Draft Regulatory Impact Analysis: Control of Emissions of Air Pollution from Category 3 Marine Diesel Engines

Chapter 1:
Industry Characterization

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1.1 Introduction

Marine transportation is a key component of the U.S. national economy, for both our internal and external trade. According to the U.S. Maritime Administration, the United States saw about 2.3 billion metric tons of goods shipped via waterborne transportation in 2006, of which about 1.4 billion, or nearly 65 percent, was foreign trade (imports and exports to and from the United States).[1] This foreign trade, carried primarily by ocean-going vessels powered by Category 3 marine diesel engines, had a value of about $1.4 trillion.

This chapter provides some basic information about the segment of the marine transportation sector, ocean-going marine that is affected by today's proposal. The material presented below is a brief synopsis of the unique attributes of the maritime industry, derived from two detailed reports prepared for this rulemaking.[2,3] These reports explore in greater detail the various aspects of the marine transportation sector and the marine fuel markets. We encourage readers to review the full reports for further information.

1.2 Marine Transportation Sector

In this report, the marine transportation sector refers to (1) Category 3 marine diesel engines, (2) the vessels that use those engines, and (3) the transportation services that use those vessels. EPA defines Category 3 marine engines as compression-ignition engines with a displacement greater than or equal to 30 liters per cylinder.[A] Category 3 engines can be incredibly large and can have anywhere from four to 20 cylinders with displacements ranging from 30 to 3,000 liters per cylinder. These engines can provide power output from 2,000 kW to over 100,000 kW. The two most common types of Category 3 engines are slow-speed diesel engines (SSD) with engine speeds of 150 rpm or less, and medium-speed diesel engines (MSD) with engine speeds of approximately 300 to 600 rpm, less common are steam or gas turbine engines. EPA adopted an initial level of emission standards for Category 3 (C3) engines on February 28, 2003 (68 FR 9746). This includes all marine diesel engines with per-cylinder displacement above 30 liters. These initial standards are identical to the standards specified in MARPOL Annex VI.

The marine transportation industry relies on a variety of large ocean-going commercial vessel types powered by C3 engines to carry goods and passengers around the world. The EPA typically defines large commercial vessels as vessels engaged in waterborne trade and/or passenger transport that exceed 400 feet in length and/or weigh more than 2,000 GT.[4] Marine

[A] Marine diesel engines with per-cylinder displacement below 30 liters, called Category 1 and Category 2 engines (C1 and C2, respectively), became regulated under an initial U. S. Environmental Protection Agency (EPA) rulemaking in 1999 (64 FR 73300, December 29, 1999). EPA adopted more stringent standards for these engines as part of the Clean Diesel Locomotive and Marine Rule, which is a three-phased program and will ensure that all locomotives and C1 and C2 marine diesel engines will produce less pollution (73 FR 37096, June 30, 2008).

vessel owners and operators include U.S. and foreign entities that provide ocean marine transportation services to many industries including: consumer goods, chemical, agricultural, petroleum, personal transportation, etc. The statistics presented in this report were compiled in 2008 using Lloyd's Register of Ships Sea-Web service.[5] Sea-Web provides detailed information on the vessels that make up the global fleet including details on the installed engines, the vessels themselves, and the owners and operators of these vessels. Engine details available include: engine designer, builder, model, type, and propulsion power rating. Vessel details include: ship type, year built, gross tonnage (GT), flag state, and actual build details (e.g., hull type). The analyses presented here are based only on vessels built in or after 1990, with at least 5,000 kW, are at least 2,000 GT, and are in-service; only vessels with complete records were included; for the purposes of this report these vessels will be referred to as the "global fleet."

Table 1-1 Characteristics of the "Global Fleet"

	AVERAGE YEAR BUILT	AVERAGE GT	NUMBER OF 2-STROKES	NUMBER OF 4-STROKES	NUMBER OF GAS TURBINES	NUMBER OF STEAM TURBINES	AVERAGE ENGINE POWER (KW)
Auto Carrier	2002	49,000	386	18	0	0	13000
Bulk Cargo	2000	37,000	4127	281	0	0	9400
Container	2001	34,000	2977	492	0	0	27000
Misc	2000	18,000	19	157	0	2	7500
Passenger	1999	42,000	7	402	16	1	10000
Reefer	1995	9,300	224	21	0	0	9700
RoRo	2000	20,000	47	137	8	0	11000
Tanker	2002	57,000	3464	191	4	182	13000

The coordinated strategy for emission controls of C3 marine engines is slightly different than previous EPA rules in that, in addition to the Clean Air Act (CAA) authority, the U.S. Government has petitioned the International Maritime Organization (IMO) to create an Emission Control Area (ECA) around most of the U.S. coastline. The regulations for C3 marine diesel engine emissions could directly impact several industries: (1) manufacturers of marine diesel engines, (2) diesel engine marinizers, (3) marine diesel engine remanufacturers, (4) boat or vessel builders which install marine diesel engines installed on their vessels, (5) vessel operators who own existing marine diesel engines with engine displacement at or greater than 30 liters per cylinder (L/cyl), (6) marine fuel manufacturers, (7) marine fuel distributors/brokers, and (8) U.S. ports.

1.2.1 Engine Types

1.2.1.1 Two-Stroke Engines

Two-stroke engines are usually SSD connected to a direct drive propulsion system. These engines have large displacements of up to 3,000 L/cylinder. SSD are used for propulsion on bulk carriers, container ships, larger tankers, general cargo and roll-on/roll-of (RoRo) ships. They are typically turbo-charged with aftercooling and have four exhaust valves per cylinder. Scavenge air enters the cylinder through a series of intake ports arranged around the bottom of the cylinder. Intake is controlled by the piston as it uncovers or covers the intake ports. Fuel injection is typically mechanical with three injectors per cylinder.

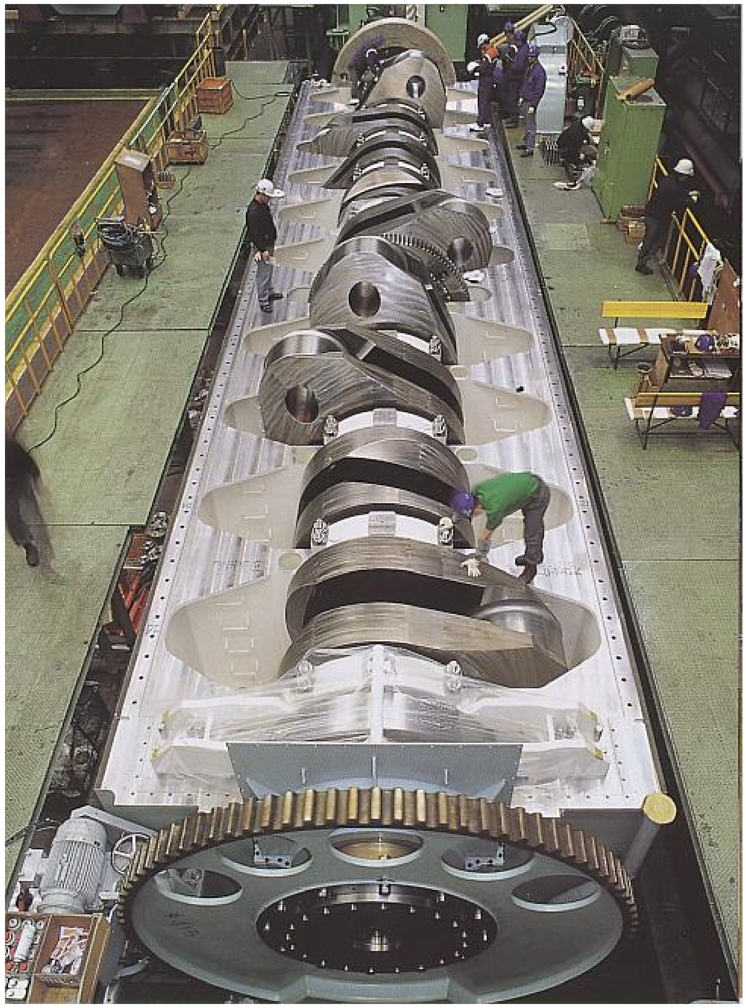
The top three two-stroke engine designers of the global fleet on a per-vessel basis are MAN which represents over 71 percent of that total, Wärtsila which produced nearly 18 percent, and Mitsubishi which captured just over 10 percent. MAN is headquartered in Munich, Germany and is a supplier of diesel engines, turbo machinery, special gear systems, trucks and buses. In 2008, MAN employed over 51,000 people and generated revenue of approximately $23 billion.[6] Wartsila is headquartered in Helsinki, Finland and is a provider of ship design, engines, generator sets, gears and other propulsion equipment. They employ nearly 19,000 people and have locations in close to 70 countries.[7] Mitsubishi Power Systems, Inc. (MPS) headquartered in Lake Mary, FL is a subsidiary company of Mitsubishi Heavy Industries, Ltd. (MHI) which employs more than 40,000 people worldwide generating more than $25 billion in annual revenues.[8] MPS produces gas and steam turbines in addition to medium speed engines up to nearly 15,000 kW, and low speed engines over 67,000 kW. MHI also builds and repairs ships, marine engines and equipment.

Table 1-2 Number of Engines Built per Year by Manufacturer

YEAR BUILT[A]	MAN	WARTSILA[B]	MITSUBISHI	OTHER	TOTAL
1990	170	86	41	0	297
1991	178	91	34	0	303
1992	171	107	46	0	324
1993	193	92	55	0	340
1994	260	108	46	0	414
1995	302	96	59	0	457
1996	352	125	67	0	544
1997	369	147	92	0	608
1998	377	136	82	0	595
1999	368	106	69	0	543
2000	331	155	62	0	548
2001	442	122	44	1	609
2002	474	80	53	0	607
2003	497	92	60	0	649
2004	579	87	80	0	746
2005	703	116	81	0	900
2006	764	115	68	0	947
2007	833	100	92	0	1025
2008	673	60	59	3	795
Total	8036	2021	1190	4	11251
Percent	71%	18%	10%	0.04%	

Notes:
[a] Assumes that the engine was built the same year the vessel was reported as being built.
[b] Wartsila count includes Sulzer engines.

Wartsila manufactures the world's most powerful diesel engine, the 14-cylinder Wärtsilä RT-flex96C marine engine has a maximum continuous power output of 84,000 kW (113,000 bhp) at 102 rpm. This engine is nearly 90 feet long, and over 44 feet tall and weighs over five million pounds, see Figure 1-1.[9,10]



Source:http://www.aucklandshipbrokers.com/index.php?option=com_content&task=view&id=100&Itemid=68

Figure 1-1 Wartsila RT-flex96C 84,000 kW SSD Engine

1.2.1.2 Four-Stroke Engines

Four-stroke engines are usually MSD engines with significantly smaller cylinder displacements (30 to 200 L/cylinder) than SSD, and typically have six to 18 cylinders. These engines are commonly connected to an electric drive propulsion system which is actually a large generator that can be used to generate auxiliary power as well as drive the propulsion systems. They are typically used as propulsion engines on smaller tankers, general cargo, RoRo, ferries, cruise ships, and as auxiliary engines on large ships for power generation or refrigeration. They are generally turbo-charged and aftercooled, have two intake and two exhaust valves per cylinder and are mechanically fuel injected with one injector per cylinder.

The top three four-stroke engine designers of the global fleet on a per-vessel basis are Wartsila which represents over 36 percent of that total, MAN which produced nearly 32 percent, and MAK which captured approximately 29 percent. MAK is owned by Caterpillar which produces medium and high speed engines of up to 16,000 kW for main propulsion, and nearly 7,700 kW for marine generator sets and is headquartered in Hamburg, Germany.[11]

Table 1-3 Number of Engines Built per Year by Manufacturer

YEAR BUILT[A]	WARTSILA[B]	MAN[C]	MAK	OTHER	TOTAL
1990	10	17	9	3	39
1991	14	19	4	1	38
1992	12	21	11	1	45
1993	22	22	11	1	56
1994	22	13	10	1	46
1995	30	19	12	1	62
1996	20	33	13	2	68
1997	34	33	9	2	78
1998	51	35	5	3	94
1999	59	34	6	5	104
2000	55	24	21	3	103
2001	49	12	21	2	84
2002	41	23	28	2	94
2003	31	34	43	2	110
2004	36	12	46	1	95
2005	22	28	44	2	96
2006	24	55	57	3	139
2007	51	60	89	7	207
2008	38	48	51	4	141
Total	621	542	490	46	1699

Notes:
[a] Assumes that the engine was built the same year the vessel was reported as being built.
[b] Wartsila count includes Sulzer engines.
[c] MAN count includes Pielstick engines.

1.2.2 Other Engine Types

Turbine powered vessels accounted for less than two percent of the global fleet, and of those 13 percent are gas turbines, while the remaining 87 percent are steam turbines. The top three turbine engine designers include General Electric (GE), Kawasaki, and Mitsubishi and together account for over 91 percent of installed turbine engines. GE sold gas turbine engines exclusively to the global fleet representing 11 percent of the turbine powered fleet, while both Kawasaki and Mitsubishi only have steam turbine engines in the global fleet, accounting for 40 and 39 percent of the turbine powered fleet respectively. Steam turbines have traditionally been the choice of Liquid Natural Gas carriers primarily because any boil-off gas could be sent through the turbine and burned.

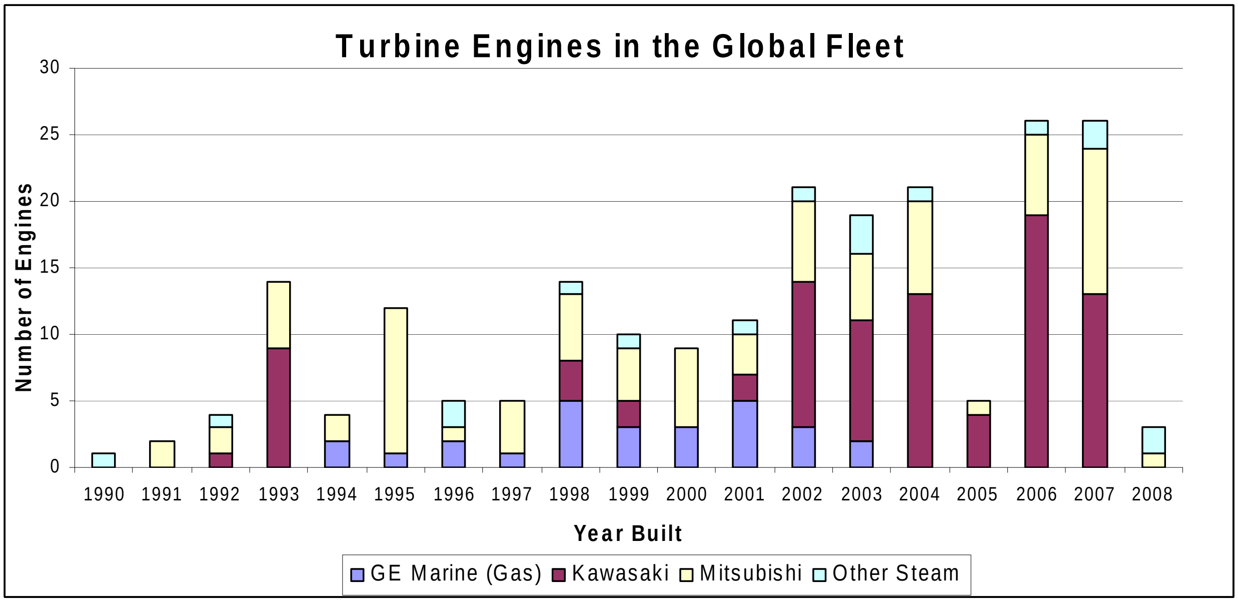


Figure 1-2 Steam and Gas Turbines in the Current Global Fleet

1.2.2.1 Auxiliary Engines

Category 3 engines can also be used for auxiliary engines as well as Category 2. They are used to generate electrical power for navigation equipment, maneuvering equipment, and crew services. The engines used to generate electrical power are typically, however, Category 2 diesel engines. Some vessels, such as refrigerated cargo vessels, may require Category 3 engines to meet electric power requirements. Cruise ships often employ diesel-electric engines that provide both propulsion and power generation. In addition to propulsion and electric power engines, an auxiliary engine is typically installed for emergency use. In 2007, over 10,000 auxiliary engines were ordered, totally 11,600 megawatts.[12,13]

1.2.2.2 Main Engines in the Global Fleet

Category 3 engines are not typically mass-produced. They are built in different configurations with varying numbers of cylinders, engine displacement, power output, and engine speed. Because of the variety of configurations and applications, the selection of the main engine is a major consideration in the overall design of a vessel. As a result, the engine selected for a specific vessel is often a unique design or configuration that is built specifically for that vessel. In many cases, C3 engines designed by these manufacturers are built under license by other companies in Europe and Asia. It can take up to two or three years to receive delivery of components such as crankshafts and engine blocks, Wartsila notes that it is not engine assembly that slows production, but delivery of these larger components from sub-suppliers.[14]

1.3 Marine Vessels

The marine transport industry relies on a variety of vessel types to carry goods and passengers around the world. These vessels are typically categorized by the type of cargo the vessel is designed to transport and by the vessel size, in terms of carrying capacity and hull dimensions. Table 1-3 outlines the vessel categories that constitute the majority of the current OGV world fleet.

Table 1-4 Vessel type, category, and size range for the majority of the OGV world fleet.

Vessel Type	Vessel Size Category	Average Size Range (DWT)
Bulk Carrier	Coastal	1,253 – 9,994 (5,576)
	Handy	10,095 – 39,990 (27,593)
	Handymax	40,009 – 54,881 (47,616)
	Panamax	55,000 – 78,932 (69,691)
	Capesize	80,000 – 364,767 (157,804)
Container	Feeder	1,000-13,966 (9,053)
	Intermediate	14,003-36,937 (24,775)
	Panamax	37,042-54,700 (45,104)
	Post Panamax	55,238-84,900 (67,216)
	Suezmax	85,250-120,892 (101,099)
Liquid Gas Carrier (Liquid Petroleum Gas (LPG) / Liquid Natural Gas (LNG))	Midsize	1,001-34,800 (7,048)
	Large Gas Carrier (LGC)	35,760-59,421 (50,796)
	Very Large Gas Carrier (VLGC)	62,510-122,079 (77,898)
General Cargo	Coastal Small	1,000-9,999 (3,789)
	Coastal Large	10,000-24,912 (15,673)
	Handy	25,082-37,865 (29,869)
	Panamax	41,600-49,370 (44,511)
Cruise / Passenger	All	1,000–19,189 (6,010)
Refrigerated (Reefer)	All	1,000–19,126 (6,561)
Roll-on / Roll-off (Ro-Ro)	All	1,000–19,126 (7,819)
Tanker	Coastal	1,000-23,853 (7,118)
	Handymax	25,000-39,999 (34,422)
	Panamax	40,000-75,992 (52,300)
	AFRAmax	76,000-117,153 (103,112)
	Suezmax	121,109-167,294 (153,445)
	Very Large Crude Carrier (VLCC)	180,377-319,994 (294,475)
	Ultra Large Crude Carrier (ULCC)	320,051-441,893 (364,896)

1.3.1 Vessel Design and Construction

Ship builders typically design their vessels based on the type of freight they intend to haul as the type of cargo transported necessitates specific design characteristics, for example, container vessels require a different structure than a vessel that hauls bulk freight. Six ship builders are responsible for the majority of commercial vessels constructed in the United States, including Bath Iron Works, Electric Boat Company, the National Steel and Shipbuilding Company (NASSCO), Avondale Operations, Ingalls Operations, and Newport News Shipbuilding. There is a much larger number of ship builders outside the United States. Since 2000, U.S. ship builders have produced 20 to 40 vessels per year, while foreign ship builders have produced 60 to 120 vessels per year.[15]

Vessel design is an iterative process that typically includes three stages: concept design, preliminary design, and contract design. The concept design stage considers the vessel's general objectives, adjusting key vessel parameters and specifications based on the owner's stated technical and economic criteria. The preliminary design stage further refines the concept design by analyzing expected performance and profitability of various alternatives for key design elements (e.g., proportions, lines, hydrostatics, layout, power). Upon completion, the preliminary design yields the final vessel attributes, including dimensions, displacement, stability, propulsive performance, and structural details.[12]

1.3.2 Vessel Building Classification Societies

Ships must be built in accordance with shipbuilding standards in the country where they are flagged or in accordance with standards imposed by the International Association of Classification Societies (IACS). The classification societies implement many of the national or international requirements that apply to marine vessels, including the various requirements under MARPOL Annex VI. Classification societies include, among others, American Bureau of Shipping, Det Norske Veritas, and Germanischer Lloyd. In the United States, the U.S. Coast Guard works closely with the American Bureau of Shipping to implement and enforce applicable requirements. It is important to note that EPA implements and enforces requirements related to exhaust emission standards cooperatively with the U.S. Coast Guard, but without the involvement of classification societies.

The global shipping industry comprises a large number of diverse firms. Vessel owners and operators provide marine transportation services in support of international trade and commodity flows over water. Every ship in the world's shipping fleet is designated by the flag of registry. The flag of registry is a useful way of characterizing the shipping industry. However, in many cases, the flag of registry has no correlation with the location of the parent company that owns/operates a vessel. This confusion results partly because "open registries" allow owners/operators to register ships in countries outside of their country of domicile (owner/operator country). The five countries with the most flagged ships in the "Global Fleet" in order are Singapore, the Marshall Islands, China, Liberia, and Panama. Table 1-5 presents these values, and shows the ships under the U.S. flag as well.

The U.S. fleet of privately owned ocean-going vessels primarily includes bulk carriers, containerships, gas carriers, general cargo vessels, passenger vessels, refrigerated container vessels, roll-on/roll-off vessels, and tankers. Containerships comprise the largest number of vessels in the U.S. commercial fleet with a total of approximately 75 ships (~45% of the total), while there are around 50 tankers (~33%). The average age of U.S.-flagged commercial ocean-going vessel is approximately 20 years.

Table 1-5 Ship Type by Country of Flag

SHIP TYPE	SINGAPORE	MARSHALL ISLANDS	CHINA[a]	LIBERIA	PANAMA	UNITED STATES OF AMERICA
Auto Carrier	22	1	2	6	173	16
Bulk Cargo	161	253	608	284	1337	11
Container	236	164	234	676	577	37
Misc	4	4	12	3	6	7
Passenger	0	0	9	0	32	2
Reefer	1	3	0	67	64	0
RoRo	0	1	2	0	11	14
Tanker	279	313	213	500	528	32
Grand Total	703	739	1080	1536	2728	119

Note:

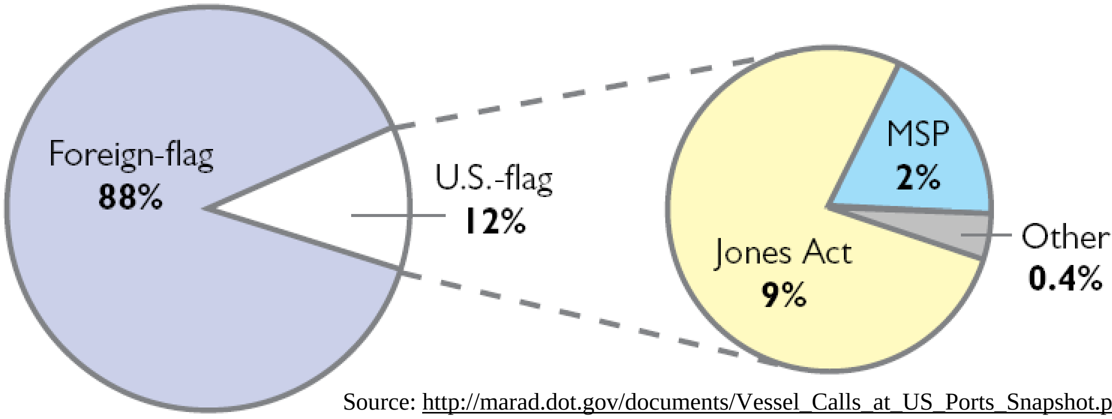
[a] This includes the People's Republic of China, Republic of (Taiwan), and Hong Kong.

Section 27 of the Merchant Marine Act of 1920, more commonly known as the Jones Act, was enacted with the goal of maintaining a domestic merchant fleet of U.S.-owned and U.S.-crewed vessels that is sufficient to carry the majority of U.S. waterborne commerce and also to assist the military in times of war. The Jones Act fleet is a subset of the total U.S. fleet and accounts for 52% of U.S.-flagged ships. The Maritime Administration (MARAD) is the U.S. Department of Transportation agency responsible for monitoring and maintaining the domestic merchant fleet, including the Jones Act fleet.

1.4 The Marine Transportation Sector

Over 95 percent of foreign trade was moved by ship in 2006.[16] Fifty ports in the U.S. handle approximately 84 percent of all waterborne domestic and international cargo; ten ports handle 85 percent of all containerized cargo and have seen a 54 percent increase in container movements between 2001 and 2006.[10] The U.S. ranks second in container traffic after China; one in nine containers is either bound for or originated from the U.S.[17] It is expected that this trade will continue to grow.

In 2007, the number of vessels calling on U.S. ports increased nearly 13 percent when looking over the past five years; of these calls 34 percent were tankers, 31 percent containerships, 17 percent dry-bulk vessels, 10 percent roll-on roll-off, and 6 percent by general cargo ships.[18] The size of vessels visiting U.S. ports has also increased, and in 2007, 54 percent of the calls to U.S. ports were by vessels less than 10 years old, up 47 percent over the previous five years.[12] Figure 1-3 shows the vessel calls by flag to U.S. Ports in 2007.[15]



Source: http://marad.dot.gov/documents/Vessel_Calls_at_US_Ports_Snapshot.pdf

Figure 1-3 2007 Vessel Calls by Flag to U.S. Ports

1.5 Marine Fuels

All marine fuel used today is created from the same basic distillation process that creates other liquid hydrocarbons such as motor gasoline, heating oil and kerosene. Distillate marine fuels are comparable to other forms of distillate hydrocarbon liquids, such as nonroad diesel fuel or No. 2 fuel oil, in that they have similar chemical properties and specification limits. Residual marine fuels, also called Intermediate Fuel Oils (IFO) or Heavy Fuel Oils (HFO), are composed of heavy, residuum hydrocarbons which are created as a by-product during petroleum refining, and can contain various contaminants such as heavy metals, water, and high sulfur levels. These contaminants can harm engines and fuel distribution lines and equipment, therefore residual fuel is typically treated and 'cleaned' of a large amount of these contaminants prior to combustion in the marine engine.

Both residual and distillate marine fuels are required to meet international fuel specifications established in the International Organization for Standardization (ISO) specification 8217 Petroleum products—Fuels (class F)—Specifications of Marine Fuels.[19] Each category of fuel is discussed below.

Marine distillate fuel is divided into four distinct fuel types: DMX, DMA, DMB, and DMC; however, only two of these fuels are commonly used in the marine transportation industry. DMX is a very low sulfur middle distillate hydrocarbon, and is therefore rather expensive when compared to other distillate fuels. This distillate type is mainly used onboard marine vessels for emergencies. The next two types of distillate fuel, DMA & DMB, are also called Marine Gas Oil (MGO) and Marine Diesel Oil (MDO) respectively. These two distillate fuels comprise the majority of marine distillate fuels sold. Lastly, DMC, is a higher sulfur fuel and is normally created by contaminating DMB fuel.

Marine residual fuel is created through traditional petroleum refining as a 'waste' product of the refining process. Typically, this fuel is rather dense and viscous, and it tends to contain heavy metals and other contaminants normally contained within crude oil. Residual fuel oil is categorized by the viscosity of the fuel at a set reference temperature and there are several categories of this fuel type; however, the most commonly used fuel in the marine transportation industry is Intermediate Fuel Oil (IFO) 180 and 380.

1.5.1 Marine Gas Oil (MGO)

MGO is a light distillate product that is clear and bright, typically amber in color, and can be manufactured by blending light cycle oil (LCO) with other light distillate oils. MGO is a relatively light and clean gas oil, compared to other marine fuels. MGO also has a relatively high cetane value and density, making it a fuel that is best suited for higher rpm engines. Typically, MGO is used for propulsion in small- to medium-sized marine vessels and for emergency, maintenance, and auxiliary engines in larger vessels.[20]

1.5.2 Marine Diesel Oil (MDO)

MDO is a distillate fuel that is a slightly heavier (i.e., higher density) gas oil and has a lower cetane value than MGO. MDO is designated as distillate marine fuel grade B (DMB) under ISO standards. Typically, MDO is created when MGO is blended with small amounts of residual fuel oil, which raises the sulfur content of the fuel beyond the maximum allowable level for MGO.

1.5.3 Intermediate Fuel Oil (IFO)

Typically, residual fuel oil is not usable as a stand-alone fuel because of purchasers' need for specific performance characteristics, primarily viscosity. Thus, residual fuel oil normally requires blending with lighter components to meet specifications for use in marine engines. Blending with lighter components typically lowers the viscosity of the residual fuel oil to produce IFO. IFO is the industry colloquial name for the most common fuel blends. These fuels are categorized by their kinematic viscosity at a set reference temperature. IFO-180 and IFO-380 are the most common fuel grades used in OGV, and these fuels are designated as residual marine fuel grades RME/F-180 and RMG/H-380 by ISO standard 8217. Additionally, since these fuels have such a high viscosity, they are normally in a 'solid' state at ambient temperatures and require constant heating in order to effectively pump and combust it in diesel engines.[5]

1.5.4 Marine Fuel Supply & Procurement

The actual volume of marine fuels supplied worldwide is the subject of great debate inside the maritime community. This is because the majority of marine fuel consumed is composed from residual waste, and other industries (such as power plants, asphalting, and roofing) use this waste as well. The current estimation is that the world consumes approximately 350 million metric tonnes of marine fuel per year (350 mmt/yr), with about eighty percent (80%), or 280 mmt/yr, being residual grade fuel.[21]

Marine fuels are purchased and delivered slightly differently than other fuels (like motor gasoline or highway diesel). Marine fuels have "brokers" to purchase fuel and arrange delivery. These broker companies typically never have custody of or title to the bunker fuel, but they represent ship operators in the solicitation and negotiation of marine fuel purchases, and they may help coordinate fuel delivery for the operators they represent. Fuel delivery can be achieved through several ways; the most widely used method both in the United States and internationally is delivery by barge. Delivery by barge allows for bunkering of vessels at port berths or at anchorage within the port boundaries

1.5.5 Fuel Monitoring and Testing

In order to ensure that the fuel delivered is actually the fuel purchased, at least four marine fuel samples are taken at the time of delivery. One sample is for the vessel (Chief Engineer), one is for the bunker supplier, one is sent to an independent laboratory for testing (e.g., DNV Petroleum Services), and one is for the International Maritime Organization (as required by MARPOL Annex VI). Additionally, there are two other documents that provide information on the quality of the fuel delivered to the vessel: the material safety data sheet (MSDS) and the bill of sale or invoice.

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