	1
	Deutz Total		1	1
	Fairbanks, Morse	4-38D8-1/8	1	1
	Fairbanks, Morse Total		1	1
	General Motors	12-567-BC	2	2
		12-645-E2	3	3
		12-645-E5	2	2
		12-645-E6	14	14
		16-567-BC	1	1
		16-645-E2	2	2
		16-645-E5	3	3
		16-645-E6	7	7
		16-645-E7B	1	1
		20-645-E5	2	2
		20-645-E6	1	1
		20-645-E7	18	18
		20-645-E7B	4	4
		8-645-E7B	2	2
	General Motors Total		62	62
	MWM	TBD441V16	4	4
	MWM Total		4	4
FISHING Total			74	74

Count of Engine			Category	
Vessel Service	Engine Design	Engine	2	Grand Total
RORO	General Electric	7FDM12	3	3
	General Electric Total		3	3
	General Motors	12-567-BC	1	1
		12-645-E6	3	3
		12-645-E7B	2	2
		16-645-E7B	2	2
	General Motors Total		8	8
RORO Total			11	11

Count of Engine			Category	
Vessel Service	Engine Design	Engine	2	Grand Total
TRANSPORT	Alco	12V251C	2	2
		12V251E	1	1
		16V251E	3	3
		16V251F	1	1
	Alco Total		7	7
	Fairbanks, Morse	12-38TD-1/8	1	1
	Fairbanks, Morse Total		1	1
	General Electric	7FDS16-A2	1	1
	General Electric Total		1	1
	General Motors	12-645-E6	1	1
		16-645-E6	1	1
		16-645-E7	1	1
		20-645-E7	1	1
		8-645-E7	1	1
	General Motors Total		5	5
TRANSPORT Total			14	14

Count of Engine			Category	
Vessel Service	Engine Design	Engine	2	Grand Total
TUG	Alco	12V251C	8	8
		12V251E	17	17
		12V251F	10	10
		16V251E	8	8
		16V251F	6	6
		18V251F	3	3
	Alco Total		52	52
	Caterpillar	3608TA	2	2
	Caterpillar Total		2	2
	Fairbanks, Morse	10-38D8-1/8	1	1
		12-38D8-1/8	1	1
		12-38TD-1/8	1	1
		8-38D8-1/8	1	1
	Fairbanks, Morse Total		4	4
	General Electric	7FDM16	1	1
	General Electric Total		1	1
	General Motors	12-567-BC	4	4
		12-645-C	3	3
		12-645-E2	6	6
		12-645-E5	4	4
		12-645-E6	66	66
		12-645-E7	1	1
		12-645-E7A	1	1
		12-645-E7B	22	22
		12-645-F7B	2	2
		12V-645-E6	1	1
		16-567-BC	23	23
		16-645	3	3

		16-645-C	1	1
		16-645-E2	13	13
		16-645-E3	2	2
		16-645-E5	15	15
		16-645-E6	67	67
		16-645-E7	33	33
		16-645-E7B	17	17
		16-645-E8	4	4
		16-645-F7B	4	4
		16-710-GA	2	2
		20-645-E5	7	7
		20-645-E7	3	3
		20-645-E7B	18	18
		8-645-E2	1	1
		8-645-E5	1	1
		8-645-E6	4	4
	General Motors Total		328	328
	MWM	TBD441V16	1	1
	MWM Total		1	1
	Niigata	6L25BX	1	1
	Niigata Total		1	1
	Wartsila	12V22	1	1
		8R22	1	1
	Wartsila Total		2	2
TUG Total			391	391

Count of Engine			Category	
Vessel Service	Engine Design	Engine	2	Grand Total
UTILITY	Alco	12V251E	3	3
		12V251F	1	1
		16V251F	1	1
		18V251F	1	1
	Alco Total		6	6
	Caterpillar	3608TA	2	2
		3612TA	1	1
	Caterpillar Total		3	3
	Fairbanks, Morse	12-38TD-1/8	1	1
	Fairbanks, Morse Total		1	1
	General Motors	12-567-BC	7	7
		12-645-C	1	1
		12-645-E2	10	10
		12-645-E6	25	25
		12-645-E7	1	1
		12-645-E7A	6	6
		12-645-E7B	2	2
		12-645-F7B	1	1
		16-645-E2	3	3
		16-645-E5	6	6
		16-645-E6	13	13
		16-645-E7	2	2
		16-645-E7B	5	5

		16-645-E8	1	1
		16-645-F7B	1	1
		8-645-E6	3	3
	General Motors Total		87	87
	MAN	6L20/27	1	1
	MAN Total		1	1
UTILITY Total			98	98

Table 17. Category 3A and 3B Engine Manufacturer Data, by Vessel Service

Count of Engine			Category		
Vessel Service	Engine Design	Engine	3A	3B	Grand Total
CONTAINER	B&W	12L90GFCA		2	2
		7L70MC		3	3
		8L80MC		1	1
		8L90GBE		2	2
		9L80MCE		4	4
	B&W Total			12	12
	Sulzer	12RND90M		5	5
		12RTA84		5	5
		6RND90		1	1
		6RTA76		2	2
		7RLB90		9	9
		7RTA76		3	3
		9RND90		3	3
		9RND90M		7	7
	Sulzer Total			35	35
CONTAINER Total				47	47

Count of Engine			Category		
Vessel Service	Engine Design	Engine	3A	3B	Grand Total
FISHING	MaK	6M453C		1	1
		6M551AK		1	1
		8M453C		1	1
		8M551AK		1	1
		9M453AK		4	4
		9M453C		1	1
	MaK Total			9	9
	Mitsubishi	8UET45/80D		1	1
	Mitsubishi Total			1	1
	Wartsila	12V32E	1		1
		6R32	1		1
	Wartsila Total		2		2
FISHING Total			2	10	12

Count of Engine			Category		
Vessel Service	Engine Design	Engine	3A	3B	Grand Total
PASSENGER	Enterprise	DMRV-16-4		1	1
	Enterprise Total			1	1

	MWM	TBD604-B12	1		1
	MWM Total		1		1
	Sulzer	6TD48		1	1
	Sulzer Total			1	1
PASSENGER Total			1	2	3

Count of Engine			Category		
Vessel Service	Engine Design	Engine	3A	3B	Grand Total
RORO	B&W	12L90GFCA		1	1
		6K90GF		1	1
		6L60MC		1	1
		6L70MC		1	1
		6S60MCE		1	1
		9K906F		1	1
		9K90GF		1	1
	B&W Total			7	7
	Pielstick	18PC2V-400	8		8
	Pielstick Total		8		8
	Sulzer	6RND90		2	2
		6RTA62		1	1
		8RND90M		2	2
		9RND90		1	1
	Sulzer Total			6	6
RORO Total			8	13	21

Count of Engine			Category		
Vessel Service	Engine Design	Engine	3A	3B	Grand Total
TRANSPORT	B&W	10K84EF		1	1
		4L80MC		2	2
		4L90GBE		2	2
		8K90GF		1	1
		Not specified		1	1
	B&W Total			7	7
	Enterprise	DMRV-12-4		3	3
		DMRV16-4		1	1
	Enterprise Total			4	4
	MaK	6M453AK		1	1
		6M601AK		1	1
		8M453AK		1	1
		8M601AK		2	2
	MaK Total			5	5
	Pielstick	12PC2V-400	1		1
		14PC2-2V-400	4		4
		16PC2V-400	5		5
		18PC2-5V-400	2		2
	Pielstick Total		12		12
	Sulzer	5RTA76		5	5
		7RTA58		1	1

		8RTA84		2	2
		9RND90		2	2
	Sulzer Total			10	10
	Wartsila	8R46		1	1
	Wartsila Total			1	1
TRANSPORT Total			12	27	39

Count of Engine			Category		
Vessel Service	Engine Design	Engine	3A	3B	Grand Total
TUG	B&W	7S28LU	2		2
	B&W Total		2		2
	Enterprise	DMRV-16-4		6	6
	Enterprise Total			6	6
	MaK	6M551AK		2	2
	MaK Total			2	2
	Pielstick	14PC2-2V-400	2		2
		14PC2-5V-400	2		2
		14PC2V-400	1		1
	Pielstick Total		5		5
	Wartsila	6R32	2		2
	Wartsila Total		2		2
TUG Total			9	8	17

Count of Engine			Category		
Vessel Service	Engine Design	Engine	3A	3B	Grand Total
UTILITY	Cooper Bessemer	KSV16T	1		1
	Cooper Bessemer Total		1		1
	Daihatsu	8DSM-32	2		2
	Daihatsu Total		2		2
	Enterprise	DMRV-16-4		1	1
	Enterprise Total			1	1
	MaK	6M453AK		1	1
	MaK Total			1	1
	Nordberg	32112		1	1
	Nordberg Total			1	1
	Wartsila	9R32D	1		1
	Wartsila Total		1		1
UTILITY Total			4	3	7

Table 18. Un-categorized Engine Manufacturer Data, by Vessel Service

Count of Engine			Category	
Vessel Service	Engine Design	Engine	Un-categorized	Grand Total
CONTAINER	MAN	K9Z78/155E	2	2
	MAN Total		2	2
	Not specified	Not specified		
	Not specified Total			
CONTAINER Total			2	2

Count of Engine			Category	
Vessel Service	Engine Design	Engine	Un-categorized	Grand Total
FISHING	....	Not specified	1071	1071
	.... Total		1071	1071
	Akasaka	AH38	1	1
		TM6SS	1	1
		UZ6SS	1	1
		Not specified	1	1
	Akasaka Total		4	4
	Alco	Not specified	2	2
	Alco Total		2	2
	Alpha	10V23L-VO	1	1
		406-24VO	1	1
		6L28/32	1	1
		8V23L-VO	1	1
		Not specified	3	3
	Alpha Total		7	7
	B&W	6-33MTF-60	1	1
	B&W Total		1	1
	Brons	12TD200	1	1
	Brons Total		1	1
	Buda	Not specified	1	1
	Buda Total		1	1
	Caterpillar	Not specified	194	194
	Caterpillar Total		194	194
	Cooper Bessemer	Not specified	4	4
	Cooper Bessemer Total		4	4
	Cummins	Not specified	26	26
	Cummins Total		26	26
	Deutz	Not specified	3	3
	Deutz Total		3	3
	Enterprise	Not specified	12	12
	Enterprise Total		12	12
	Fairbanks, Morse	Not specified	11	11
	Fairbanks, Morse Total		11	11
	General Electric	Not specified	3	3
	General Electric Total		3	3
	General Motors	Not specified	138	138
	General Motors Total		138	138
	Gray	Not specified	1	1
	Gray Total		1	1
	Kromhout	8F/SW240	1	1
	Kromhout Total		1	1
	MaK	9M452AK	1	1
		Not specified	1	1
	MaK Total		2	2
	MAN	Not specified		
	MAN Total			
	Niigata	Not specified	1	1
	Niigata Total		1	1
	Nohab	Not specified		
	Nohab Total			

	Nordberg	Not specified	2	2
	Nordberg Total		2	2
	Normo	BRM-8	2	2
		BRM-9	1	1
		KRMB-9	1	1
		KVMB-12	2	2
		KVMB-18	1	1
		Not specified	1	1
	Normo Total		8	8
	Penta	TAMD120B	1	1
	Penta Total		1	1
	Polar	F216V-A	2	2
		F216V-B	2	2
	Polar Total		4	4
	Not specified	Not specified		
	Not specified Total			
	Not specified	Not specified	249	249
	Not specified Total		249	249
	Stork	Not specified	1	1
	Stork Total		1	1
	Stork-Werkspoor	16SW280	1	1
	Stork-Werkspoor Total		1	1
	Wartsila	Not specified		
	Wartsila Total			
	Westinghouse	Not specified	1	1
	Westinghouse Total		1	1
	White Superior	Not specified	1	1
	White Superior Total		1	1
	Wichmann	10V28A	1	1
		4AXA	2	2
		Not specified	2	2
	Wichmann Total		5	5
FISHING Total			1756	1756

Count of Engine Vessel Service	Engine Design	Engine	Category Un-categorized	Grand Total
PASSENGER	....	Not specified	1	1
	.... Total		1	1
	Baudouin	Not specified	1	1
	Baudouin Total		1	1
	Caterpillar	Not specified	1	1
	Caterpillar Total		1	1
	De Laval	Not specified		
	De Laval Total			
	Enterprise	Not specified	2	2
	Enterprise Total		2	2
	Fairbanks, Morse	Not specified	1	1
	Fairbanks, Morse Total		1	1
	General Electric	Not specified		
	General Electric Total			
	General Motors	Not specified	3	3
	General Motors Total		3	3
	MaK	Not specified		

	MaK Total			
	Not specified	Not specified	2	2
	Not specified Total		2	2
PASSENGER Total			11	11

Count of Engine			Category	
Vessel Service	Engine Design	Engine	Un-categorized	Grand Total
RORO	Busch-Sulzer	Not specified	1	1
	Busch-Sulzer Total		1	1
	Caterpillar	Not specified	1	1
	Caterpillar Total		1	1
	Cooper Bessemer	Not specified	1	1
	Cooper Bessemer Total		1	1
	Fairbanks, Morse	Not specified	3	3
	Fairbanks, Morse Total		3	3
	General Electric	Not specified	3	3
	General Electric Total		3	3
	General Motors	Not specified	1	1
	General Motors Total		1	1
	MAN	14V52/55A	3	3
		9L52/55A	3	3
	MAN Total		6	6
	Not specified	Not specified		
	Not specified Total			
	Stork-Werkspoor	6TM620	2	2
	Stork-Werkspoor Total		2	2
	Sulzer	6RLB66	2	2
		6RND68	1	1
		6RND68M	2	2
		7RND76M	5	5
	Sulzer Total		10	10
	Werkspoor	18TM410	5	5
	Werkspoor Total		5	5
RORO Total			33	33

Count of Engine			Category	
Vessel Service	Engine Design	Engine	Un-categorized	Grand Total
TRANSPORT	....	Not specified	14	14
	.... Total		14	14
	B&W	6K67GF	2	2
		7K67GF	1	1
		8K45GF	2	2
		9-84VT2BF-180	1	1
	B&W Total		6	6
	Busch-Sulzer	Not specified	1	1
	Busch-Sulzer Total		1	1
	Caterpillar	Not specified	5	5
	Caterpillar Total		5	5
	Cooper Bessemer	Not specified	3	3
	Cooper Bessemer Total		3	3
	Deutz	Not specified	1	1

	Deutz Total		1	1
	Enterprise	Not specified	1	1
	Enterprise Total		1	1
	Fairbanks, Morse	Not specified	7	7
	Fairbanks, Morse Total		7	7
	General Motors	Not specified	11	11
	General Motors Total		11	11
	Gray	Not specified	1	1
	Gray Total		1	1
	Hamilton	Not specified	1	1
	Hamilton Total		1	1
	Kromhout	9FCHD240	1	1
	Kromhout Total		1	1
	MaK	6M451AK	1	1
		Not specified	1	1
	MaK Total		2	2
	MAN	9L52/55B	1	1
	MAN Total		1	1
	Nordberg	Not specified	3	3
	Nordberg Total		3	3
	Rathbun-Jones	Not specified	1	1
	Rathbun-Jones Total		1	1
	Smit-Bolnes	307HD	1	1
	Smit-Bolnes Total		1	1
	Sulzer	5RLA90	1	1
		5RLB90	5	5
		5RND76M	5	5
		6RND76M	2	2
		7RND68	1	1
		7RND76	2	2
	Sulzer Total		16	16
	Wichmann	Not specified	1	1
	Wichmann Total		1	1
	Winton	Not specified	1	1
	Winton Total		1	1
TRANSPORT Total			78	78

Count of Engine			Category	
Vessel Service	Engine Design	Engine	Un-categorized	Grand Total
TUG	....	Not specified	84	84
	.... Total		84	84
	Alco	Not specified	2	2
	Alco Total		2	2
	Alpha	12V23L-VO	1	1
		14V23L-VO	2	2
	Alpha Total		3	3
	B&W	7L67GFCA	1	1
	B&W Total		1	1
	Bolnes	Not specified	1	1
	Bolnes Total		1	1
	Brons	12GV-H	1	1
		Not specified	2	2
	Brons Total		3	3

Caterpillar	Not specified	77	77
Caterpillar Total		77	77
Cooper Bessemer	Not specified	2	2
Cooper Bessemer Total		2	2
Crepelle	6SN3	1	1
Crepelle Total		1	1
Cummins	Not specified	1	1
Cummins Total		1	1
Enterprise	Not specified	12	12
Enterprise Total		12	12
Fairbanks, Morse	Not specified	49	49
Fairbanks, Morse Total		49	49
General Electric	Not specified	1	1
General Electric Total		1	1
General Motors	Not specified	323	323
General Motors Total		323	323
Imperial	Not specified	1	1
Imperial Total		1	1
Kromhout	Not specified	2	2
Kromhout Total		2	2
MaK	Not specified	1	1
MaK Total		1	1
Mirrlees	Not specified	2	2
Mirrlees Total		2	2
Nohab	F25.8V	1	1
	Not specified	4	4
Nohab Total		5	5
Nordberg	Not specified	4	4
Nordberg Total		4	4
Polar	F212V	1	1
	F212V-D	1	1
	F28V-B	3	3
	F28V-D	2	2
	SF16RS-C	1	1
	SF18VS-F	1	1
	Not specified	5	5
Polar Total		14	14
Not specified	Not specified	11	11
Not specified Total		11	11
Rathbun-Jones	Not specified	1	1
Rathbun-Jones Total		1	1
Skinner Unaflow	Not specified	1	1
Skinner Unaflow Total		1	1
Stork	Not specified	1	1
Stork Total		1	1
Stork-Werkspoor	Not specified	1	1
Stork-Werkspoor Total		1	1
Sulzer	Not specified	1	1
Sulzer Total		1	1
Waukesha	Not specified	1	1
Waukesha Total		1	1
Westinghouse	Not specified	1	1
Westinghouse Total		1	1
White Superior	Not specified	3	3

	White Superior Total		3	3
	Wichmann	10AXAG	1	1
		5AXA	2	2
	Wichmann Total		3	3
	Winton	Not specified	1	1
	Winton Total		1	1
TUG Total			614	614

Count of Engine			Category	
Vessel Service	Engine Design	Engine	Un-categorized	Grand Total
UTILITY	....	Not specified	51	51
	.... Total		51	51
	Alco	Not specified	1	1
	Alco Total		1	1
	Alpha	6SL28L-VO	1	1
	Alpha Total		1	1
	B&W	8-35VBF-62	1	1
	B&W Total		1	1
	Caterpillar	Not specified	72	72
	Caterpillar Total		72	72
	Cooper Bessemer	Not specified	1	1
	Cooper Bessemer Total		1	1
	Cummins	Not specified	3	3
	Cummins Total		3	3
	De Laval	Not specified	1	1
	De Laval Total		1	1
	Deutz	Not specified	2	2
	Deutz Total		2	2
	Enterprise	Not specified	3	3
	Enterprise Total		3	3
	Fairbanks, Morse	Not specified	8	8
	Fairbanks, Morse Total		8	8
	Fiat	Not specified	1	1
	Fiat Total		1	1
	General Motors	Not specified	71	71
	General Motors Total		71	71
	Kromhout	8F/SW240	1	1
		9F/SW240	3	3
		Not specified	2	2
	Kromhout Total		6	6
	Lugger	L6125A	1	1
	Lugger Total		1	1
	M.T.U.	Not specified		
	M.T.U. Total			
	MAN	Not specified	1	1
	MAN Total		1	1
	Mitsubishi	Not specified	1	1
	Mitsubishi Total		1	1
	Nohab	F26R	1	1
		Not specified	1	1
	Nohab Total		2	2
	Nordberg	Not specified	4	4
	Nordberg Total		4	4

	Polar	F26R-A	1	1
		F26R-B	1	1
		F26R-D	2	2
		SF16RS-D	1	1
		SF16RS-F	2	2
		Not specified	1	1
	Polar Total		8	8
	Not specified	Not specified		
	Not specified Total			
	Not specified	Not specified	5	5
	Not specified Total		5	5
	Stork	Not specified	2	2
	Stork Total		2	2
	Stork-Werkspoor	8SW280	1	1
	Stork-Werkspoor Total		1	1
	Waukesha	Not specified	1	1
	Waukesha Total		1	1
	Werkspoor	6TM410	1	1
		9TM410	1	1
	Werkspoor Total		2	2
	White Superior	Not specified	1	1
	White Superior Total		1	1
	Wichmann	4AXA	2	2
		5AXA	1	1
	Wichmann Total		3	3
UTILITY Total			254	254