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The Impacts of Globalisation on International Maritime Transport Activity

Past trends and future perspectives

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FOREWORD

This paper was prepared by James J. Corbett and James Winebrake, Energy and Environmental Research Associates, the United States, as a contribution to the OECD/ITF *Global Forum on Transport and Environment in a Globalising World* that will be held 10-12 November 2008 in Guadalajara, Mexico. It discusses the impacts of globalisation on international maritime transport activity – past trends and future perspectives.

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"It has been said that arguing against globalization is like arguing against the laws of gravity."
Kofi Annan

1. Introduction

1. Shipping has been an important human activity throughout history, particularly where prosperity depended primarily on international and interregional trade. In fact, transportation has been called one of the four cornerstones of globalization, along with communications, international standardization, and trade liberalization [*Kumar and Hoffmann*, 2002]. Due to a number of technological, economic, and socio-cultural forces, only the rare country can keep itself fully isolated from the economic activities of other countries. Indeed, many countries have seen astonishing economic growth in the recent past due to their willingness to open their borders and markets to foreign investment and trade. This increased flow of knowledge, resources, goods, and services among our world's nations is called "globalization", formally defined as "the development of an increasingly integrated global economy marked especially by free trade, free flow of capital, and the tapping of cheaper foreign labor markets." (Merriam-Webster, www.merriam-webster.com/dictionary/globalization, accessed 2008).

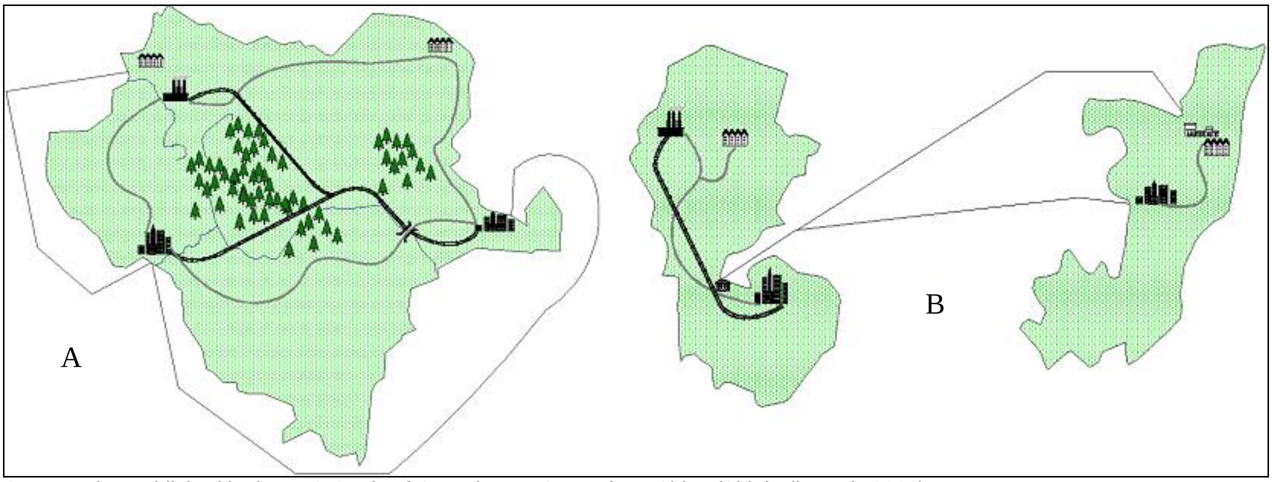
2. Globalization trends are heralded or disclaimed, respectively, as beneficial or detrimental to global stability, the environment, peace, and sustainable development. While judgment of these claims is beyond this chapter's scope, this chapter discusses *maritime transportation*, an enabler of globalization. We demonstrate that transportation (in general) and shipping (in particular) have been and remain key ingredients in fostering globalization. In fact, the maritime industry has transformed its technologies, national registries, and labor resources over the past decades to serve the demands of globalization.

3. In this chapter, we will first discuss the symbiotic relationship between globalization and maritime shipping, whereby globalization has increased the demands for maritime shipping, while maritime shipping (as an integrated component in a larger goods movement system) has more fully enabled globalization. Next, we will discuss the energy use and environmental consequences that maritime shipping has had on global, regional, and local ecosystems. Finally, we will present some ideas on how maritime shipping may proceed to contribute to globalized markets in a manner that limits adverse environmental impacts. We expect that over the coming decades, the maritime industry is likely to transform again in response to a globalized understanding of environmental and energy issues.

2. Maritime Shipping and Goods Movement

4. Global goods movement is a critical element in the global freight transportation system that includes ocean and coastal routes, inland waterways, railways, roads, and air freight. In some cases, the freight transportation network connects locations by multiple modal routes, functioning as modal substitutes (see Figure 1a). A primary example is containerized shortsea shipping, where the shipper or logistics provider has some degree of choice how to move freight between locations. However, international maritime transportation is more commonly a complement to other modes of transportation (see Figure 1b). This is particularly true for intercontinental containerized cargoes and for liquid and dry bulk cargoes, such as oil and grain. Here, international shipping connects roads, railways, and inland waterways through ocean and coastal routes.

Figure 1. Ocean shipping as (A) a substitute and (B) as a complement for other freight modes

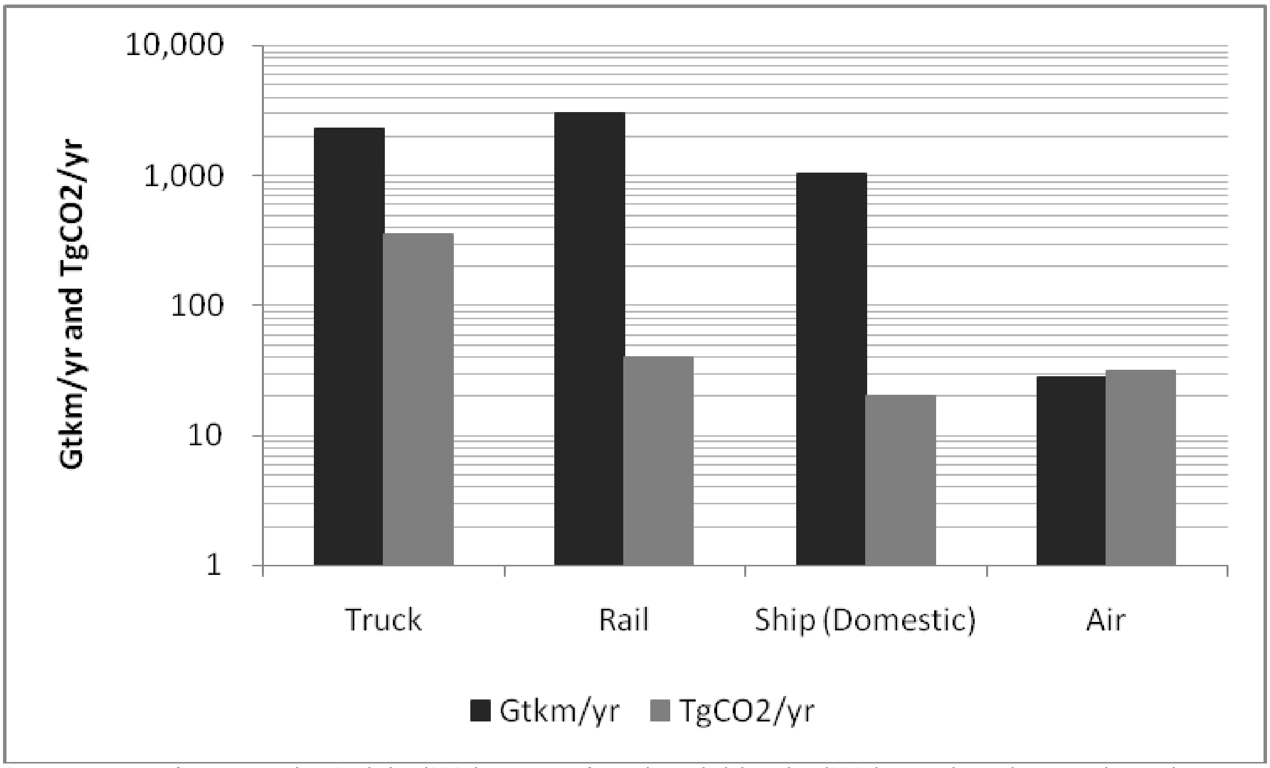


Source: First published in the IMO Study of Greenhouse Gases from Ships (Skjølsvik *et al*., 2000).

5. Mode choice (especially for containerized cargo movement) involves balancing tradeoffs to facilitate trade among global corporations and nations. In the current global economy, competing factors have been time, cost, and reliability of delivery. Low cost modes may be less preferred than faster modes if the cargo is very time sensitive; however, slower, lower cost modes often carry much more cargo and, with proper planning, these modes can reliably deliver larger quantities to meet just-in-time inventory needs. Analogous to a relay race, all modes are needed to deliver containerized cargo from the starting line to the finish line.

6. Mode share in freight transportation can be measured in several ways, but a common metric is in terms of the work done in cargo tonne-kilometers (tkm). The European Union and the United States have similar mode shares for trucking, about 40-45% of total freight transport work [*Environmental Protection Agency*, 2005a; *European Commission et al.*, 2006b]. However, it is important to note that European waterborne freight (inland river and shortsea combined) is second in mode share, moving about 40%-44% of the cargo tkm in recent years [*European Commission et al.*, 2006a; *European Commission et al.*, 2006b]; in the United States, rail freight tkm is slightly greater than road freight. Moreover, these statistics ignore seaborne trade which accounts for ~40,000 giga-tkm (one Gtkm = 10^9 tkm) of cargo movement among all trading nations from distances outside the domains from which national statistics are reported. Figure 2 summarizes mode share comparisons in the US for 2005.

Figure 2. Comparison of demand and carbon emissions by freight mode share for the US, 2005.



Source : Bureau of Transportation Statistics (2007); Energy Information Administration (2007). Note that units are on log scale.

3. The Global Economic Role of Maritime Shipping

7. Marine transportation is an integral, if sometimes less publicly visible, part of the global economy. The marine transportation system is a network of specialized vessels, the ports they visit, and transportation infrastructure from factories to terminals to distribution centers to markets. Maritime transportation is a necessary complement to and occasional substitute for other modes of freight transportation. For many commodities and trade routes, there is no direct substitute for waterborne commerce. (Air transportation has replaced most ocean liner passenger transportation and transports significant cargo value, but carries only a small volume fraction of the highest value and lightest cargoes; while a significant mode in trade value, aircraft move much less global freight by volume, and at significant energy per unit shipped.) On other routes, such as some coastwise or shortsea shipping or within inland river systems, marine transportation may provide a substitute for roads and rail, depending upon cost, time, and infrastructure constraints. Other important marine transportation activities include passenger transportation (ferries and cruise ships), national defense (Naval vessels), fishing and resource extraction, and navigational service (vessel-assist tugs, harbor maintenance vessels, etc.).

8. Globalization is motivated by the recognition that resources and goods are not always collocated with the populations that desire them, and so global transportation services are needed (and economically justified if consumer demand is great enough). For example, until the 1950s, most crude oil was refined at the source and transported to markets in a number of small tankers [sized between 12,000 and 30,000 deadweight tonnage (dwt)]. However, economies of scale soon dictated that oil companies would be better off if they shipped larger amounts of crude from distant locations to refineries located closer to product markets. Product could then be more efficiently distributed to points of consumption using a host of

transportation modes. This realization ultimately led to the emergence of large tanker vessels (*e.g.*, greater than 200,000 deadweight tons) and drove down the per-unit cost of intercontinental energy transportation.

9. Similarly, rather than palletize grains, minerals, and other commodities, dry bulk cargo ships were designed to deliver cargoes in raw or semi-raw condition from where they were found or grown to processing facilities (*e.g.*, mills and bakeries) closer to final market. Along with containerization and advances in cargo handling and shipboard technology, these measures reduced crew sizes and longshore labor requirements which also reduced the per-unit cost of ocean cargo transport.

10. Lastly, globalization identified labor markets overseas that encouraged transport of semi-raw materials and intermediate products where manufacturing costs were lower. With low-cost petroleum energy for vessel propulsion, facilitated by vessel economies of scale, the per-unit costs of semi-finished and retail products were minimized by multi-continent supply chains. Today it is common for agri-products to be harvested on one continent, shipped to another for intermediate processing, transported to a third continent for final assembly, and then delivered to market. For example, cotton grown in North America may be sent to African fabric mills, and then to Asian apparel factories before being returned to North America for sale in retail stores. Orange juice, wine, and other products have also found markets on continents where seasonal or climatic limitations require an offshore source, or entered into competition with domestic production at higher labour costs.

11. Another trend associated with globalization is the pace at which trade occurs. Globalization has encouraged transactions of goods and services in smaller packets delivered "just-in-time". This has increased the "velocity of freight" which justified in the 1970s faster, small containerized vessels, and over the last two decades justified faster, large containerized vessels. In a globalized economy, containerization offers the advantage of integrated freight transportation across all modes. Analogous to the more uniform transport of liquid crude oil or unprocessed grains, containerization standardized the shipping package, reducing the per-unit cost of transporting most finished goods.

12. Data showing the effect of globalization on unitized cargoes is shown in Figure 3, where increased container shipping represents significant increase in global transport of finished and semi-finished products from regions with inexpensive skilled labor to consumer markets. The fact that containerized cargo has outpaced other bulk cargo is a testament to the impacts of globalized trade involving consumer products and international labor (as opposed to just raw materials).

13. The relationship among maritime shipping, economic growth, and trade is depicted in Figure 4. This figure shows trends over the past 16 years for OECD countries in terms of gross domestic product (GDP, measured in year 2000 US$), trade (measured as exports plus imports in year 2000 US$), and fuel sold for international maritime transport (measured in thousands of tonnes). Figure 5 shows the relationship between trade and GDP for OECD countries as measured in year-to-year percent growth between 1992 and 2006. The figure and accompanying linear regression equation indicates that for every percentage increase in GDP for OECD, there has historically been ~4% rise in trade. Similar data are shown for the US in Figure 6 (a) and (b). These figures show scatter plots relating US GDP and freight movement (measured in terms of ton-miles and container traffic in twenty foot equivalent units, or TEUs).

Figure 3. The effect of globalization on unitized cargoes

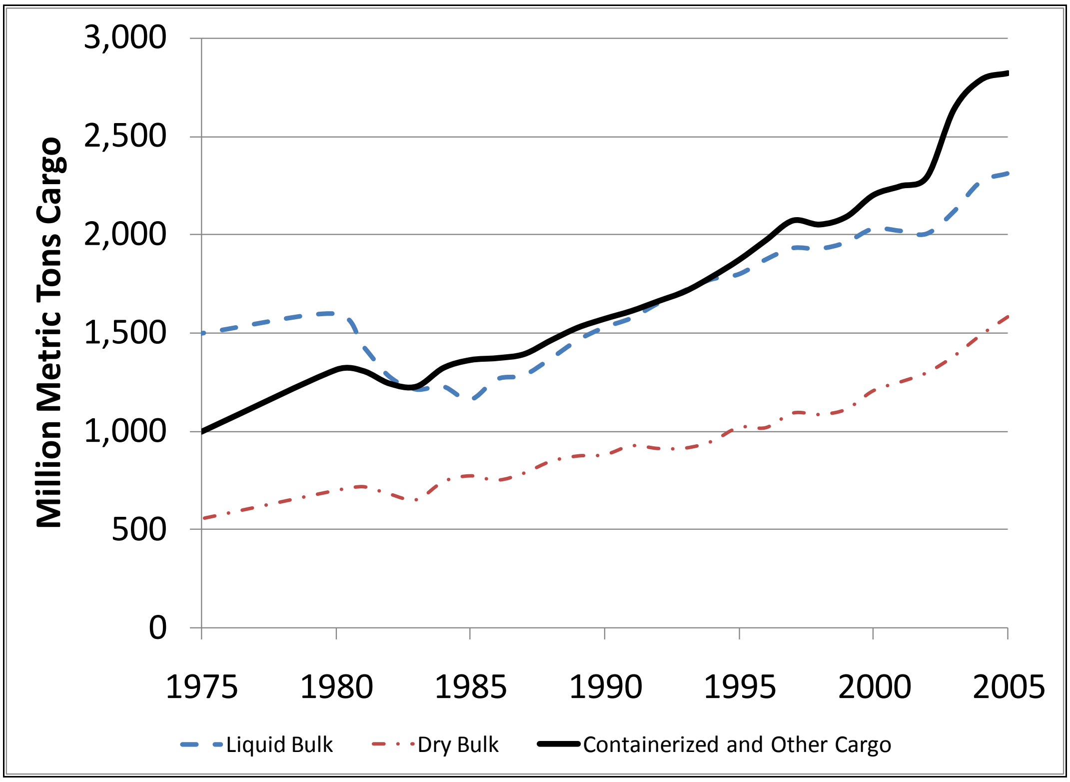


Figure 4. Trends in OECD GDP, exports and imports, and international bunker fuel supply, 1992 – 2006

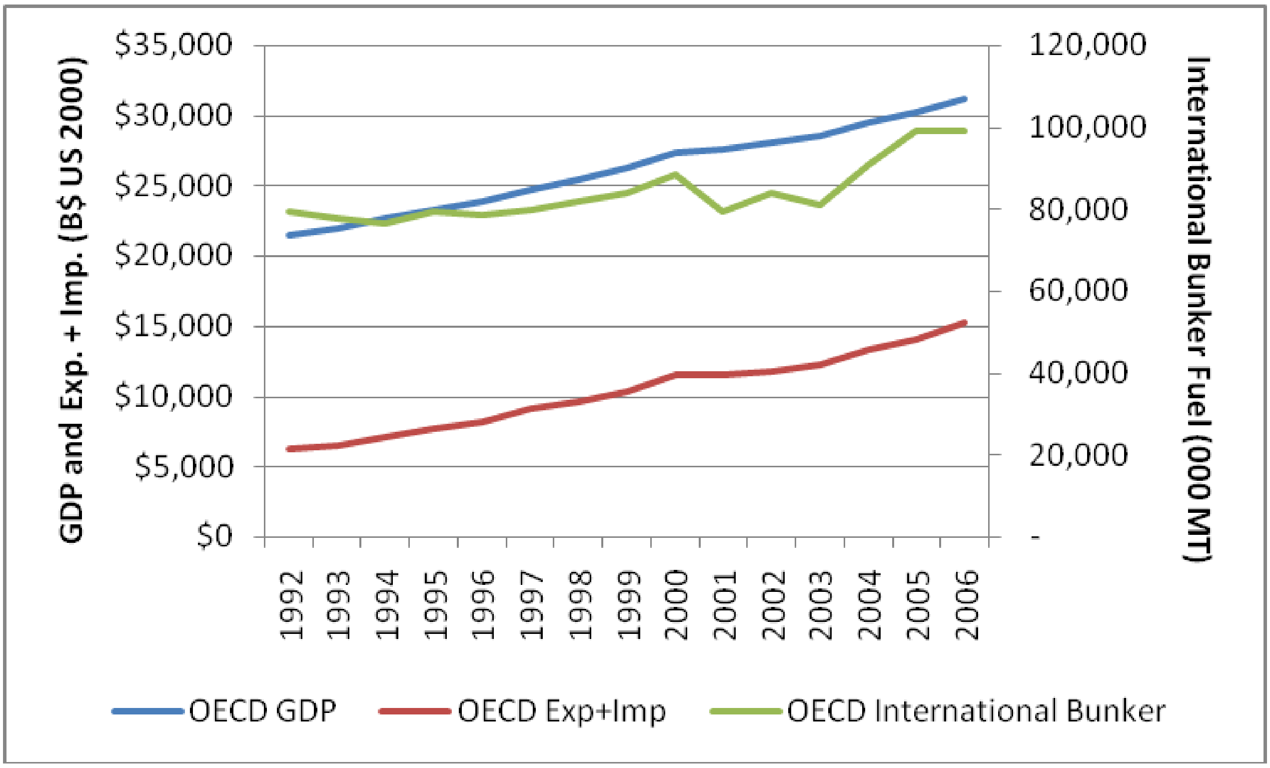


Figure 5. Relationship between OECD economic growth and growth in exports and imports, 1992 – 2006

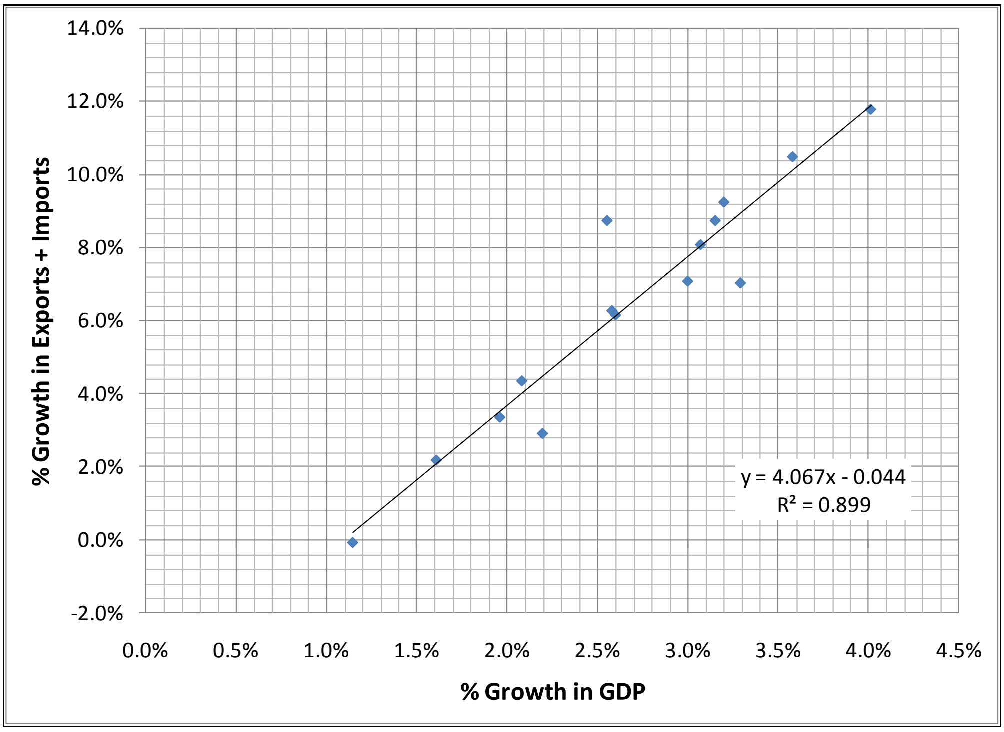
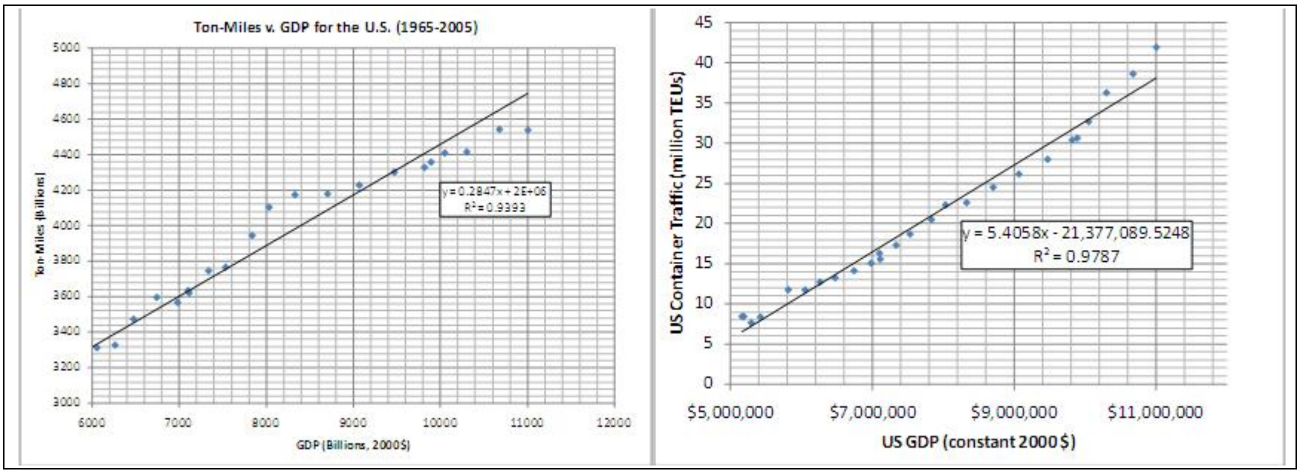


Figure 6. Relationship between cargo shipments and container traffic (TEUs) and GDP as measured in ton-miles for the U.S., 1965 – 2006



4. Maritime Transformations Responding to Globalization

14. Aside from the shift of human labor (oars) to wind-driven sail, the first modern energy conversion in marine transportation was the shift from sail to combustion. Two primary motivators for energy technology innovation – greater performance at lower cost – caused this conversion. Figure 7 and Figure 8 illustrate how this shift was completed during the first half of the 20th Century, using data from Lloyds Register Merchant Shipping Return for various years. Essentially, newer and larger ships adopted combustion technologies as part of an economy of scale. These technologies enabled trade routes to emerge regardless of the latitudes without consistent winds (referred to as the doldrums), supporting both international industrialization and modern political superpower expansion. As shown in these figures, the conversion of fleet tonnage to the preferred technology was achieved much more rapidly than the phase out

of smaller ships using the outdated technology; this lead in conversion by tonnage was because the new technology was installed on the larger and newer vessels. Initially, these ships were powered by coal-fired boilers that provided steam first to reciprocating steam engines and later to high-speed steam turbines that drove the propeller(s). Later, the introduction of the industry's first alternative fuel – petroleum oil – enabled the introduction of modern marine engines. This pattern is repeated in many technology changes for marine transportation: some ship operators continue to use long-lived vessels purchased on the second-hand market while industry leaders replace their fleets to achieve new markets or realize economies of scale.

15. The switch from coal to oil was motivated by a desire to reduce costs and improve vessel performance. According to British Admiral Fisher's remarks to Winston Churchill in 1911 (quoted in Yergin's 1991 book, *The Prize*, page 155), a cargo steamer could "*save 78 percent in fuel and gain 30 percent in cargo space by the adoption of the internal combustion propulsion and practically get rid of stokers and engineers.*" Essentially, the commercial sector (and soon followed by the military) converted to oil-fired boilers and oil-fueled internal-combustion, compression-ignition engines in order to save money and achieve performance advantages.

16. Globalization motivations to reduce the per-unit cost of shipping were the primary purpose for this conversion to "alternative fuel" in the early 1900s, rather than energy conservation or even fuel cost savings. Oil-powered commercial ships required fewer crew and enjoyed a greater range of operations between fueling. This was not only of commercial interest; military vessels appreciated these advantages and the fact that refueling at sea could be accomplished more quickly and easily. Oil powered ships also accelerated more quickly than coal-powered systems, and could achieve higher speeds. Given these strong incentives, international shipping switched virtually the entire fleet from coal to oil over five decades.

17. Figure 7and Figure 8 also illustrate the conversion from steam to motor power. In 1948 steam ships accounted for 68% of the ships in the fleet and 79% of the fleet tonnage, while motor ships accounted for 29% of ships and only 20% of the tonnage; sail still powered 4% of vessels but only 1% of registered ship tonnage. By 1959, motor ships accounted for 52% of vessels and 39% of registered tonnage in the fleet, and in 1963 motor ships represented 69% of vessels and 49% of registered tonnage. By 1970, motor ships dominated the fleet both in terms of ships and cargo tonnage, with 85% and 64%, respectively.

Figure 7. Gross maritime shipping tonnage by vessel technology, 1900 – 2000

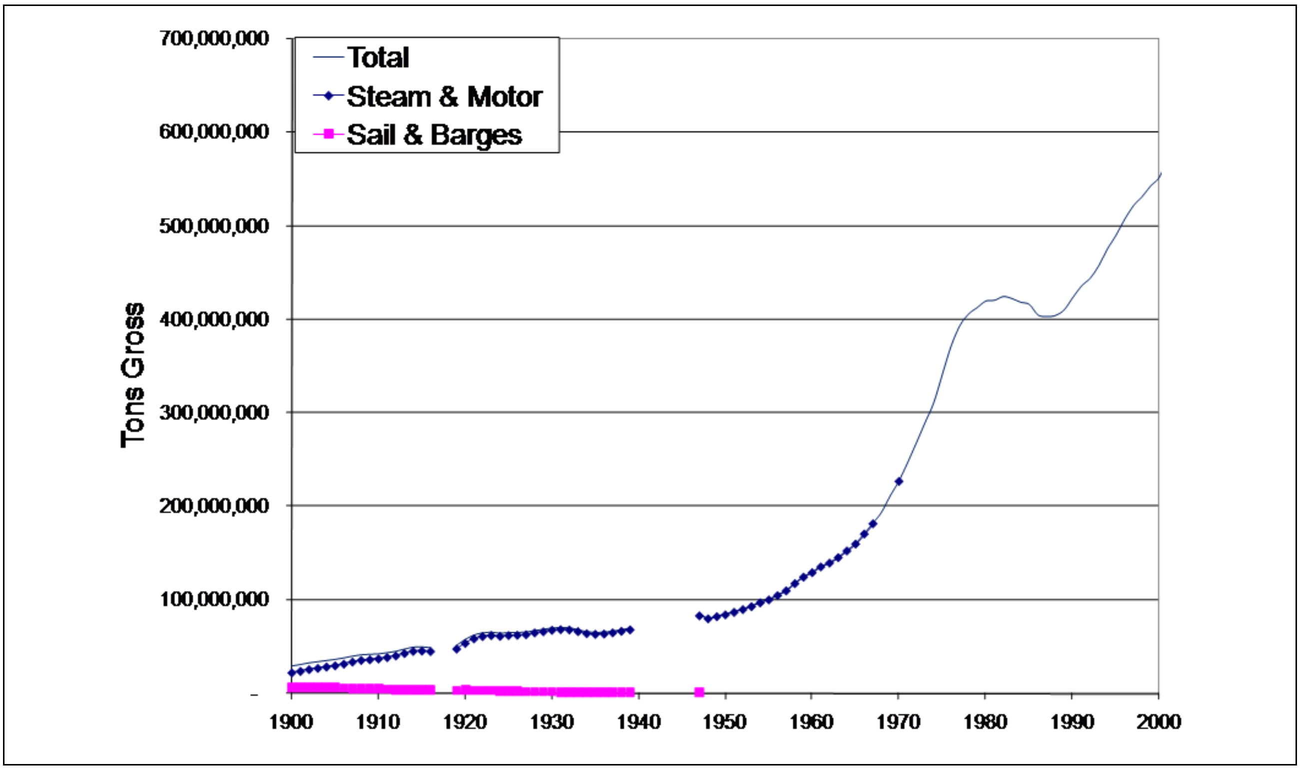
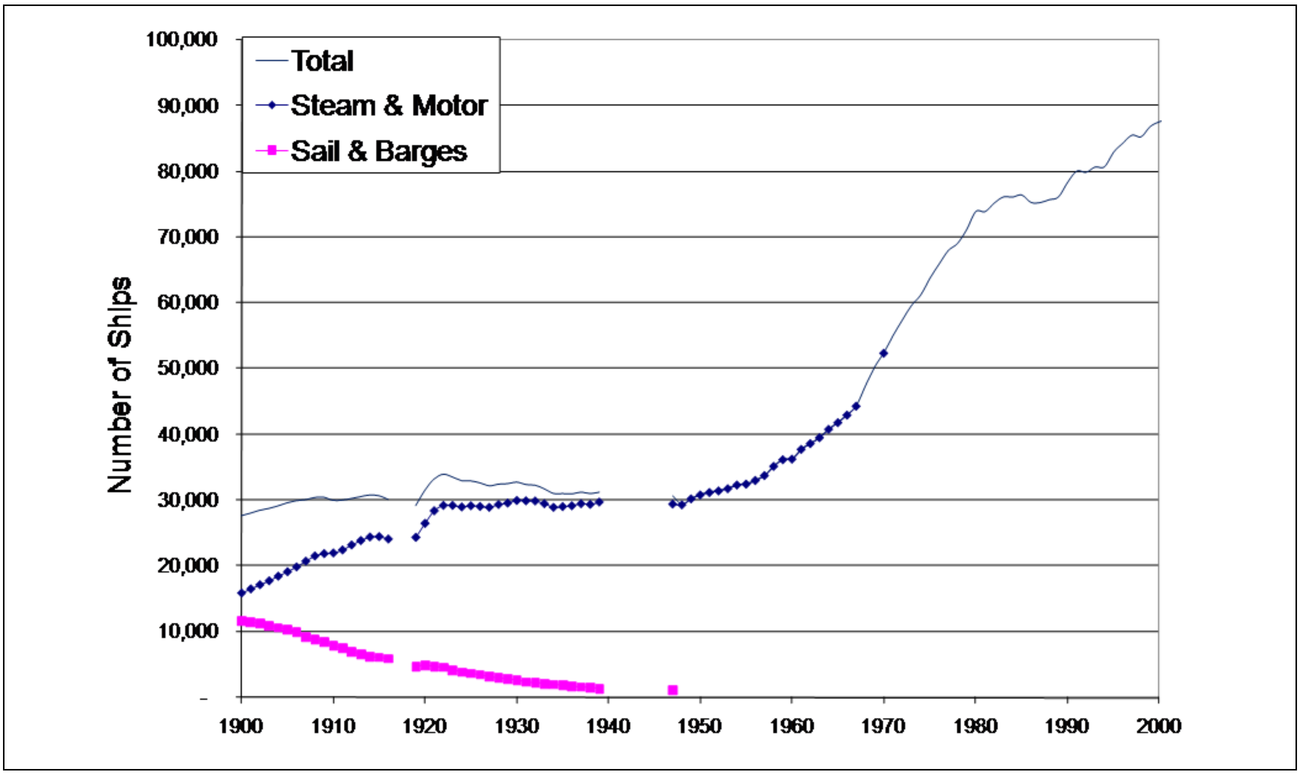
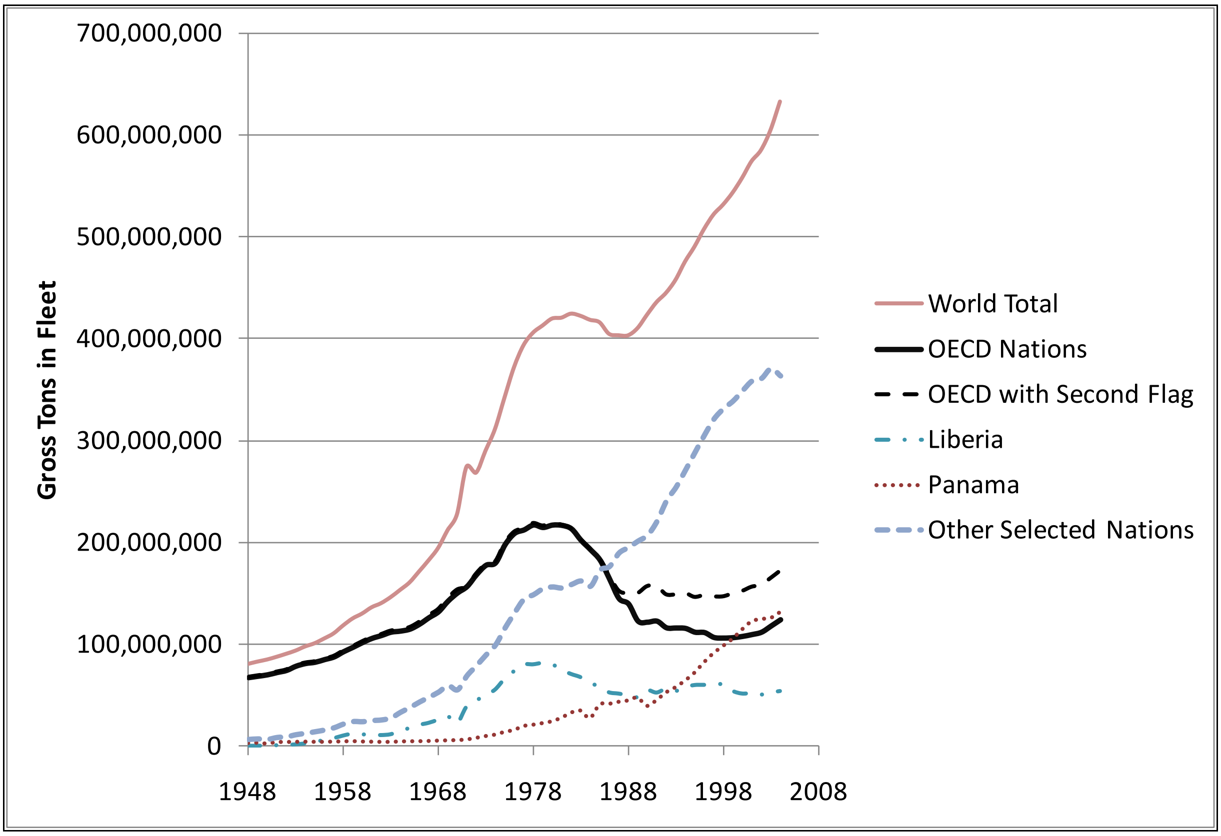


Figure 8. Number of ships by vessel technology, 1900 – 2000



18. After the fuel conversion was implemented, the next big shift was to more fuel-efficient marine diesel engines through gains in thermal efficiency in converting energy potential of the fuel into mechanical work. Engine efficiencies increased from 35% to 40% in 1975 to more than 50% percent today [*Corbett*, 2004]. This and other technological advancements allowed maritime shipping to meet the transportation demands driven by a growing globalized economy. Figure 9 shows the increases in gross tonnage in the worldwide fleet since 1948 by vessel flag. Globally, gross tonnage has increased rapidly, even though vessel flags have largely transitioned from OECD nations to others.

Figure 9. Gross tonnage by vessel flag, 1948 – 2006

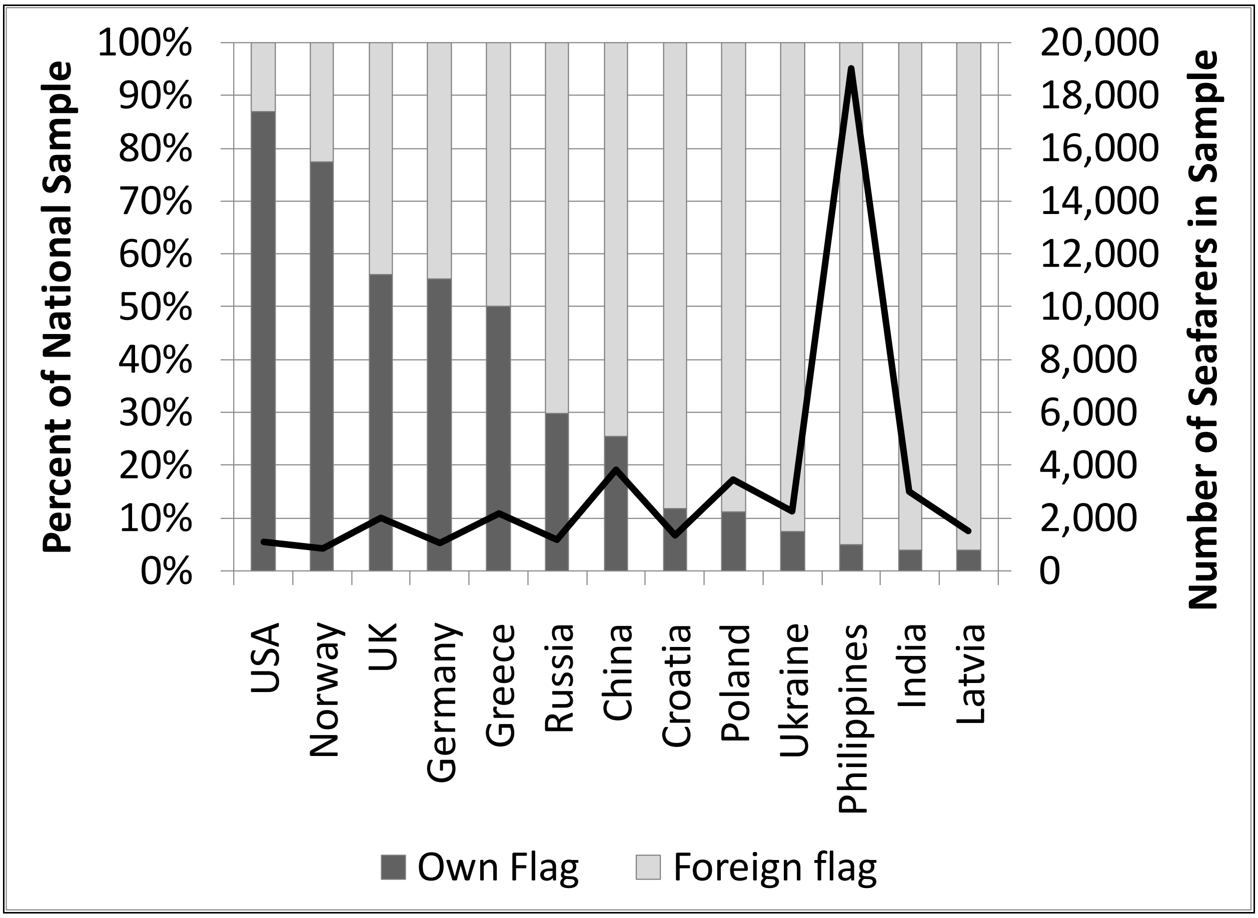


19. The shift to registering ships internationally was preceded by and continues to be associated with a shift to more international seafaring labor – although it must be noted that seafaring has long been an international industry. This has resulted in multinational crews (*e.g.*, officers largely from one group of nations and unlicensed crew from overlapping or different nationalities). With very explicit international qualification standards, crew training, and port state authority to inspect ships, most modern ships are operated by talented international labor. Except where flag registry includes citizenship requirements, like in the United States, qualified seafarers are largely hired according to economic rather than residency criteria. A recent global labor market study obtained a sample of international seafarers by nationality and flag of service [*Obando-Rojas*, 2001]. As shown in Figure 10, most seafarers work on vessels that are registered in nations other than their nationality.

20. Maintaining a professionally skilled and motivated labor force of seafarers across ranks and nationalities remains an issue of international importance. Maritime transport involves labor that resides at their place of work, where between 10 and 35 crew per ship operate the largest moving vehicles ever

constructed 24 hours per day for most of the year. The working conditions routinely involve motion, noise, vibration, and highly technical tasks that are associated with long working hours, varying shift patterns – all elements contributing to workplace fatigue that increases risk of human error during operations that can lead to environmental incidents and catastrophes. Although full discussion is beyond the scope of this chapter, these issues are part of the globalization of maritime transport and on the environmental performance of shipping.

Figure 10. Flags of employment for selected nationalities



5. Energy and Environmental Impacts of Maritime Shipping

21. The expansion of goods movement to meet the needs of a globalized world does not come free. In particular, there are a number of energy and environmental impacts associated with the movement of goods. For example, the energy use and emissions associated with transporting freight can be significant [*Energy Information Administration*, 1998; *Organisation for Economic Co-Operation and Development (OECD) and Hecht*, 1997; *Skjølsvik et al.*, 2000]. According to the U.S. EPA, heavy duty truck, rail, and water transport together account for more than 25% of U.S. CO_2 emissions, about 50% of NOx emissions, and nearly 40% of PM emissions from all mobile sources [*Environmental Protection Agency*, 2005a; b]. In Europe, these modes generate more than 30% of the transportation sector's CO_2 emissions [*Bates et al.*, 2001].

22. That said, shipping is not only among the least costly modes of transportation, but also the most energy efficient (with some exceptions generally proportional with high vessel speed and low service

capacity). Because fuel costs can represent between 20% and 60% of shipping costs, operators have strong economic motivation to operate ships efficiently and to employ propulsion technologies that reduce fuel consumption per cargo ton-km. For example, the use of high-temperature, high-pressure (HTHP) engines that can combust low-cost residual fuels (a byproduct of petroleum refining) stems directly from the desire to reduce fuel expenditures.

23. Nevertheless, a consequence of marine engine technologies is increased air pollution. These HTHP engines oxidize nitrogen effectively (thereby increasing NOx emissions), and emit many of the impurities of residual fuel (including sulfur, toxics, and heavy metals) out the ship stack. Among freight modes, waterborne transportation has been shown to cause significant air pollution locally in port communities, add to long-range pollution transport in coastal regions of heavy trade, and contribute to climate change on a global scale [*Capaldo et al.*, 1999; *Corbett and Fischbeck*, 1997; *Corbett et al.*, 1999; *Corbett and Koehler*, 2003; 2004; *Endresen et al.*, 2003; *Kasibhatla et al.*, 2000; *Lawrence and Crutzen*, 1999; *Skjølsvik et al.*, 2000]. Oceangoing shipping is also the least regulated freight mode, at least for air pollution. These issues are discussed in more detail in the following sections.

5.1 Energy and power trends in maritime freight transportation

24. The global fleet of oceangoing vessels numbers over 108,000; of these, ~46,000 are used to move cargo. These ships are responsible for 2-4% of the world's annual fossil fuel consumption [*Corbett*, 2004]. A profile of the internationally registered fleet of ships greater than 100 gross tons is shown in To reduce operating expenses, marine engines have been designed to burn the least costly of petroleum products. Residual fuels are preferred if ship engines can accommodate its poorer quality, unless there are other reasons (such as environmental compliance) to use more expensive fuels. Of the two-stroke, low-speed engines, 95% use HFO and 5% are powered by MDO [*Corbett and Koehler*, 2003]. Fuel consumed by 70% of the four-stroke, medium-speed engines is HFO, with the remainder burning either MDO or MGO. Four-stroke, high-speed engines all operate on MDO or MGO. The remaining engine types are small, high-speed diesel engines all operating on MDO or MGO, steam turbines powered by boilers fueled by HFO, or gas turbines powered by MGO.

25. The nations selling the most fuel to commercial ships are typically nations with strong interests in the cargoes or services those ships provide. Organization of Economic Cooperation and Development (OECD) nations account for roughly half of these fuel sales and provide one illustration of historical consumption trends in the overall fleet [*Energy Information Administration*, 2001; *International Energy Agency*, 1977-1997]. Table 2 summarizes fuel quantities sold by the top nations selling international marine fuels [*International Energy Agency and Organisation for Economic Cooperation and Development*, 2007a; b]. The US currently provides ~15% of the world's marine fuels, similar to the volume sold by Singapore.

26. Transport vessels account for almost 60% of the ships and nearly 80% of the energy demand of the internationally registered fleet (not including military ships). Considered along with military ships, cargo ships account for 40% of the world fleet of vessels and 66% of world fleet fuel use. The registered fleet has approximately 84,000 four-stroke engines with total installed power of 109,000MW and some 27,000 two-stroke engines with total installed power of 164,000MW. Engines with ''unknown'' cycle types and ''turbines'' together make up only about 2.5% of total installed power for main engines.

27. Fuel types used in marine transportation are different from most transportation fuels. Marine fuels, or *bunkers*, can be generally classified into two categories: residual fuels and other fuels. Residual fuels, also known as heavy fuel oil (HFO) or intermediate fuel oil (IFO), are a blend of various oils obtained from the highly viscous residue of distillation or cracking after the lighter (and more valuable) hydrocarbon fractions have been removed. Since the 1973 fuel crisis, refineries adopted secondary refining

technologies (known as thermal cracking) to extract the maximum quantity of refined products (distillates) from crude oil. As a consequence, the concentration of contaminants such as sulfur, ash, asphaltenes, and metals has increased in residual fuels.

28. To reduce operating expenses, marine engines have been designed to burn the least costly of petroleum products. Residual fuels are preferred if ship engines can accommodate its poorer quality, unless there are other reasons (such as environmental compliance) to use more expensive fuels. Of the two-stroke, low-speed engines, 95% use HFO and 5% are powered by MDO [*Corbett and Koehler*, 2003]. Fuel consumed by 70% of the four-stroke, medium-speed engines is HFO, with the remainder burning either MDO or MGO. Four-stroke, high-speed engines all operate on MDO or MGO. The remaining engine types are small, high-speed diesel engines all operating on MDO or MGO, steam turbines powered by boilers fueled by HFO, or gas turbines powered by MGO.

Table 1. Profile of 2002 world commercial fleet, number of main engines, and main engine power

Ship type	Number of ships	Percent of world fleet	Number of main engines	Percent of main engines	Installed power (MW)	Percent of total power	Percent of energy demand[1]
Cargo Fleet	43,852						
Container vessels	2,662	2%	2755	2%	43,764	10%	13%
General cargo vessels	23,739	22%	31,331	21%	72,314	16%	22%
Tankers	9,098	8%	10,258	7%	48,386	11%	15%
Bulk/combined carriers	8,353	8%	8781	6%	51,251	11%	16%
Non-Cargo Fleet	44,808						
Passenger	8,370	8%	15,646	10%	19,523	4%	6%
Fishing vessels	23,371	22%	24,009	16%	18,474	4%	6%
Tugboats	9,348	9%	16,000	11%	16,116	4%	5%
Other (research, supply)	3,719	3%	7500	5%	10,265	2%	3%
Registered Fleet Total	88,660	82%	116,280	77%	280,093	62%	86%
Military Vessels	19,646	18%	34,633	23%	172,478	38%	14%
World Fleet Total	108,306	100%	150,913	100%	452,571	100%	100%

1) Percent of energy demand is not directly proportional to installed power because military vessels typically use much less than their installed power except during battle. Average military deployment rate is 50% underway time per year [*Navy*, 1996]; studies indicate that when underway, Naval vessels operate below 50% power for 90% of the time [*NAVSEA*, 1994]. Therefore, energy demand was adjusted in this Table to reflect these facts. The data upon which military vessel power was based specified the number of engines aboard Naval ships. This table was previously presented in other publications [*Corbett and Koehler*, 2003; *Corbett*, 2004].

29. The nations selling the most fuel to commercial ships are typically nations with strong interests in the cargoes or services those ships provide. Organisation of Economic Co-operation and Development (OECD) nations account for roughly half of these fuel sales and provide one illustration of historical consumption trends in the overall fleet [*Energy Information Administration*, 2001; *International Energy Agency*, 1977-1997]. Table 2 summarizes fuel quantities sold by the top nations selling international marine fuels. The US currently provides ~15% of the world's marine fuels, similar to the volume sold by Singapore.

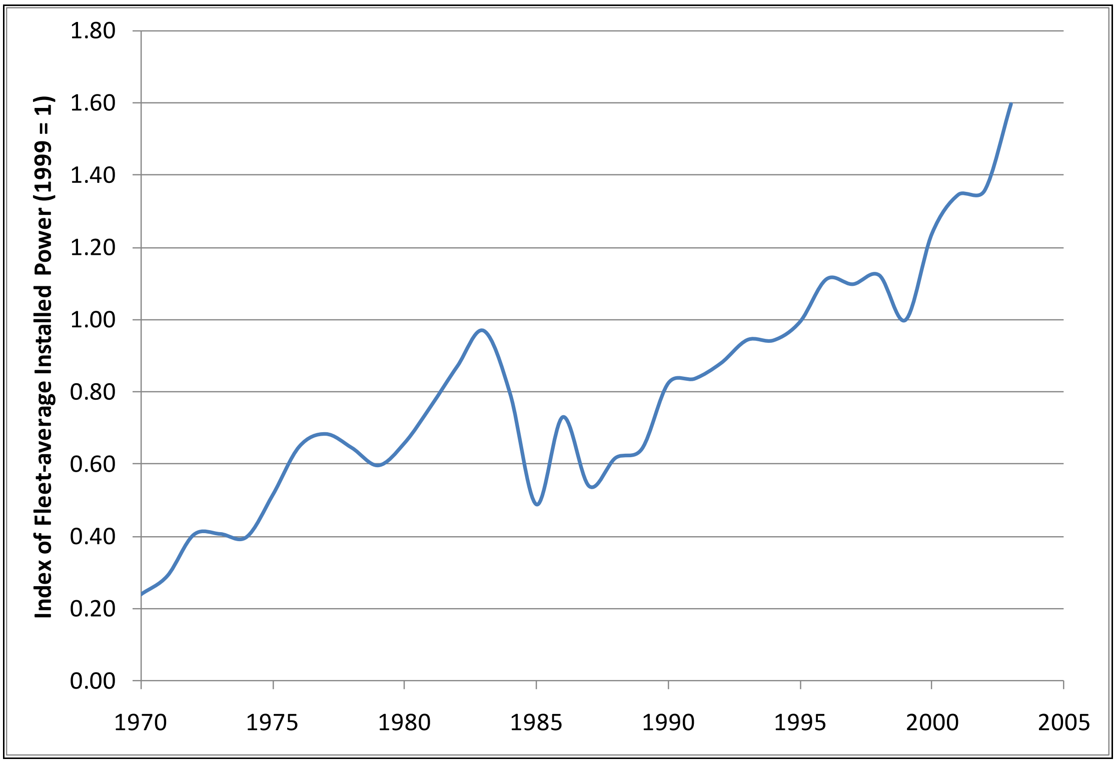
Table 2. International marine fuel sales by nation as percent of world bunkers, 2003 - 2005

	2003		2004		2005	
World	150,568	100%	167,734	100%	175,330	100%
OECD	81,425	54%	91,326	54%	99,140	57%
OECD North America	20,873	14%	26,213	16%	27,930	16%
United States	*19,559*	*13%*	*24,828*	*15%*	*26,455*	*15%*
OECD Europe	47,860	32%	51,442	31%	53,787	31%
OECD Pacific	12,692	8%	13,671	8%	17,419	10%
Non OECD	69,143	46%	76,408	46%	76,190	43%
Singapore	*20,809*	*14%*	*19,567*	*12%*	*25,479*	*15%*

Source: International Energy Agency and OECD (2007a) and (2007b).

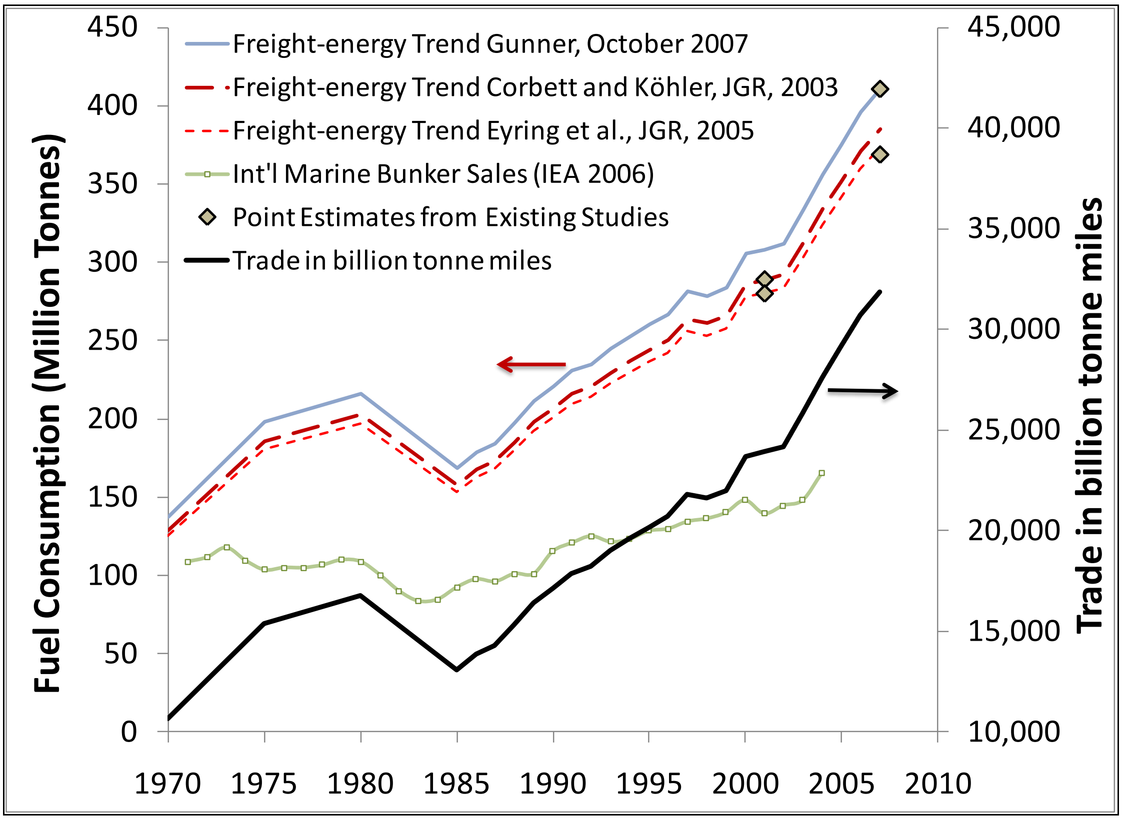
30. The switch to more fuel-efficient engines described in the previous section was more than offset by increased engine power requirements to meet rapidly expanding demand for more and faster global trade. This is illustrated in Figure 11, which depicts average installed power indexed to 1999; these values are estimated from vessels in service as reported in 2003 vessel registry data.

Figure 11. Average installed power (kW) for world-wide vessel fleet, 1970 - 2003



31. Recent estimates based on ship activity and installed engine power also conclude that the world fleet of ships (including cargo, noncargo, and military vessels) consumes some 280 million tonnes of fuel per year, with more than 200 million tonnes required for cargo ships alone (although there is some debate on this value, see Figure 12). The International Maritime Organization Informal Cross Government/Industry Scientific Group of Experts estimated that in 2007 global merchant marine fuel oil consumption was in the range of 369 million tonnes, and that in 2020 this would increase to some 486 million tonnes [*International Maritime Organization*, 2007].

Figure 12. Fuel consumption in million tonnes



5.2 Energy Data Issues for Characterizing Global Maritime Shipping

32. The term "*international marine fuel*" introduces a classification problem for environmental assessments. The basic issue is whether statistics describe total energy consumption by shipping or not. Understanding what portion of ocean shipping energy is described by international marine sale statistics requires a historical review of energy cooperation and reporting among nations.

33. The IEA was established in 1974 within the OECD framework, in part, to promote "co-operation with oil producing and other oil consuming countries with a view to developing a stable international energy trade as well as the rational management and use of world energy resources in the interest of all countries" [*Scott*, 1994]. The IEA Agreement on an International Energy Program (IEP) was designated to be the "focal point for the industrial countries' energy co-operation on such issues as: security of supply, long-term policy, information "transparency", energy and the environment, research and development and international energy relations" [*Scott*, 1994].

34. This required the development of energy statistics, particularly for oil supplies that were disrupted during the 1973 oil crisis. Motivated by energy security (including an oil sharing system), these statistics were to be the basis for emergency allocations among signing nations. According to the IEA agreement [*Scott*, 1994], fuels were to be included within a nation's "oil stocks" if, among other conditions, they were a) in barges; b) in intercoastal tankers; c) in oil tankers in port; or d) in inland ship bunkers. Fuels were to be excluded from domestic stocks if, among other conditions, they were a) in seagoing ships' bunkers; or b) in tankers at sea.

35. International marine fuels statistics were not intended to represent the total energy used by ships engaged in global commerce. Rather, these data were used to differentiate those fuels within a nation's domestic stock from those not eligible for emergency allocation calculations within the oil emergency sharing system. Specifically, the IEP agreement tasked the "Standing Group on Emergency Questions" to consider common rules for the treatment of marine bunkers in an emergency, and of including marine bunkers in the consumption against which stocks are measured" [*Scott*, 1994]. Later, the IEA clarified that a nation's marine fuel stocks "may not be counted if they are held as international marine bunkers, since such bunkers are treated as exports under a 1976 Governing Board decision incorporated into the Emergency Management Manual (EMM)" [*Scott*, 1994].

36. Since then, IEA definitions have been reworded to be more consistent with reporting guidance under IPCC [*Houghton et al.*, 1997; *International Energy Agency*, 1987]. Currently, the IEA defines "international marine bunkers (fuel) [to] cover those quantities delivered to sea-going ships of all flags, including warships. Consumption by ships engaged in transport in inland and coastal waters is not included." The IEA defines national navigation to be "internal and coastal navigation (including small craft and coastal vessels not purchasing their bunker requirements under international marine bunker contracts). Fuel used for ocean, coastal and inland fishing should be included in agriculture."

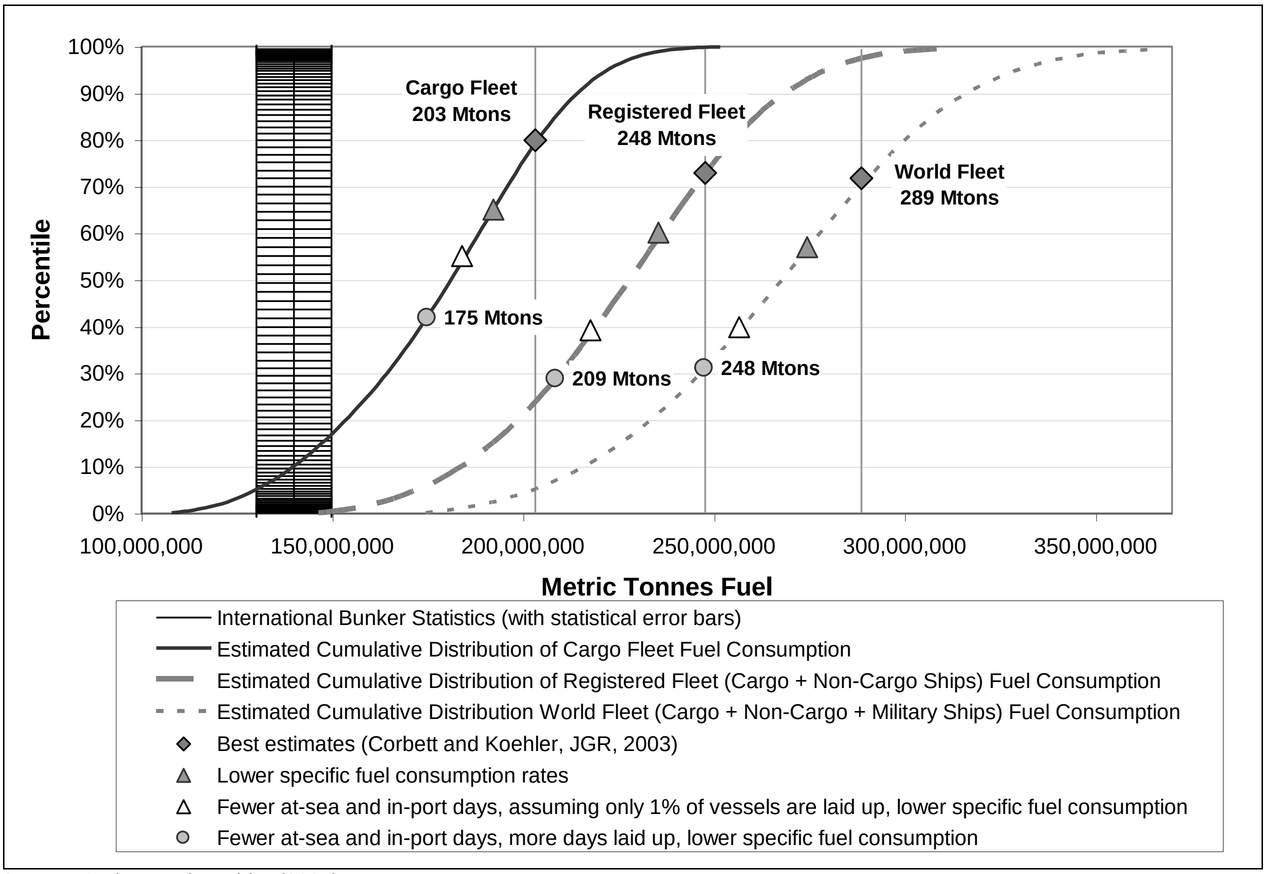
37. This definition leads to significant error in terms of estimating total energy used by the fleet when historical sales data is misinterpreted as complete energy consumption by oceangoing ships. For example, in 1997 and 1999 published work, Corbett and Fischbeck clearly assumed that international marine fuel sales represented consumption [*Corbett and Fischbeck*, 1997; *Corbett et al.*, 1999]. Later work produced activity-based methodologies and guidance that identified best practices for calculating updated global estimates [*Houghton et al.*, 1997; *ICF Consulting*, 2005; *Thomas et al.*, 2002; *UNFCCC and Subsidiary Body for Scientific and Technological Advice*, 2004]. In 2003 and 2004, Corbett and Koehler replaced these sales-based assumptions with activity-based estimates of ship energy requirements based on manufacturer maintenance data for engine operating hours and duty cycle loads. Using these inputs, the study exposed the bias of sales statistics and suggested the error could range between 25% for cargo ships and a factor of two for the world fleet [*Corbett and Koehler*, 2003; 2004].

38. Some disagreement remains about the degree to which energy use in shipping is coupled to the work done moving waterborne commerce [*Endresen et al.*, 2007]. Figure 13 illustrates how different input parameters can produce different estimates of oceangoing fleet fuel consumption [*Corbett and Koehler*, 2004]. Specifically, assuming fewer at-sea days due to ship lay-up (i.e., periods not in productive service) or in-port days results in less engine activity and fewer emissions than derived from maintenance data provided by industry. Independent work largely confirms the validity of activity-based methodologies and supports the insight that world marine fleet energy demand is the sum of international fuel sales plus domestically assigned fuel sales [*Endresen et al.*, 2005; *Endresen et al.*, 2003; *Endresen et al.*, 2004b]. Some debate continues about the best estimates of global fuel usage within these bounds, but the major elements of activity-based inventories are widely accepted. Considering the range of current estimates using activity-based input parameters, oceangoing ships consume 2-4% of world fossil fuels.

39. In fact, recent efforts to apply activity-based methods to regional inventories have begun to address the inherent undercounting bias in using international marine fuel sales statistics. The Core Inventory of Air Emissions in Europe (CORINAIR), under the Co-operative Programme for Monitoring and Evaluation of the Long Range Transmission of Air Pollutants in Europe (EMEP) funded by the European Environmental Agency [*Woodfield and Rypdal*, 2003], adapted better criteria for labeling traffic as international or domestic that conforms to pollution-inventory guidance requirements rather than IEA energy allocation criteria [*Thomas et al.*, 2002].

40. Fuel used by ships is allocated for emissions inventory purposes according to a simple but more accurate check list with regard to the voyage characteristics [*Thomas et al.*, 2002]. This may still leave unresolved the problem of using energy statistics collected by OECD and IEA – especially with regard to the past. However, applications of the activity-based methodology to past fleet data provide important insights to overall assessment of oceangoing ship emissions trends.

Figure 13. Activity-based estimates of energy use and international marine sales statistics demonstrating effect of input parameters on estimates



Source: Corbett and Koehler (2004).

41. Eyring *et al.* (2005) and Endresen *et al.* (2007) independently estimate fuel usage over a historical period from 1950 to 2000. Although they differ in their results, both works confirm that fuel sales do not fully describe ship activity, and provides insight into bias in marine fuels statistics developed under the IEA allocation criteria. Ship activity over the past half century increased marine fuel energy use more substantially than implied by international marine fuel sales statistics. Four important explanatory insights are suggested by these data.

1. The analysis by Erying *et al.* indicates that early marine fuel statistics reported by IEA accounted for most fleet activity. Similar to the work by Corbett and Koehler, Eyring *et al.* rely upon engine operating histories maintained by engine manufacturers. Endresen *et al.* largely confirms the insight that IEA represents most fuel used by the fleet, although this work suggests dramatic efficiency gains in shipping since 1971 to offset much of the divergence reported by others. For example, while shipping has become more productive, Endresen *et al.* suggest that at-sea days declined by ~16% from an average of 215 days in 1970 to an average of 181 days in 2000. As shown in Figure 13, lower activity-based adjustments produce lower fuel use estimates.

2. IEA guidance differentiating domestic bunker sales from international sales produced clear divergence in later years. Endresen *et al.* adjust their model parameters to minimize this difference, where Eyring *et al.* and others do not apply as many downward-adjusting assumptions (see Figure 13). Time-at-sea adjustments by Endresen *et al.* would indicate that reducing time in port and maximizing time underway improved ship productivity prior to 1970, but that transitions in the fleet, including containerization after 1970, continued to achieve productivity increases with ~16% fewer at-sea days.

3. Explanatory factors for this divergence could either be a) improved compliance with IEA guidance over time, and/or b) increased frequency of voyage segments that include at least two ports within a nation. The clarity of IEA bunker fuel designation criteria suggests compliance to be both simple and consistent among nations and over time. If so, a primary cause of divergence between total fuel use and international fuel sales would perhaps be increased multiple-port calls within a nation over time. This change in voyage behavior is consistent with the rise of containerized shipping during the 1970-1980 decade where increasing divergence would be expected during rapid transition to multi-port containerized logistics, followed by stabilized container service patterns and constant differences between fuel usage and statistics.

4. Divergence (among estimates and/or categorical designations) will continue to require explanation and/or reconciliation. This discrepancy may remain controversial because not all statistical sources for marine fuels define international marine fuels the same way [*Olivier and Peters*, 1999].

5.3 Environmental Impacts of maritime activity[1]

5.3.1 Taxonomy of Environmental Impacts

42. Environmental impacts from ocean shipping are several, and they can be summarized in different contexts. For this overview, environmental impacts of ocean shipping will be categorized as either *episodic* or *routine*. These designations help to explain why some aspects of ocean shipping, such as stack emissions, are so challenging to address. Example environmental impacts under this taxonomy are listed in Table 3. Some pollution related to ocean shipping is not directly from the ships, but from efforts to serve the ocean shipping sector through port infrastructure maintenance and fleet modernization.

43. Episodic pollution discharges are among those best understood by the commercial industry and policy makers, as evidenced by the international conventions and national regulations addressing them. The dominant mitigation approach is to prohibit pollution episodes from occurring (as in ocean dumping), to design systems that are safer (as in double-hulls to prevent oil spills or traffic separation schemes to avoid collisions), to confine activities that produce untreated discharges to safer times or locations (*e.g.*, environmental windows for dredging), to require onboard treatment before discharge (*e.g.*, oily water separators), and/or to provide segregated holding and transfer to reception facilities at port (as in sewage handling).

44. Routine pollution releases are different than episodic discharges because they represent activities necessary for the safe operation of the vessel, whether at sea or in port. Regulation of routine releases has lagged policy action to address episodic discharges, partly because these impacts were not as well understood in the past, and partly because operational behavior must change and/or new technology is required.

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1. This discussion is adapted or excerpted from Houghton *et al.* (1997), ICF Consulting (2005) and Thomas *et al.* (2002).

Table 3. Overview of types of ocean shipping pollution

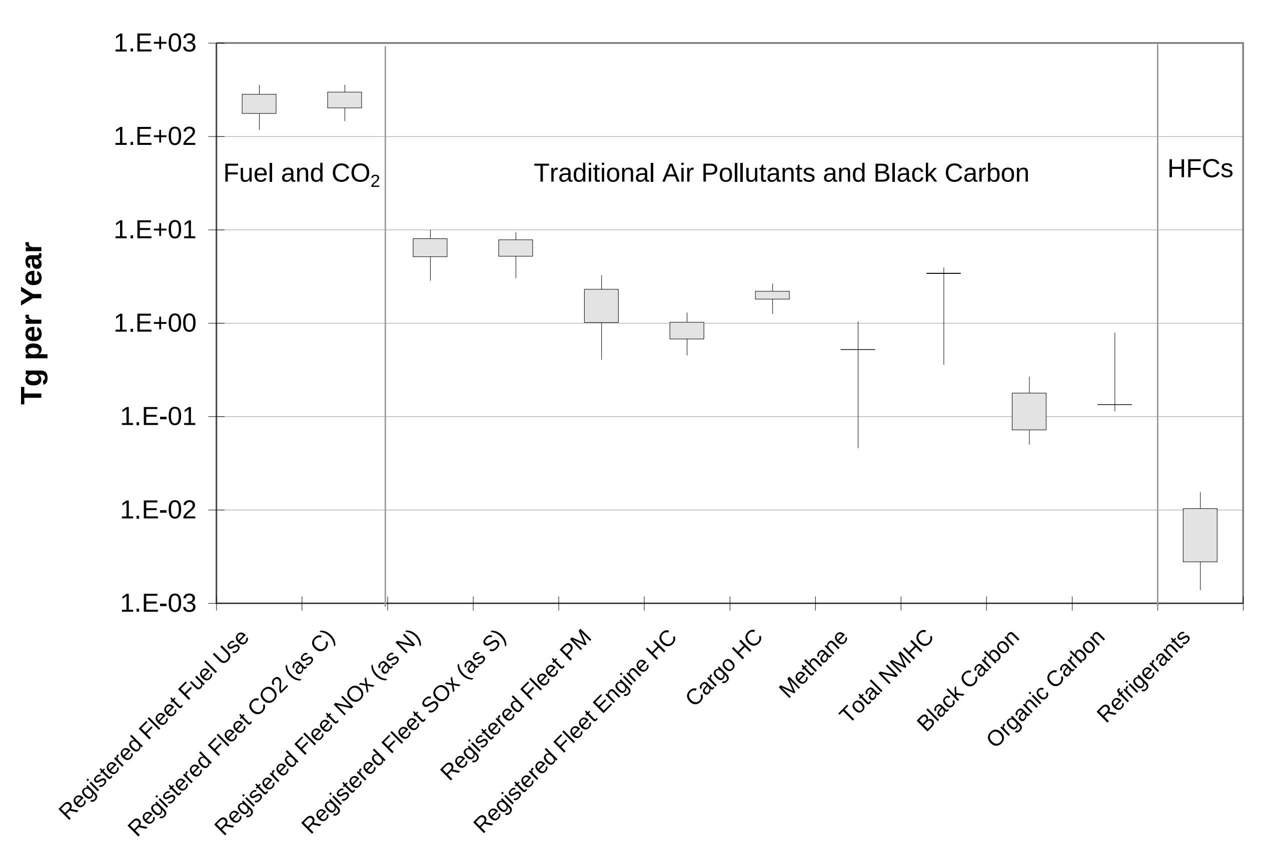
Episodic environmental events	Routine environmental events
Vessel-based	
Oil spills	Engine air emissions
Ocean dumping	Invasive species introductions (ballast water/hull fouling)
Sewage discharges	Hull coating toxics releases
Oily wastewater	Underwater noise
Vessel collisions	
Ship-strikes with marine life	
Port-based	
Dredging	Stormwater runoff
Port expansion	Vessel wake erosion
Ship construction, breaking	Cargo-handling air emissions

5.3.2 Air Pollution from Maritime Shipping

45. Figure 14 illustrates emissions estimates discussed above for 2002, including NOx (as elemental nitrogen), SOx (as elemental sulfur), and particulate matter (PM_{10}), hydrocarbons and methane (from both engines and cargoes), black carbon and organic carbon (constituents of PM with climate implications), and refrigerants. The figure shows estimated ranges of fuel use and carbon dioxide alongside the other emissions using a log-scale. Given the proportional relationship between air pollution and energy consumption, trends in ship emissions have followed a similar pattern to the energy trends displayed in Figure 12.

46. Many efforts are now underway to reduce air pollution from ships, which have been shown to cause significant human health problems [*Corbett and Winebrake*, 2007; *Corbett et al.*, 2007]. A number of emissions control technologies and operational strategies are in use or currently being evaluated, especially for pollutants such as NOx and PM. These emissions controls have been categorized as either pre-combustion, in-engine, or post-combustion controls [*Corbett and Fischbeck*, 2002]. A list of technologies for selected pollutant reductions are shown in Table 4. It should be noted that many of these technologies require increased energy demand, and therefore increases in CO_2 emissions. This suggests that technology alone may not solve environmental issues, and that alternative energy sources or more sustainable freight logistics or operations may play a role.

Figure 14. Summary of estimated ranges in global emissions from maritime shipping, 2002



Note: Box-plots represent the 5th and 95th percentile results from uncertainty analysis; whiskers extend to lower and upper bounds.

Table 4. List of example air pollution control technologies for maritime shipping

Stage	Control technology	Target Pollutant
Pre-combustion	Fuel water emulsification	NO_x
	Humid air motor	NO_x
	Combustion air saturation system	NO_x
In-engine	Aftercooler upgrades	NO_x
	Engine derating	NO_x
	Injection timing delay	NO_x
	Engine efficiency improvements	NO_x, SO_x, PM, CO_2
Post-engine	Selective catalytic reduction	NO_x
	Seawater scrubbing	SO_x
	Diesel particulate filters	PM
	Diesel oxidation catalysts	PM
Vessel designs	Hull form	CO_2, energy ratio pollutants
	Propeller	CO_2, energy ratio pollutants

5.3.3 Invasive Species

47. Another important environmental problem due to globalization is the introduction of invasive species [*Bright*, 1999]. Research consistently identifies shipping (hull fouling, solid and water ballast) as a major invasion pathway since the 1500s when global maritime trade established routine intercontinental waterborne routes. [*Ricciardi*, 2006; *Ruiz et al.*, 2000a; *Ruiz et al.*, 2000b; *Wonham and Carlton*, 2005]. Native species can be transported by ships many thousands of miles and then released into non-native

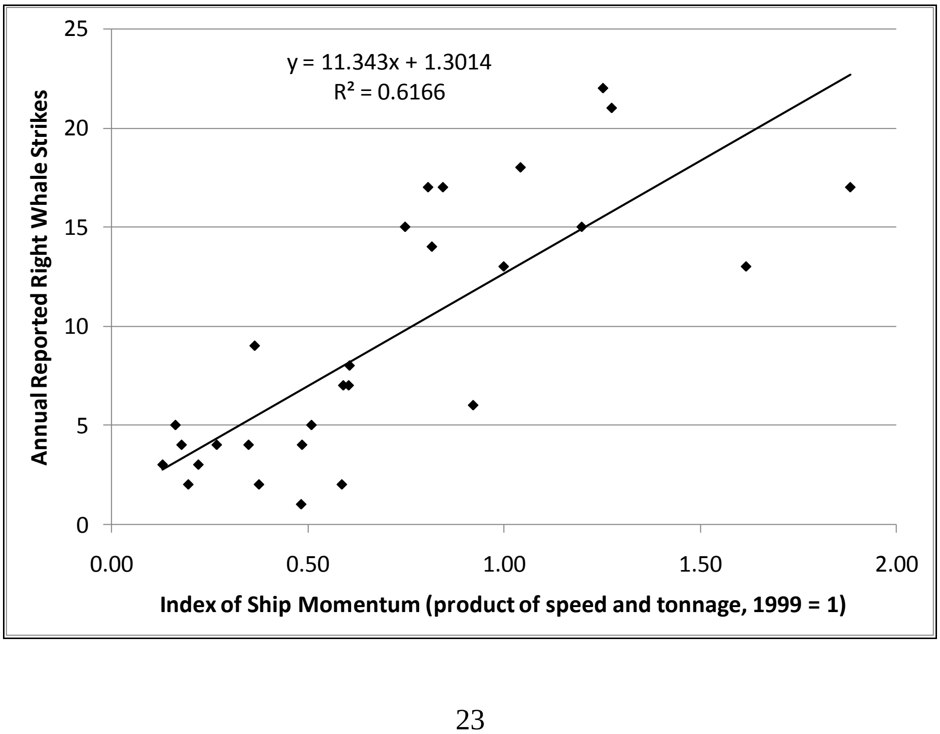
waters. These “non-native species” sometimes have the capacity to become “invasive”, i.e., they can reproduce rapidly and tip sensitive species balance that often exists in a given ecosystem.

48. Trends in non-native species invasions have tended to be correlated with increased seaborne trade and ship tonnage. However, recent research has also suggested that species invasions may be more related to increased diversity of global transportation routes and cargoes traded than to the volume of shipping or trade activity. One recent study suggests that exponential trends in cumulative species invasions from ship ballast could result from constant introduction rates and species survivability [*Endresen et al.*, 2004a; *Wonham and Pachepsky*, 2006]. The significant costs associated with aquatic invasive species [*Lovell et al.*, 2006] have motivated efforts to establish a global, integrated technology policy framework to prevent non-native species introductions by ships [*Firestone and Corbett*, 2005; *International Maritime Organization*, 2004; *Theis et al.*, 2004]. New technologies and operational approaches are now being developed to remove and destroy non-native species in ship ballast waters.

5.3.4 Endangered Species and Mammal Strikes

49. Shipping’s shift to larger and faster ships is also associated with increased lethality to marine mammals and other animals that may be struck by vessels [*Vanderlaan and Taggart*, 2007]. The reported number of vessels striking large whales worldwide has increased 3-fold since the 1970s, as has the number, sizes, and speeds of vessels in the world fleet (Corbett *et al*, under review). Figure 15shows the relationship between annual reported North Atlantic right whale strikes and average global ship momentum. North Atlantic right whales (Eubalaena glacialis) are critically endangered throughout their range along the eastern coast of North America (NOAA, 2003). The primary risk right whales face within this area, along with several other species of large whales, is being struck by large vessels transiting between ports along the eastern seaboard of the United States (Laist *et al*., 2001). Approximately 35% of all right whale deaths documented between 1970 and 1989 have been attributed to ship strikes; while data from the period 1991-1998 attribute 47% of right whale deaths to ship strikes [*Knowlton and Kraus*, 2001; *Laist et al*., 2001]. The relationship illustrated in Figure 15 implies that as ships become larger and increase their speeds (in order to meet the demands of a globalized economy) an increase in mammal strikes will likely occur.

Figure 15. Relationship between right whale strikes and global average ship momentum



6. Creating a Sustainable Intermodal Freight System

50. The intrinsic connection between maritime transportation, international trade, and globalization trends will continue as long as economic wealth continues to derive from consumption of goods and services. While predicting the future changes in global economics is beyond this chapter scope, little evidence exists for a decoupling between the world economy and freight transport. In other words, if the future reveals a saturation effect to global economy, then maritime transport will likely follow such a trend. Hypothetically, scenarios explaining a fundamental change in the connection between trade and global economic growth would require significant changes in population demographics or social valuation of goods and services that decouple wealth from imports and exports, or a shift to greater consumption of services with a general dematerialization in the social culture. None of the current global scenarios or forecasts focused on climate, energy, or economics make these decoupling assumptions as far as we know.

51. Demands for global shipping bring with them a host of environmental problems, some of which were discussed in detail above. We conclude with a discussion of the ways in which environmental standards are also becoming a global responsibility, modifying the performance expectations of global industries to serve economic demands while reducing environmental impacts. Specifically, we suggest that maritime transport will increasingly improve its environmental performance as it responds to two motivating forces. First, regulatory and advocacy attention will impose pressure external to the maritime transportation market, through both international and territorial policy action. Second, the continued development of environmental performance metrics in global, multi-firm supply-chain networks will create market-based incentives for less-polluting maritime transportation.

52. Scholars identify three dimensions of globalization and the structure of the global economy [*Angel et al.,* 2007]: a) foreign direct investment; b) international trade; and c) global networks of firms as vehicles for production, trade, and investment. The first is a hallmark of maritime transport, as discussed above with regard to fleet registry, ownership, and crewing trends. The second is the defining business of global shipping. And global shipping firms are at least described within the third dimension; in fact, we observe that containerization especially is promoting the vertical integration of firms in international logistics.

53. There is also a shift from national-level regulation and negotiated transboundary territorial agreements (which are de facto global standards applicable to a region), to global frameworks of environmental standards that address region-specific requirements and network requirements for international supply chain processes. The clearest recent example is the recently proposed revisions to the International Maritime Organization MARPOL Annex VI in response to plans for strict territorial standards by the European Union (followed by other nations and regions) [*Finland et al.*, 2005; *IMO Working Group on Air Pollution from Ships*, 2006; *International Maritime Organization*, 1998; *International Maritime Organization and Marine Environment Protection Committee*, 2008].

54. Moreover, global environmental concerns (*e.g.*, biodiversity and climate change) are driving growing interest and importance of industrial practices, whether directly controlled or outsourced among international firms. The expectation that industry sectors will act to meet expectations driven by market attention has been shown to diffuse new standards and practices along the international supply chain [*Corbett and Kirsch*, 2001; *Corbett*, 2005] as part of global integration of environmental dimensions of product and service quality [*Pil and Rothenberg*, 2003].

55. Maritime transportation is being required, like other global industries, to better protect the resources and services our environment provides for future generations, and to mitigate the impacts on ecosystems, global climate and ocean processes, and human health. These demands oblige the maritime sector to consider the policy instruments for setting standards, including international treaty, national

regulation, industry-based standards, requirements negotiated through third-party agreements (non-governmental organizations or NGOs), and industry associations [*Angel et al.*, 2007]. Firm-based and third-party standards exist for other industry sectors, with examples including the U.S. Energy Star ratings, ISO 9000, ISO 14000, etc. For shipping, the classification societies have acted to provide third-party standards for environmental management that some maritime firms are adopting [*American Bureau of Shipping*, 2005].

56. Globalized motivation to improve the environmental performance of maritime transport can be summarized by two statements:

Maritime transportation is becoming directly required to meet environmental performance standards through IMO, European Community, and North American regulation.

Shipping is becoming explicitly included in the network-based environmental standards as part of the multi-firm supply chain (*e.g.*, corporate carbon footprints, and life-cycle analyses [*Weber et al.*, 2007; *Winebrake et al.*, 2006; 2007a; b]).

57. Meeting these objectives requires consideration of a *sustainable intermodal freight system* [*Winebrake et al.*, 2008]. A sustainable intermodal freight system is one that enhances goods movement around the globe in a way that is environmentally responsible, equitable, and efficient. Such a system involves all current primary modes of freight transportation – road, rail, water, air, and pipeline – working in harmony.

58. But a sustainable intermodal freight system also has tradeoffs. The demands placed on our freight system are currently driven by consumer value for commodities and finished products. The level of this value will often dictate the method and mode of transportation. In practice this objective of meeting consumer demands will be exhibited through cost, time-of-delivery, and reliability. Shippers make their decisions on transport mode based on a complicated calculus of how badly a consumer needs a good (and thus, how much they are willing to pay to have it shipped). Some consumers and businesses are willing to pay more to receive an item almost immediately and with high reliability – often equating to air or truck service; while others are comfortable waiting for a good and paying less – implying a rail or water mode of transport.

59. Regulation raises some fears among the industry with regard to the changing nature of shipping competiveness as illustrated by debates about phase-in periods for double hulls, cleaner fuels, and less-toxic hull coatings. However, as firms shift to network-based standards in response to environmental concerns, maritime transport may recognize that competitiveness will be enhanced through leading adoption of operations and technology that meet increased demands by shippers for transparency and improvement with regard to environmental benchmarks – especially for energy, CO_2, and emissions. More importantly, the attributes of maritime transportation that compare best with other modes may create conditions where modal competitiveness favors this sector. For example, as vessels switch to cleaner fuels and less-polluting engines, the energy intensity advantage of shipping and rail more so than long-haul trucking and air freight.

60. Interestingly, however, the modes of transport that are emphasized in the marketplace (namely, those that deliver goods quickly), are also the most polluting. Air and truck freight, as shown earlier in this chapter, emit more than 10 times more CO_2 than rail and ship; alternatively, the emissions controls for trucking result in more similar PM emissions among the onroad, rail, and water modes per cargo movement. Until the environmental and human health impacts of these emissions are incorporated into the price of the transportation (i.e., they are "*environmental externalities*"), the true social costs of freight transport decisions are not addressed in the market. This may imply strong consideration of policies that

attempt to internalize such external costs – perhaps through technological mandates, emissions standards, fees, or taxes.

61. The sustainable intermodal freight transportation solution will require coordinated efforts among industry, government, and academia, along with improved understanding by the general public about how their food, clothing, housing, and other material needs are delivered. As these efforts proceed, the maritime transport industry will continue to involve technologies (including environmental control technologies for air emissions, ballast water, hull coatings, etc.), energy systems (including alternative fuels, increased power plant efficiencies, improved hull and propeller designs, and even novel concepts like wind-assist kites), and operational changes (such as speed reduction, mode rebalancing, and changing route patterns).

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