April 2006

Global Trade and Fuels Assessment - Future Trends and Effects of Designating Requiring Clean Fuels in the Marine Sector: Task Order No. 1

Draft Report

Prepared for

Barry Garelick
Russ Smith
U.S. Environmental Protection Agency
Office of Transportation and Air Quality (OTAQ)
1200 Pennsylvania Ave., NW
Washington, DC 20460
EPA Contract Number EP-C-05-040

Prepared by

RTI International
Health, Social, and Economics Research
Research Triangle Park, NC 27709

EnSys Energy & Systems, Inc.
5134 Lexington Ridge Drive
Lexington, MA 02421

Navigistics Consulting
1740 Massachusetts Avenue
Boxborough, MA 01719

RTI Project Number 0209701.001

RTI Project Number
0209701.001

Global Trade and Fuels Assessment - Future Trends and Effects of Designating Requiring Clean Fuels in the Marine Sector: Task Order No. 1

Draft Report

April 2006

Prepared for

Barry Garelick
Russ Smith
U.S. Environmental Protection Agency
Office of Transportation and Air Quality (OTAQ)
1200 Pennsylvania Ave., NW
Washington, DC 20460
EPA Contract Number EP-C-05-040

Prepared by

RTI International*
Health, Social, and Economics Research
Research Triangle Park, NC 27709

EnSys Energy & Systems, Inc.
5134 Lexington Ridge Drive
Lexington, MA 02421

Navigistics Consulting
1740 Massachusetts Avenue
Boxborough, MA 01719

---

*RTI International is a trade name of Research Triangle Institute.

CONTENTS

Section **Page**

SECTION 1
INTRODUCTION

The U.S. Environmental Protection Agency (EPA), along with other regulatory bodies in the U.S. and Canada, are considering whether to designate one or more SO_x Emission Control Areas (SECAs) along the North American coastline, as provided for by MARPOL Annex VI. This addition to the international MARPOL treaty went into effect on May 19, 2005 and places limits on both NO_x and SO_x emissions. According to the terms of the treaty, ships calling on ports in signatory countries must use bunker fuel with a sulfur content at or below 4.5 percent. Countries participating in the treaty are also permitted to request designation of SECAs, in which ships must treat their exhaust to a level not exceeding 6.0 grams of SO_x per kilowatt-hour or further reduce the sulfur content of their fuel to 1.5 percent. The Baltic and North Sea areas have already been designated as SECAs, and the effective dates of compliance in these bodies of water are 2006 and 2007, respectively.

To evaluate possible recommendations regarding North American SECAs, EPA requires a thorough examination of potential responses by the petroleum-refining and ocean-transport industries to such a designation, along with any resulting economic impacts. As Task Order #1 under this contract between RTI International and EPA, this report provides a foundation for these recommendations through developing the knowledge, data, and modeling capabilities needed for such an analysis. Thus, the analytic team comprised of RTI, EnSys Energy & Systems, and Navigistics Consulting has assessed current and future conditions in global-fuels market to provide this foundation. Accomplishing the goals of this report involved several component tasks:

- Examining the current petroleum-refining industry and bunker-fuel markets,
- Developing a model of shipping activities with Navigistics Consulting to estimate future demands for marine bunker fuels, and
- Enhancing the EnSys model of petroleum refining (*World Oil Refining Logistics and Demand*, or the WORLD model) to include the new information on bunker-fuel markets and then using the model to establish baseline projections of future refining activities.

This section provides a background for the analysis by discussing existing regulations on marine bunker fuels. It then summarizes how the components of the analysis are implemented and examines the resulting implications of “Business-as-Usual” (BaU), or baseline, conditions for the international marine fuel markets in the years 2012 and 2020.

1.1 Regulations and Options for Compliance

Existing regulations regarding marine bunker fuels provide an important backdrop for the modeling conducted in this analysis and, as such, are summarized in this section – along with an initial discussion of how bunker-fuel markets may comply with regulations. The International Maritime Organization's (IMO) "MARPOL Annex VI" sets out a series of regulations impacting international marine bunker fuels. These new regulations center on limits for emissions of nitrous oxides (NO_x), sulfur oxides (SO_x), and volatile organic compounds (VOCs). Fuel quality regulations in Annex VI have been implemented in the form of the ISO-8217 2005 specification (see Figure 4-2 for details and discussion). This specification updates selected bunker qualities, provides protections to prevent the blending of used lubricating oil (ULO) into marine fuels, and limits the presence of refinery streams which contain high levels of "catalyst fines".

The MARPOL Annex VI sets limits on NO_x emissions as a function of ships' engine speed, which range from a high of 17 grams per kilowatt-hour (gm/kWh) for engines running at less than 130 rpm to a low of 9.8 gm/kWh for engines running at or above 2000 rpm. Since residual bunker fuels contain nitrogen that is typically at a level equal to around 20% of the fuel's sulfur content, NO_x emissions will be impacted in part by fuel quality (as well as by specific combustion conditions). For example, a bunker fuel containing 3% sulfur will contain around 0.6% nitrogen, which translates into around 3 gm of NO_x per kWh (Hanashima, 2006). This level is well below the standard set for NO_x emissions, however, residuum desulfurization in a refinery also reduces nitrogen levels and can therefore play into the comparative economics of bunker-fuel sulfur reduction versus other options (e.g., on-board abatement of SO_x).[1]

Through the ISO-8217 specifications, MARPOL Annex VI sets a limit on SO_x emissions, expressed as a maximum 4.5% fuel sulfur content. This compares to a prior maximum limit of 5%. The new level was set based on a survey of residual bunkers qualities (the intermediate fuel oil, or "IFO," grades), which showed that essentially all bunkers currently supplied have sulfur contents below 4.5% (see Figure 1-1). Since the same survey showed global average residual bunker fuel content is currently around 2.7%, this change has limited practical impact on bunkers quality. More significant for any potential future SO_x regulations is the fact that MARPOL Annex VI explicitly allows for on-board abatement as an alternative means for meeting SO_x requirements (thus recognizing that the ultimate goal is a reduction in SO_x emissions, rather than

---

[1] To cover the eventuality that NO_x may need to be considered in any future investigations of SECAs, EnSys added the nitrogen contents of residual streams to the WORLD model, along with impacts on nitrogen content of desulfurization.

a reduction of fuel sulfur content *per se*). The IMO, however, has yet to set up necessary guidelines for this provision.

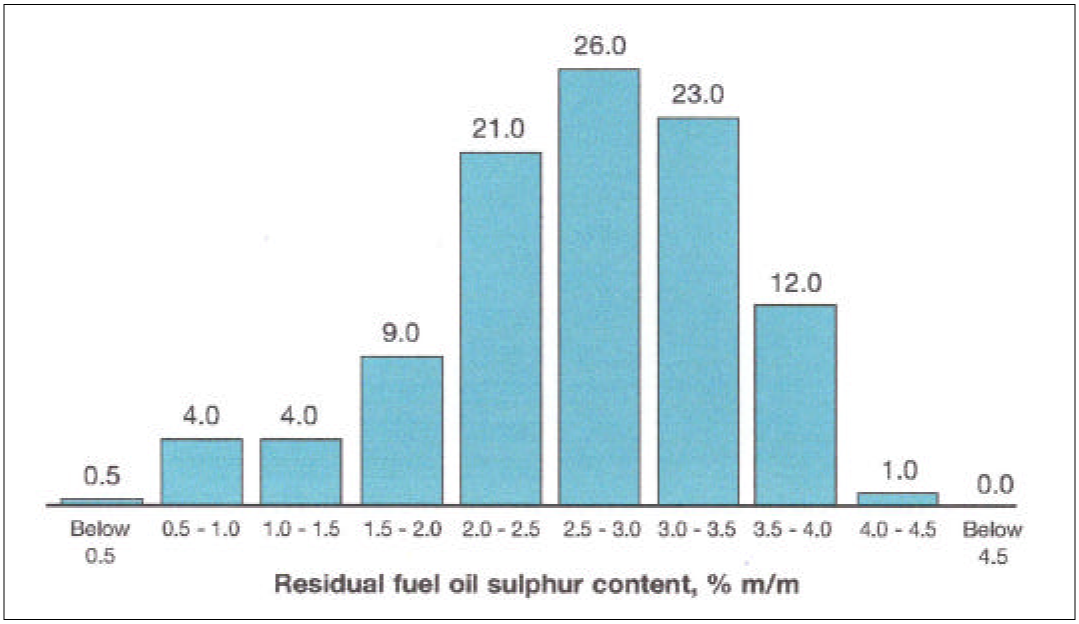


Figure 1-1. Sulfur Content in Bunker Fuels

Figure 1-2 below illustrates the current timeline of the MARPOL Annex VI and other SECA-related regulations. In addition establishing emissions limits and considering reductions achieved through on-board abatement, MARPOL Annex VI and ISO-8217 2005 explicitly allow for the existence of regional SECAs. In the European Union (EU), these agreements have been established with a marine fuel sulfur maxima of 1.5%, potentially advancing to 0.2% and 0.1% on marine distillates. Again, these regulations recognize on-board abatement as an alternative, with a stated standard of 6 gm SO_x / kWh (to correspond to the initial 1.5% sulfur limit).

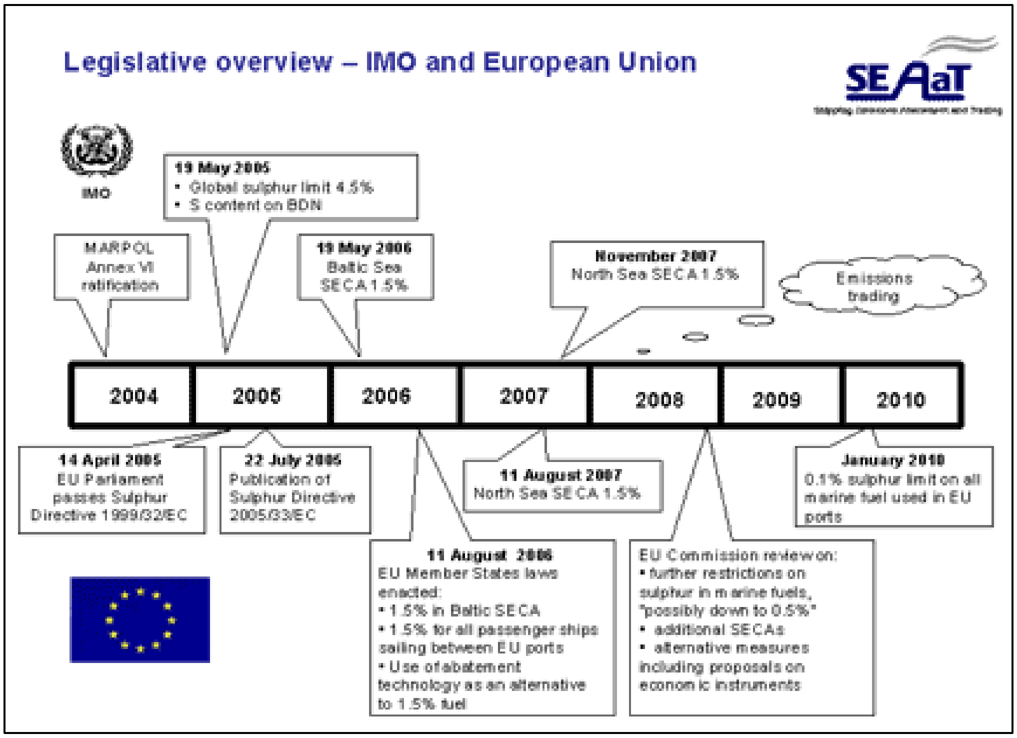


Figure 1-2. Timeline of MARPOL Annex VI and SECA Implementation

Beyond currently announced initiatives, it appears likely that the MARPOL Annex VI regulations and newly effective EU SECAs are only the first steps of progressively tightening regulation of marine fuels qualities. This is being driven by the fact that, as major steps are being taken to reduce sulfur in other products, especially in gasoline and non-marine distillates, bunkers are becoming an increasingly significant – and unacceptable - source of SO_x and other emissions. Current intentions are for a second round of IMO/ISO marine fuels regulations to be established by 2008 and be enforceable by 2011/2012, with potential further steps beyond. In addition, the EU is expected to tighten the initial SECA regulations beyond 2008. Required residual bunker-fuel sulfur levels could move to as low as 0.5% regionally, or even globally. One current element of uncertainty is the size of the geographic areas of future SECAs, i.e., how many miles offshore they will apply. This in turn affects the proportion of total bunkers consumption that will need to comply with SECA regulations. Anticipated policy decisions on this issue will have significant implications for any analysis conducted in the future regarding the potential effects of North American SECAs.

Marine Environment Protection Committee (MEPC) - 53rd session 18-22 July 2005

Review of Annex VI

The Committee agreed on the need to undertake a review of Annex VI and the NOx Technical Code with a view to revising the regulations to take account of current technology and the need to further reduce emissions from ships. MEPC instructed the Sub-Committee on Bulk Liquids and Gases (BLG) to carry out the review by 2007, and specifically to:

- examine available and developing techniques for the reduction of emissions of air pollutants; review the relevant technologies and the potential for a reduction of NOx emissions and recommend future limits for NOx emissions;
- review technology and the need for a reduction of SOx emissions and justify and recommend future limits for SOx emissions;
- consider the need, justification and possibility of controlling volatile organic compounds emissions from cargoes;
- with a view to controlling emissions of particulate matter (PM), study current emission levels of PM from marine engines, including their size distribution and quantity, and recommend actions to be taken for the reduction of PM from ships. Since reduction of NOx and SOx emission is expected to also reduce PM emission, estimate the level of PM emission reduction through this route;
- consider reducing NOx and PM emission limits for existing engines;
- consider whether Annex VI emission reductions or limitations should be extended to include diesel engines that use alternative fuels and engine systems/power plants other than diesel engines; and
- review the texts of Annex VI, NOx Technical Code and related guidelines and recommend necessary amendments.

The language in these regulations, and the economics of the refining and shipping industries, lead to a situation where several, non-exclusive, options can potentially be used to achieve compliance with SECAs. While some of these options are not fully explored in this report (they will be evaluated in the next steps of the analysis), it is still important to note the range of responses. Among these options are:

1) Desulfurize refinery fuels and use lower sulfur content fuel.
2) Use only middle distillates for bunker fuel.
3) Reduce SO_x emissions via on-board scrubbers (also helps reduce particulate matter, PM).
4) Reduce NO_x emissions by lowering nitrogen content of the fuel.
5) NO_x and PM reductions via on-board emission controls and engine design.
6) Undertake custom blending of fuels on board and/or use segregated bunkers tanks.
7) Establish emissions trading, which could allow trading of marine and shore-based credits.
8) Switch to alternative fuel sources (e.g., LNG).
9) To the extent feasible, some ship owners might also elect non-compliance through re-registration of ships to a country that has not ratified the IMO standards.

There is general industry agreement in principle on the need for SO_x emissions reduction. There are, however, major industry concerns over operational issues, such as custom blending of fuels on board due to safety and other concerns (Gregory, 2006). Similarly, there is industry agreement about a reduction in NO_x limits for new engines, but also concerns about the application of NO_x limitations to existing engines due to practicality and cost factors (Metcalf, 2006) and concerns about a regional approach to NO_x controls due to technical considerations (Gregory, 2006).

With regard to emissions trading and sulfur reduction, the European Commission has been asked to give particular consideration to proposals for alternative or complementary measures and to consider submitting proposals on economic instruments in their 2008 review. For NO_x reductions, the Commission studies suggest that, given the range of technologies, there is a sound basis for a trading environment (Madden, 2006). In addition, SO_x emissions trading and compliance monitoring schemes are being actively promoted.

Initial studies indicate on-board scrubbing is cheaper in terms of cost per ton of SO_x removed than refinery residual desulfurization. However, the technology is only just reaching the commercial demonstration stage (with initial positive results). Issues have also been raised over how to ensure compliance and how to dispose onshore of the resulting sludge waste. Scrubbing requires an extended lead time to achieve widespread utilization and is least costly when built in to new ships, rather than retrofitted onto existing ones (where retrofit costs are estimated on the order of $1-4 million). Current estimates also indicate ships will have to spend appreciable time in SECA areas for scrubbing to be economic. Conversely, building a refinery residual desulfurization unit with ancillaries could cost of the order of $500 million and, if done, would create a feedstock that could be more attractive for upgrading to light clean fuels than for sale as low-sulfur residual fuel for bunkers or inland use. Within any one SECA, it is not certain what proportion of compliance will be achieved by scrubbing versus fuel supply and what the impact on that balance is of complementary regulations on NO_x and PM in addition to SO_x.

1.2 Summary of the Analysis

The purpose of this report is to develop the information and modeling techniques that would be required if EPA decides to proceed with an analysis of the potential effects of designating North American SECAs as part of the MARPOL Annex VI. In support of these goals, this report details the development of techniques to estimate bunker demands in the shipping industry and also enhancements that have been made to the EnSys WORLD model of the petroleum-refining industry. The resulting information from these processes is used to establish baseline projections of international petroleum markets in the years 2012 and 2020, against which the effects of SECAs on shipping and bunker fuel demands could be evaluated.

RTI and Navigistics Consulting developed a multi-step approach for estimating future bunker demands involving: (1) identifying major trade routes, (2) estimating volumes of cargo of various types on each route, (3) identifying types of ship serving those routes and carrying those cargoes, (4) characterizing types of engines used by those ships, and (5) identifying the types and estimated quantities of fuels used by those engines. In general, this approach can be described as an "activity-based" approach with a focus on the international cargo vessels that represent the majority of fuel consumption. Similar techniques for combining data on specific vessels with data on engine characteristics have been used in other analyses (e.g., Corbett and Koehler [2003, 2004]; Koehler [2003]; Corbett and Wang [2005]; and Gregory [2006]). The approach in this analysis extends these previous works by linking ship data to projections of world-wide trade flows from Global Insights (2005) in order to determine the total number of trips undertaken in each year and hence fuel use.

The methodology gives the following results for historical and forecasted bunker-fuel consumption:

- World-wide bunker use in 2001 is estimated at 278 million tons, of which around 212 million tons are residual fuels.
- Between 2001 and 2020, total consumption grows at an average annual rate of 3.1% (from 2006 to 2020, the growth rate is 2.6%).
- Around 47 million tons of bunker fuel was used in 2001 to transport international cargo flows into and out of the United States (not all of which is purchased in the U.S.).
- This fuel consumption related to U.S. trade is forecasted to grow at around 3.7% between 2001 and 2020 (or 3.4% from 2006 to 2020), which is somewhat higher than the world average because of high growth in container traffic arriving at U.S. ports.

The estimates of world-wide bunkers are quite similar to those in the published works cited above, in spite of differences in techniques. Koehler (2003) uses calculations of average engine loads, run times, and specific fuel consumption for the existing vessel fleet to come up with bunker fuel demands of around 281 million tons. Similarly, Corbett and Koehler (2003, 2004) estimate bunker demands at 289 million tons in 2001. These findings on fuel consumption tend to be significantly higher than data published by the International Energy Agency (IEA), which places international marine bunkers at around 140 million tons per year, of which around 120 million tons are residual fuels (see the discussion of these points in Section 4.2). Given the far-reaching implications of these demand estimates for petroleum markets and related potential effects of future SECAs, this analysis has chosen to evaluate baseline conditions in the refining industry for both IEA's bunker-fuel estimates and the estimates developed in this report (termed the "RTI" estimates for clarity).

For this report, these two bunker-fuel estimates are incorporated in the EnSys WORLD model, which is a comprehensive, bottom up model of the global oil downstream. It encompasses crudes and non-crudes supply, refining operations and investment, crude, products and intermediates trading/transport, product blending/quality and demand. It yields as outputs detailed simulations of how this global system can be expected to operate under a wide range of different circumstances, with outputs including price effects as well projections of sector operations and investments. WORLD is not a forecasting tool *per se*, but rather uses as a starting point a global supply-demand world-oil price outlook - in this study, the outlook is based on the Energy Information Administration's (EIA) *Annual Energy Outlook 2006* Reference Case.

To accomplish the goals of this study, WORLD has been expanded to incorporate seven grades of bunker fuels, covering the major distillate and residual grades used in the marine shipping industry. The latest international specifications applying to low-sulfur grades of these fuels were also included because of their applicability for future SECAs. In addition, flexibility was built in to allow the model user to vary the proportion of SECA compliance that is achieved through fuel sulfur reduction versus other means such as on-board abatement or emissions trading. This was necessary since it is feasible that widespread adoption of on-board abatement could enable shippers to continue using high sulfur bunker fuels – and might even enable refiners to raise the sulfur level towards the upper limit of 4.5% from today's average global level of 2.7% and still meet required SO_x emission standards. Similarly, since any eventual estimates of bunker-fuel production costs in SECA cases will derive directly from refinery processing costs, a technology review of the WORLD model assumptions was undertaken. This involved checking on capital costs for the processes with the most influence on costs of reducing sulfur in bunkers. Finally, to ensure that the model was correctly specified for any future policy scenarios that might be run on implementation of SECAs, the related regulations were thoroughly reviewed.

Once these processes were complete, business-as-usual cases (consistent with the regional oil supply and demand projections from AEO) were set up in WORLD. The resulting BaU cases for the years 2012 and 2020 were then executed on both the IEA and RTI bunkers estimates - key results from all four cases are included in the body of the report. The full results are rich in detail, however, the important drivers that will impact on future SECA analyses revolve around the outlook for product demand. Since the rigorous analysis of shipping activity and fuel consumption conducted in this report estimates high bunkers demands, the impacts of SECAs or other marine fuels regulations will be similarly greater than for those estimated using lower demand forecasts. A second major driver evident in these and other WORLD analyses is that the on-going shift toward distillates, especially in Europe and non-OECD regions, will materially alter gasoline and distillate trade patterns, their product pricing and refining investments and economics. These developments will in turn impact the market and supply effects of SECAs and other global marine fuels regulations.

The overall objective of the refinery modeling conducted under Task #1 of this contract was to develop and implement any modifications to the WORLD model that are needed to accommodate details of bunkers grades and other issues such as updated technology costs, etc. These features have been successfully implemented and applied (the 2012 and 2020 BaU cases were developed and represent a sound starting basis to examine the impacts of broader SECA regulations and/or tighter global marine fuels limits). Section 5 provides details of the WORLD model estimates for the BaU cases.

This modeling foundation is particularly important because the nature of the MARPOL Annex VI regulations and goals, and the characteristics of the international marine fuels industry, mean that there is a much greater potential for variability in future scenarios than is true for most types of fuels regulations. The WORLD model can be used to case study such alternative scenarios and address key uncertainties through case studies. Among these, which will be important in the follow-up SECA analyses, are the following:

- The regional make up of bunkers demand.
- Associated with this, the extent to which consumption of low sulfur bunkers for SECA compliance will be met by supplies within the SECA or elsewhere.
- The degree to which compliance with the MARPOL regulations will be achieved through improved fuel quality versus via on-board scrubbing and/or emissions trading. Using the WORLD model, plausible “high” and “low” scenarios can be applied and analyzed (the model has already been set up to deal with these).
- Whether bunkers blend compositions need to be more tightly restricted to capture ship operational limits such as relate to fuel instability.

1.3 Organization of this Report

The remainder of this report is organized as follows to accomplish the goals of Task #1:

- Section 2 presents a profile of the marine bunker fuels, their refining processes, and the overall supply chain used to deliver the fuels to marine vessels.
- Section 3 develops a model of shipping activity and estimates bunker fuel demands.
- Section 4 describes how the analysis of baseline conditions in petroleum markets is implemented in the WORLD model.
- Section 5 then presents estimated results from the WORLD model regarding BaU conditions in 2012 and 2020.
- Section 6 summarizes and discusses implications for future SECA analyses.
- Appendix A provides additional information on options for reducing SOx emissions.
- Appendix B reviews cost assumptions regarding refinery technologies used in the analysis of the WORLD model.

SECTION 2
OVERVIEW OF THE MARINE FUELS INDUSTRY

This section provides an overview of the marine fuels industry, which is a very complex network of organizational and trade relationships and is also quite geographically dispersed. The supply chain for this industry begins with integrated petroleum refineries, where "bottoms" from atmospheric and vacuum distillation unit operations are combined to form the bulk of residual fuel stocks (see Section 2.2). Marine distillates historically come from poorer quality distillate recycle streams that are unsuitable for upgrading to diesel fuel or other low-sulfur products. The dominant producers of marine fuels are divisions of the major petroleum firms such as Shell Trading (STUSCO) and BP Marine. Around the world, these large producers are joined by hundreds of smaller firms that contract to transport, blend, and sell low-quality stocks to the shipping industry.

Although some of the major petroleum refiners also contract for and deliver marine fuels, much of the worldwide volume is sold to firms that operate bunkering facilities around the world. These large firms, including the Chemoil Group, O.W. Bunker, and the Chinese government-owned Chimbusco, purchase blended stocks from the producers and also blend, transport, and store some products themselves. As much as 25 percent of the world's marine fuels are purchased and resold by brokers or other intermediaries that never actually take physical control of the bunker fuel. Arbitrage activities of these firms help keep the worldwide market efficient, as excess price differentials are quickly exploited and eliminated.

The final stage of the marine fuel supply chain is the bunkering itself, which can either be done while the ship is docked at a port or directly from bunker barges while the ship is anchored. There are hundreds of bunkering ports around the world and thousands of firms that provide the actual bunkering service. Logistics and transport cost factors influence the location of these bunker ports. In addition to being located close to supply sources (petroleum refineries) and consumers of transported goods (major population centers), bunkering ports are often strategically located along high-density shipping lanes. The largest port of this type is in Singapore and handles more than twice as much bunker fuel volume as the next biggest provider. Panama and Gibraltar are other examples of strategically located facilities. In North America, the largest facilities follow the general pattern suggested by location theory. Los Angeles, San Francisco, New York, Philadelphia, Houston, and New Orleans are close to both refinery supply and transport destinations.

The following subsections briefly review characteristics of marine fuels, the petroleum refining process (focusing on distillation and additional downstream treatment processes that further refine crude oil into higher-value petroleum products), and the supply chains that deliver the refined marine fuels.

2.1 Marine Fuel Types

Marine fuels used in vessel bunkering are primarily comprised of heavy distillate and residual fuels. For this reason, the remainder of this subsection focuses on these two refinery production outputs (the complete refining process is discussed in more detail in Section 2.2). There are three major types of marine fuel: diesel, residual, and a combination of the two to create a fuel type known as "intermediate" fuel oil (IFO). A large number of marine fuel grades within these three types represent the broad spectrum of fuels available to the shipping industry for vessel bunkering. In this section, the various grades of marine fuel are introduced using the colloquial industry names to group the different fuels types. See Section 4 for a more specific breakdown of the product specifications of marine fuels.

Distillate and residual fuels are blended into various combinations to derive the different grades of marine fuel oil. Table 2.1 lists examples of the major marine fuel grades and their vernacular industry nomenclature. In terms of cost, distillates are more expensive than intermediates, and residual fuels are the cheapest marine fuel-oil option.

Table 2-1. Marine Fuel Types

Fuel Type	Fuel Grade	Colloquial Industry Name
Distillate	DMX, DMA, DMB, DMC	Gas Oil or Marine Gas Oil (MGO)
Intermediate	RME/F-25, RMG/H-35	Marine Diesel Fuel or Intermediate Fuel Oil (IFO180 and IFO380)
Residual	RMA- RMH, RMK, and RML	Fuel Oil or Residual Fuel Oil

Source: Adapted from EPA, 1999.

Marine fuel characteristics depending on the refinery systems complexity (Spreutels and Vermeire, 2001). Hydroskimming create marine fuels by blending straight run product streams, while more advanced cracking refineries use produce similar products by blending outputs from catcracker and visbreaker units. See section 2.2 for highlights these manufacturing specifications.

Distillates and/or residual fuel oil stocks are blended with blending components or cutter stocks to achieve internationally-accepted product specifications provided by the 1987 (revised in 1996) international standard, ISO 8217, that defines the requirements for fuel grades for use in marine diesel engines. Marine fuel grades carry three letters, the first "D" or "R" specifies "distillate fuel" vs. "residual fuel". The second "M" signifies "marine fuel" use. The third letter designates the individual grade. Distillate marine (DM) fuels have three grades from A to C. Residual marine (RM) fuels have fifteen grades depicted by letters A through H, K and L. For example, RME -35 stands for "Residual Marine fuel E at a maximum viscosity (at 100 degrees C) of 35 centistokes (EPA, 1999).

Marine Fuel Blending Stocks

As described in Section 2.2, "hydroskimming" type refineries produce straight run stocks used in marine fuel blending, including light diesel, heavy diesel, and straight run residue. More complex refineries derive similar blending stock components as the output from fluidized bed catalytic cracking (FCC) units which includes light and heavy diesel, as well as light cycle gas oil (LCO) and heavy cycle gas oil (HCO). HCO also comes from the residual output from visbreaker units. These blending stocks are mixed with existing product streams from a refinery to manufacture a variety of marine fuel grades.

Marine Gas Oil (MGO)

Marine gas oil is the result of blending LCO with distillate oil to produce one of the highest marine fuel grades. MGO is more expensive because it is a lighter fraction and better quality fuel that diesel fuel. This type of fuel is produced at cracking refineries after vacuum distillate feedstock is put through a FCC catcracker. The catcracker produces FCC gasoline and LCO. MGO is a fuel best suited for faster moving engines (Spreutels and Vermeire, 2001).

Marine Distillate Oil (MDO)

Straight run marine gas oil and distillate type marine distillate oil (MDO) are manufactured by combining kerosene, light, and heavy gasoil fractions. DMA and DMB are typically used in small to medium sized marine vessels. Distillate fuels or heavy (high and low sulfur) distillates, and light fuel oil represent the more expensive range of marine fuels as they are most closely related to diesel fuel used in other transportation sectors. DMC is heavier fuel oil and may sometimes be referred to as an intermediate fuel oil because it can be blended with residual fuel. MDO is manufactured by blending DMC with 10 to 15 percent residual fuel

(Spreutels and Vermeire, 2001). MDO is a more expensive than the more common intermediate fuel types.

Intermediate Fuel Oil (IFO)

Residual marine fuel grade G (RMG-35) is one of the more common residual fuels used in transoceanic sea-going vessels. Also known as IFO380, this residual marine fuel is manufactured at the refinery and contains visbroken residue, HCO, and LCO (Spreutels and Vermeire, 2001). IFO380 typically has a high sulfur content of 5 percent. IFOs less than 380 such as IFO180 represent a blend starting with IFO380 and blending it with a cutterstock of marine diesel, gasoil, LCO, or some combination of the three. IFO180 has a lower viscosity and metals content, but maintains the same sulfur content as IFO380.

2.2 Refining of Petroleum Products (Including Marine Fuels)

The refining processes used to produce petroleum products, including marine fuels, involve the physical, thermal and chemical separation of crude oil into its major distillation fractions, followed by further processing (through a series of separation and conversion steps) into finished petroleum products. EPA's sector notebook of the petroleum industry (EPA, 1995) details the primary products of refineries grouped into three major categories: **fuels** (motor gasoline, diesel and distillate fuel oil, liquefied petroleum gas, jet fuel, residual fuel oil, kerosene, and coke); **finished nonfuel products** (solvents, lubricating oils, greases, petroleum wax, petroleum jelly, asphalt, and coke); and **chemical industry feedstocks** (naphtha, ethane, propane, butane, ethylene, propylene, butylenes, butadiene, benzene, toluene, and xylene). This discussion focuses on the "fuels" product category, and specifically the distillate and residual fuels that are blended to form marine fuels.

Refineries are complex operations and often have unique configurations based on the properties of the crude oil to be refined (which varies significantly depending on the source) and the desired distribution of refined products. The major unit operations outlined below represent a generic set of operations found in refineries around the world. Figure 2-1 illustrates general unit operations and product flows for a typical refinery. These refinery operations can be broken down into four major stages: distillation, desulfurization, refining, and blending.

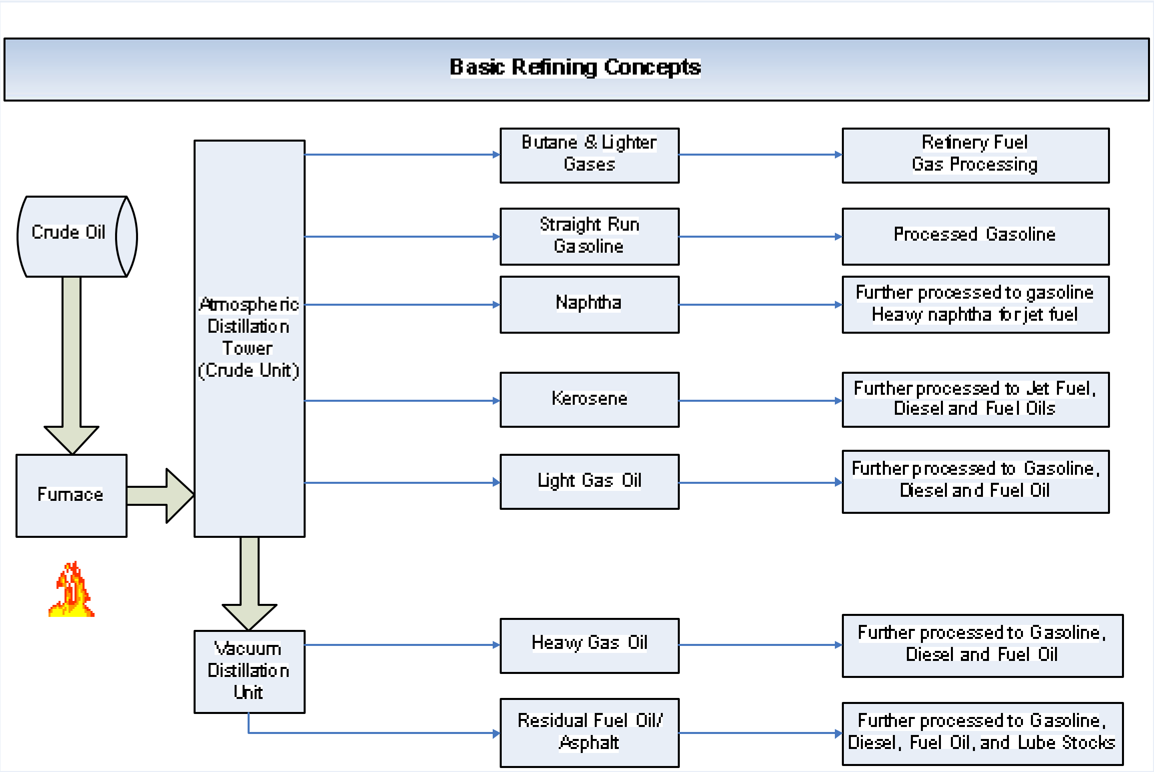


Figure 2-1. Basic Refining Process and Product Streams

Source: Adapted from Marcogliese, 2005.

Following an initial desalting process to remove corrosive salts and excess water, crude oil is fed into an atmospheric distillation column that separates the feed into the subsequent distillation fractions. The lightest of the fractions, which include light gasoline, ethane, propane, and butane (also know as the top gases), are further processed through reforming and isomerization to produce gasoline or may be diverted to lower-value uses such as liquefied petroleum (LP) gas and petrochemical feedstocks. The middle-boiling fractions, which include kerosene, gasoil, and spindle oil, make up most of the aviation fuel, diesel, and heating oil produced from the crude feed. The remaining undistilled liquids (called "bottoms") represent the heavier fractions that require vacuum distillation at very low pressures (0.2 to 0.7 psia) to facilitate volatilization and separation. Vacuum distillates and residues can be further processed through catalytic cracking and visbreaking into low-value products such as residual fuel oil, asphalt, or petroleum coke.

The lower middle distillates may also require additional processing through additional downstream processing. These fractions are treated using one of several techniques including: "cracking/visbreaking," which breaks apart large hydrocarbon molecules into smaller ones; and "combining" (e.g., alkylation, and isomerization), which joins smaller hydrocarbons to create larger more useful molecules, or reshaping them into higher value molecules. Additionally catalytic "hydrocracking" is a downstream processing method used to crack fractions that can not be cracked in typical cracking units. These fractions include middle distillates, cycle oils, residual fuel oils, and reduced crudes. Typically, the feedstock to a hydrocracking unit is first hydrotreated to eliminate any impurities (e.g., sulfur, nitrogen, oxygen, halides, and trace metals) that could deactivate the catalyst.

Following the completion of downstream processing stages, several product streams are blended by the refinery to produce finished products. Generally, these blending operations include gasoline, middle distillate, and fuel oil blending.

2.2.1 Primary Refinery Inputs

Crude oil is the dominant input in the manufacture of refined petroleum products, accounting for approximately 79 percent of total material costs of U.S. refineries, or $132 billion in 2002, according to the latest Economic Census (U.S. Bureau of the Census, 2004). Table 2-2 provides a summary of these inputs. Similarly, crude accounts for over 92 percent of the volume of refinery inputs in the United States. Crude oil is likely to have greater representative share of both material costs and inputs in developing countries due fewer environmental regulatory product specifications.

Table 2-2. Total U.S. Refinery Input of Crude Oil and Petroleum Products in 2004

Product	Year 2004 (1,000s barrels)	% of Total
Crude Oil	**5,663,861**	**92.3%**
Natural Gas Liquids	**154,356**	**2.5%**
Other Liquids	**316,838**	**5.2%**
Other Hydrocarbons/Oxygenates	150,674	2.5%
Other Hydrocarbons-Hydrogen	28,039	0.5%
Oxygenates	122,635	2.0%
Fuel Ethanol	74,095	1.2%
MTBE	47,600	0.8%
All Other Oxygenates	940	0.0%
Unfinished Oils (net)	186,826	3.0%
Motor Gasoline Blending Components (net)	-18,558	-0.3%
Aviation Gasoline Blending Components (net)	-2,104	0.0%
Total Input to US Refineries	**6,135,055**	**100.0%**

Source: EIA, 2005a.

Crude Oil

Characteristics of crude oil – including relative density, sulfur, and acid content – have a significant influence on the distribution of petroleum products a refinery is able to produce. The cost of production also varies significantly depending on the type of crude oil used in the refining process. Such characteristics tend to vary significantly based on the crude's regional origins.

Crude-oil density can be measured using the API gravity number, which provides a measure of relative density. Crude oils are typically classified as light, medium, and heavy oils. Light crude has the highest API number, equating to low density, which makes this crude type the easiest to refine into gasoline products. Heavy crudes, with the lowest API number and higher relative density, require additional processing to obtain the same distribution of refinery products.

Sulfur content determines whether a specific type of crude is "sweet" (low sulfur) or "sour" (high sulfur). Sweet crude is defined as crude oil with a sulfur content of less than 0.5 percent, and sour crude has sulfur content higher than 0.5 percent. Sweet crude is less corrosive due to low levels of sulfur compounds such as hydrogen sulfide (H_2S). Sour crude requires additional equipment and processing to extract the higher amounts for sulfur.

Crude oils' relative density and sulfur content vary, depending on the region of the world that it was extracted from. Light, sweet crude types typically have the highest prices due to limited availability and high demand. Heavy, sour crude typically sells at a discount relative to the light sweet crude due to its relative abundance, compared to light sweet, and its high sulfur content. Light sweet crude includes WTI (West Texas Intermediate) found in the western hemisphere, and Brent (North Sea Crude) found in Europe. Heavy sour crude includes Arabian Heavy (Middle East) and Maya (Mexico). Figure 2-2 illustrates the spectrum of crude qualities. Density is plotted along the horizontal and sulfur content along the vertical axis.

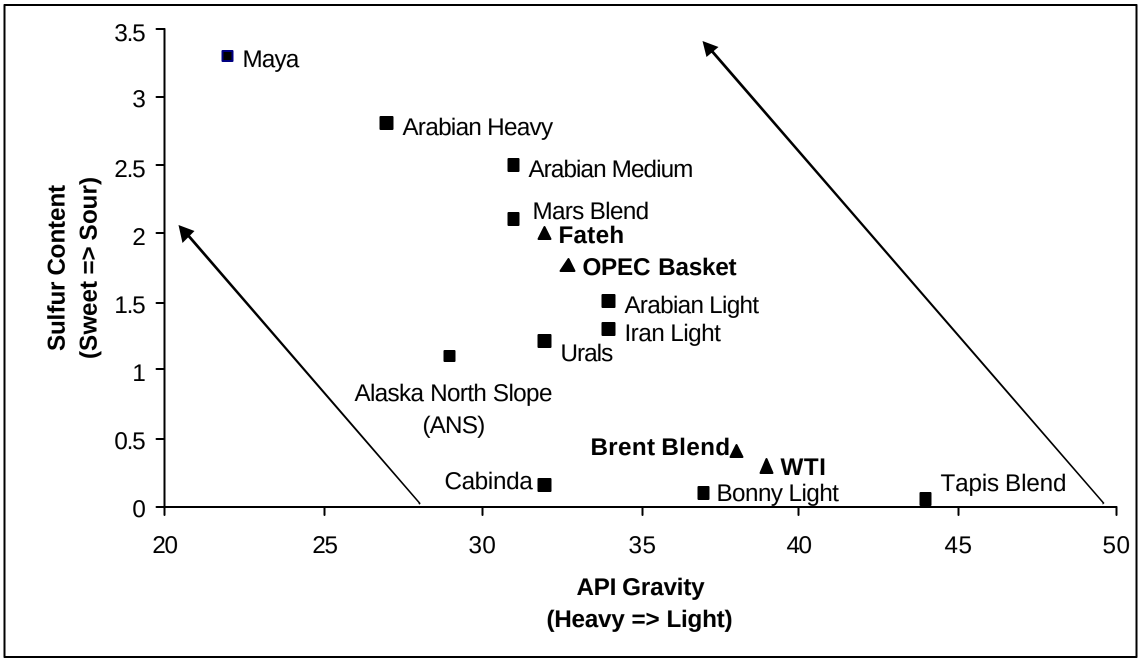


Figure 2-2. Quality by Crude Type

Source: Adapted from Marcogliese, 2005.
Note: ? = Benchmark Crude Types

In Figure 2-2, crude types near the lower right-hand corner of the figure represent the crude types that require the least amount of processing. As you move towards the top left-hand corner of the figure, the crude is more difficult to process. The majority of the world's supply of crude oil is light to medium sour, which is trending towards heavier and more sour crude as reserves of light sweet crude are depleted (Marcogliese, 2005).

WTI, Brent, and Dubai Fateh are the most commonly used benchmarks. These benchmark crude types are used in international trading, and varying qualities of crude are sold at a discount or premium relative to the benchmark price. OPEC has its own reference known as the OPEC Basket, which consists of 11 crude types and represents the weighted average of density and sulfur content for all the member countries' crude types, according to production levels and export volumes. Table 2-3 lists these 11 crudes:

Table 2-3. Crude Oil Types Included in the OPEC Basket

Type of Crude	Country of Origin
Saharan Blend	Algeria
Minas	Indonesia
Iran Heavy	Islamic Republic of Iran
Basra Light	Iraq
Kuwait Export	Kuwait
Es Sider	Libya
Bonny Light	Nigeria
Qatar Marine	Qatar
Arab Light	Saudi Arabia
Murban	UAE
BCF 17	Venezuela

Source: EIA, 2005b.

Blending Stocks and Additives

Following initial atmospheric distillation of crude oil, a variety of specialized inputs may be added to output product streams (see Figure 2-1) in downstream units to enhance the refinery's ability to recover a desired mix of products. Among these products might be unfinished oil, residual fuel oil used as input to a vacuum distillation unit (see Table 2-2 for a list of additives). Motor gasoline and aviation fuels require blending components that include oxygenates as well as other hydrocarbons. While they are counted as "refinery inputs," they are brought to saleable specifications in terminals and blending facilities, not in conventional refineries.

2.2.2 Refinery Production Models

Across the globe, refineries are typically concentrated near major consumption areas, based on the principal that transporting crude oil is cheaper than transporting refined products. In addition, proximity to consumption areas allows refineries to more quickly respond to seasonal or weather-related demand shifts (Trench, 2005). Their goal is to meet the regional demand for petroleum products, hence maximizing the value of product mix produced. For example, in the United States, as well as other developed countries, refineries strive to maximize gasoline and low-sulfur diesel fuels, while simultaneously minimizing output of lower value heavy oils such as residual fuel and petroleum coke.

Building on the basic refinery concepts presented in Figure 2-1, refineries can be grouped into four basic configurations: topping, hydroskimming, cracking (*medium* conversion), and coking (*high* conversion). Each configuration builds on the previous production model by adding on additional downstream processing equipment that allows the refinery to further expand its yield of the desired mix of petroleum products.

Topping Refineries

Topping refineries are the simplest example of a refinery production model. Their primary function is to produce feedstocks for petrochemical manufacturing. Topping refineries typically consist of storage tanks, an atmospheric distillation unit, and recovery facilities for top gases and light hydrocarbons such as ethane/propane/butane. These facilities produce naphtha, but do not produce gasoline (Reliance, 2005).

Hydroskimming Refineries

Building on the basic topping configuration, hydroskimming refineries incorporate hydrotreating (distillate desulfurizer) and catalytic-reforming units to improve the output of high value fuels such as distillates and straight-run gasoline. Table 2-4 lists the typical mix of product yields from hydroskimming refineries.

Table 2-4. Typical Production Yield from a Hydroskimming Refinery

Product	% Yield
Propane/butane	4%
Gasoline	30%
Distillate	34%
Heavy fuel oil & other	32%
Total Yield	**100%**

Source: Marcogliese, 2005.
Note: *Gasoline* includes reformulated gasoline (RFG), conventional, CARB, and Premium. *Distillate* includes jet fuel, diesel, and heating oil.

These facilities typically rely primarily on light sweet crude as their primary input in order to minimize the resulting heavy fuel and residual fuel products because they have limited upgrading capabilities of distilled fractions. Hydrotreating removes impurities such as sulfur, nitrogen, oxygen, halides and trace metals. Hydrotreating also upgrades the quality of these fractions by converting olefins and diolefins to paraffins to reduce gum formation in fuels (EPA, 1995). Catalytic reforming units process straight-run low-octane gasoline and naphthas into high-octane aromatics through four reactions that to create aromatics by removing hydrogen from the feedstock (see EPA [1995] for details of these reactions).

Cracking Refineries

Cracking refineries build in complexity from the hydroskimming configuration by adding vacuum distillation, catalytic cracking, and alkylation units. The vacuum distillation unit further fractionates heavy "bottoms" from the atmospheric distillation process into gas oil and residual fuel. Table 2-5 lists the typical mix of product yields from cracking refineries. The total yield of 104% represents a volumetric gain due to the cat cracker's ability to convert large hydrocarbon molecules into multiple smaller molecules. These facilities typically rely on light sour crude as the primary input. Moderate upgrading capabilities allow cracking refineries to increase the yield of higher value products as well as gain volumetric output per volume of crude oil input (Marcogliese, 2005).

Table 2-5. Typical Production Yield from a Cracking Refinery

Product	% Yield
Propane/butane	8%
Gasoline	45%
Distillate	27%
Heavy fuel oil & other	26%
Total Yield	**104%**

Source: Marcogliese, 2005.
Note: *Gasoline* includes reformulated gasoline (RFG), conventional, CARB, and Premium. *Distillate* includes jet fuel, diesel, and heating oil.

The catalytic cracking unit (i.e., fluidized and moving-bed) uses heat, pressure, and catalysts to breakdown heavy complex hydrocarbon molecules (i.e., gas oil) into smaller/lighter molecules such as Light Cycle Oil (LCO). LCO is then processed with other distillates in the hydrotreating process to remove to produce diesel and heating oils. Once the LCO and FCC Gasoline are removed, an alkylation unit converts the remaining iosbutane feedstock into alkylates (i.e., propane/butane liquids), which are widely-used blending additives in high octane gasoline production.

Coking Refineries

Coking refineries extend the cracking refinery by adding hydrogen processing, hydrocracker, and delayed coking units to increase their capabilities to convert fuel oil into distillates (Reliance, 2005). Coking refineries are able to use medium to heavy sour crude as the primary input to the refining process. These refineries also have the highest light product yields and volume gains, compared to other refinery configurations (Marcogliese, 2005).

Table 2-6. Typical Production Yield from Coking Refineries

Product	**% Yield**
Propane/butane	7%
Gasoline	58%
Distillate	28%
Heavy fuel oil & other	15%
Total Yield	**108%**

Source: Marcogliese, 2005.
Note: Gasoline includes reformulated gasoline (RFG), conventional, CARB, and Premium. Distillate includes jet fuel, diesel, and heating oil.

The hydrogen facility produces hydrogen that is used as a feedstock in the hydrocracker as well as the hydrotreater units. The hydrocracker units apply hydrogen and significant pressure in a fixed-bed catalytic cracking reactor. Feedstocks for this unit include low distillate fractions, as well as LCO, residual fuel oils. The hydrogen mitigates the formation of residual fuels and increases the yield in middle distillate fuels such as diesel and jet fuels (EPA, 1995). Delayed coking is a thermal cracking process that upgrades and converts petroleum residuum (heavy fuel oil) into liquid and gas product streams. The delayed coker unit eliminates residual fuel oil leaving behind a solid concentrated carbon material know as petroleum coke (Ellis and Paul, 1998).

2.2.3 Refineries Around the World

There are major concentrations of refineries around the world, representing 674 individual installations and 82.4 million barrels per day of crude oil refining capacity at the end of 2004 (OGJ, 2004). The number of operable refineries had fallen by 43 from 717 in 2003, which represented a decline of 6.4 percent. Over the last five years, the number of refineries worldwide has declined, while the total crude capacity has continued to rise (Nakamura, 2004).

Table 2-7 summarizes the number, estimated crude capacity, and fuel "processing" capacity for refineries in seven world regions at the end of 2004. Historically, the mature markets of the United States and Europe have contained the largest number of refineries. However, recent dramatic growth in Asian markets has resulted in increased number of refineries in South Korea, along with other South Pacific countries.

Table 2-7. Refinery Presence by World Region in 2004

Region	Refinery Count	Crude Capacity	Fuels Processing Capacity[a]	Processing Capacity as % of Crude
		(barrels\calendar day)		
Africa	46	3,230,362	506,470	2.4%
Asia & Oceania	161	20,695,031	2,052,728	10.0%
Central & South America	66	6,572,359	529,190	3.5%
Eastern Europe & Former U.S.S.R.	86	9,764,712	1,467,693	15.0%
Middle East	45	6,471,615	691,730	10.5%
North America	159	20,476,228	5,598,388	86.5%
Western Europe	111	15,198,594	2,480,458	76.8%
World Total	**674**	**82,408,901**	**13,326,657**	**16.2%**

Source: OGJ, 2004.

a. Processing capabilities are defined as conversion capacity (catalytic cracking, and hydrocracking) and fuels producing processes (catalytic reforming and alkylation) divided by crude distillation capacity (% on crude) this measure represents the presence of downstream processing technology that improves the refinery's ability to produce high value refined products such as high octane gasoline.

The concentrations of refineries in Asia, North America, and Western Europe represent approximately 68 percent of total refinery capacity. North American and Western European refineries have invested heavily in processing units that will maximize their output of gasoline and other high value outputs. This is illustrated by their processing capabilities as a percent of crude capacity. In other regions of the world, refineries rely on atmospheric distillation to obtain straight-run product streams. As a result, residual fuel oil tends to be a greater share of total refinery output in these regions.

Refineries typically address regional fuel demands, while maintaining only a minimal stock of additional output for international trade and unexpected supply shocks due to weather. They are constrained by local demand, as well as the crude types that are proximal to the facility. Table 2-8 lists the 25 largest refinery companies of the world by total crude capacity. These firms represent 60 percent of the world's crude refining capacity. The refinery companies on this list have focused on expanding capacity and reducing the total number of operable refineries over the last ten years (Nakamura, 2004).

Table 2-8. World Largest Refinery Companies by Capacity in 2004

Rank	Company	Crude Capacity (1,000s b/cd)
1	ExxonMobil Corp.	5,693
2	Royal Dutch/Shell	4,934
3	BP PLC	3,867
4	Sinopec	2,793
5	Petroles de Venezuela SA	2,641
6	Total SA	2,622
7	ConocoPhillips	2,615
8	ChevronTexaco Corp.	2,063
9	Saudi Aramco	2,061
10	Petroleo Brasileiro	1,965
11	Valero Energy Corp.	1,930
12	Petroleos Mexicanos	1,851
13	China National Petroleum Corp.	1,782
14	National Iranian Oil Corp.	1,474
15	Nippon Oil Co. Ltd.	1,157
16	OAO Lukoil	1,150
17	Respsol YPF SA	1,106
18	Kuwait National Petroleum Co.	1,085
19	OAO Yukos	1,048
20	Pertamina	993
21	Marathon Ashland Petroleum LLC	935
22	Agip Petroli SpA	906
23	Sunoco Inc.	880
24	SK Corp.	817
25	Indian Oil Corp. Ltd.	777

Source: Nakamura, 2004.

Many of the largest refinery companies have been investing heavily to supply Asian markets due to anticipated long-term growth in the region, which growing at approximately four percent, compared to the more mature markets of Europe and Japan that are expected to grow at less than one half of one percent (Mergent, 2005). This high growth in Asia can largely be attributed to expected growth in the transportation sector, including both freight shipping and personal vehicles.

As discussed, refinery products are diverse in character and functionality, and the specific mix of products will vary dramatically depending on the refinery's configuration and type of crude used. Table 2-9 summaries how these effects alter production of different refinery products varies across regions of world in 2002.

Table 2-9. World Refinery Product Outputs of World Refineries per Day for 2002

Region	Motor Gasoline	Distillate Fuel Oil	Residual Fuel Oil	Other	Total Refinery Products
	(Million Barrels per Day)				
Africa	9.6	4.5	1.2	5.7	21.0
Asia & Oceania	3.6	5.8	2.8	7.2	19.3
Central & South America	3.4	5.1	2.1	4.2	14.8
Eastern Europe & FSU	1.3	1.6	1.2	1.9	6.0
Middle East	1.3	2.0	1.7	1.7	6.7
North America	0.9	1.8	1.6	2.0	6.3
Western Europe	0.5	0.7	0.7	0.8	2.7
World Total	**20.6**	**21.4**	**11.2**	**23.6**	**76.8**

Source: EIA, 2005c.

Motor gasoline is the highest-value product in the refinery output mix, hence facilities typically engineer their unit operations to maximize its production. In North America, motor gasoline is typically the largest share of refined products – representing 46 percent of refinery output per day – while distillate and residual fuel accounted for 21 and 6 percent, respectively, in North America's refineries output. However, in all other major regions of the world, motor gasoline represented less than 20 percent of total refinery output on average. Figure 2-3 illustrates these regional differences in the distribution of motor gasoline, diesel, and residual fuel production for seven world regions.

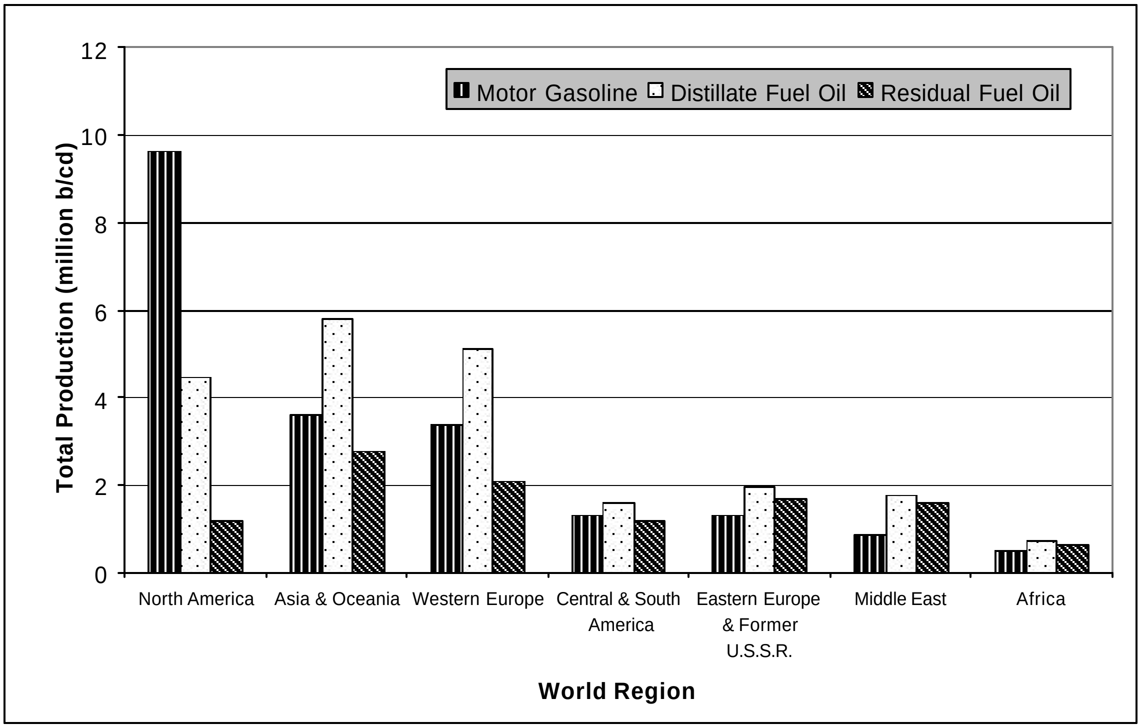


Figure 2-3. Product Outputs of World Refineries per Day in 2002

Source: EIA, 2005d.

Distillate fuel represents the largest share of refinery outputs for all regions outside of North America, on average accounting for 30 percent of total refinery products in 2002. Residual fuel oil accounted for an additional 21 percent, on average. Other products such as petroleum feedstocks, jet fuels, and LPG gas accounted for 17, 5, and 6 percent respectively.

The demands for gasoline in mature markets (e.g., United States, Europe, and Japan), and resulting refinery configurations, have resulted in dramatic reductions in production of residual and distillates. North American refinery executives agree that relative market prices for refined motor gasoline make it a more attractive refinery output than low-sulfur residual fuels (BunkerWorld, 2005). Despite the potential of hydroprocessing to treat high sulfur residual fuels, the technology is not yet cost effective for refiners.

For these reasons, bunker fuels may witness shortages as refineries continue to keep pace with demands for motor gasoline and other high value refined products in the North America and Western Europe, where motor gasoline prices are equally high relative to other refined products (these trends are included in the WORLD model and discussed in Sections 4 and 5). Industry experts have estimated that the North America could witness a shortage of low-sulfur residual fuel of 20 million metric tons per year by 2015 and a surplus of high sulfur residual oil of 40 million metric tons per year (BunkerWorld, 2005). To address these shortages, the industry expects an increase in low-sulfur residual fuel oil imported from South America or other areas of the world with low conversion capacity (and thus high residual fuel output).

In developing regions such as the African, the Middle Eastern, and Asian markets, availability of sweet crude supplies, coupled with limited conversion capacity in existing regional refineries, will result in continued production of residual fuels. Over time, as sweet crude becomes increasingly scarce and the sulfur content of crude feedstocks increases, refineries in these regions will be forced to upgrade their conversion capacity by adding additional downstream processing to existing facilities or the share of heavy distillates and residual fuel oils of their total refinery outputs will increase.

Finally, as China's market for fuel demand increases, Chinese oil companies are beginning to compete with U.S. and European companies for depleting supplies of the world's crude oil. The Energy Information Administration (EIA) predicts that China will begin to invest in petroleum products in countries around the world, including Canada and South America, which have traditionally represented over 25 percent of the United States' energy imports. China signed its first oil deal with Venezuela in 2004, marking the beginning of a battle for resources with more mature markets such as the United States. If China continues to increase its presence in the West through acquiring petroleum resources that traditionally supplied residual fuel-oil demands in North America, any shortages in residual fuel-oil could increase exponentially (Mergent, 2005).

2.3 Bunker Fuel Suppliers

The supply chain providing marine fuels to the shipping industry is a complex network of organizational and trade relationships and is quite geographically dispersed. Aside from integrated petroleum refiners such as the operations discussed in Section 2.2, the industry's supply chain includes traders, suppliers, brokers, bunkering-service providers or facility operators, and bunkering ports. The information available on different segments of the bunker-fuel supply chain varies dramatically, and hence this section not comprehensive, but rather intended to provide an overview of the industry focusing on four of the largest bunkering ports (Singapore, Rotterdam, Fujairah and Houston).

Around the world, there are approximately 400 major bunkering ports. Logistics and transport cost factors influence the location of these bunker ports as well as local environmental regulations. In addition to being located close to supply sources (petroleum refineries) and consumers of transported goods (major population centers), bunkering ports are often strategically located along high-density shipping lanes. For example, Singapore handles more than twice the bunker-fuel volume of Rotterdam, the next largest port. Panama and Gibraltar are examples of strategically located facilities. In North America, the largest facilities follow the general pattern suggested by location theory - with Los Angeles, San Francisco, New York, Philadelphia, Houston, and New Orleans close to both refinery supply and transport destinations.

2.3.1 Singapore

Singapore's strategic location, in regards to the Straight of Malacca, makes it the largest port in the world in terms of cargo throughput and bunker-fuel sales. The total cargo throughput in 2005 equaled 423 million tons. The port of Singapore handles large volumes of oil[1] and dry bulk cargo. In 2005, Singapore surpassed Hong Kong by almost 1 million twenty-foot equivalent units (TEUs) and claimed the lead in handling containerized cargo (Sina, 2006). Its tonnage of containerized, oil, and dry-bulk cargo has been steadily increasing over the past five years. Although the number of vessel calls has been slowly declining, Singapore still handles more vessel calls than any other port in the world - almost 173,000 vessel calls in 2005. (MPAS, 2005a).

The port of Singapore is also the largest bunker fuel market in the world. Bunker turnover was reported at 25.48 mmt (million metric tons) in 2005 (MPAS, 2006b). Turnover at the port grew at the average rate of 5.6 percent over the past six years, equaling 20.8 mmt in 2003 and 23.6 mmt in 2004. Heavy fuel-oil sales accounted for 71 percent of total bunker sales by volume in 2004, with lighter fuel and distillate oils accounting for 19 percent and others (including lube oils) for remaining 2 percent. (MPAS, 2005c). The majority of bunker deliveries to vessels in the port of Singapore are made by bunker tankers, however, other types of deliveries are available as well.

Refineries

Singapore is the one of the top three refining centers in the world, accompanied by Houston and Rotterdam. Petroleum refining accounted for approximately 16.5 percent of Singapore's Gross Domestic Product (GDP) in 2004. Singapore's refineries have major influence on Asian markets: their petroleum product exports were valued at $17.5 billion in

---

[1] Including chemical and gas

2004.[2] Singapore also exported $4.7 billion worth of bunker fuels, which equalled 2.6 percent of national GDP (SMTI, 2005).

Operating at 92 percent capacity, the top three refineries in Singapore have a combined production of around 1.3 million bpd (EIA, 2005f). Out of that quantity, bunker fuels consumed in the Singapore shipping market comprise approximately 400,000 bpd. Another 400,000 bpd are consumed locally for various purposes, and the remainder (mostly gasoline and diesel fuels) are exported to Vietnam, China, and Indonesia (Reuters, 2006).

Refineries producing bunker fuel that is sold in the local market are:

- **Jurong Island Refinery,** owned by ExxonMobil
    - Capacity of 605,000 bpd
- **Pulau Bukom Island Refinery**, owned by Royal Dutch/Shell
    - Capacity of 458,000 bpd
- **SRC Jurong Island Refinery,** partially owned by Singapore Refining Corporation (SRC), partially owned by ChevronTexaco through its subsidiary Caltex
    - Primary plant – a joint venture between SPC and Caltex (ChevronTexaco) with 285,000 bpd capacity
    - Owns a bunker storage terminal on the Pulau Sebarok Island, with storage capacity of 1.4 million barrels

These three refineries have a combined storage capacity of 88 million barrels, and the demands for storage have been increasing. Singapore's three largest independent storage operators, Vopak, Oiltanking, and Tankstore, have been utilizing 90 percent of their combined total capacity of 22.3 million barrels in the past five years. Production plans are underway that, when complete, will almost triple the storage capacity of local operators (EIA, 2005f).

Even though refining has a strong presence in Singapore, imports of refined petroleum products equalled $12.6 billion (11.4 percent of national GDP) (SMTI, 2005). Consumption of imported oil products reached 750,000 bpd in 2004 (EIA, 2005f). The Singapore bunker fuel market is very diverse - fuel from all major refineries around the world gets delivered to the port.

---

[2] Numbers are reported in US dollars

Even though no numerical data are readily available, based on qualitative assessments, majority of these world imports come from Venezuela, Chile, and Russia (Bunkerworld, 2005d).

Bunker Traders

There are 23[3] companies that serve as traders in the Singapore shipping market. Among them are smaller local companies such as Bunker House Petroleum, as well as larger international oil companies such as Lukoil and OW Bunker. Among the leaders are OW Bunker and Hin Leong, the latter of which recently scheduled construction of the largest petroleum terminal in the area with total storage capacity of 14.5 million barrels.

Bunker Suppliers

Thirty-four companies serve as bunker suppliers, with an additional 18 that perform functions of suppliers and traders. Three refinery operators are also among top four suppliers (British Petroleum, Shell, and ExxonMobil). They are joined by Global Energy Trading, a smaller company that owns and operates 14 vessels at the port. Other major suppliers include Consort Bunkers, Singapore Petroleum Company, Chevron Singapore, OW Bunker, and Chemoil (SMP, 2006).

Barge Operators

The number of independent barge operators is also large: there are 32 companies performing this function in the port of Singapore. The bunker barge fleet contained approximately 120 vessels of various sizes in 2005 (Bunkerworld, 2005e). The largest among the barge operators is Ocean Tankers, a sister company of Hin Leong, which owns and operates 70 bunker barges.

2.3.2 Rotterdam

Rotterdam is the second largest port in the world with throughput of more than 369 million tonnes of cargo in 2005 (Port Authority of Rotterdam, 2005). Some 30,000 seagoing vessels call at the port every year and 110-120 thousand inland vessels. Activities related to the port contribute around 12 percent of the Gross National Product of the Netherlands (Bunkerworld, 2000). Overall, the port of Rotterdam has experienced a 5 percent increase in

---

[3] Consort Bunkers Pte Ltd, Searights Maritime Services Pte ltd, Bunker House Petroleum Pte Ltd, Northwest Resources Pte Ltd, Golden Island Diesel Oil Trading Pte Ltd, Lukoil Asia Pacific Pte Ltd, Alliance Oil Trading Pte Ltd, Costank (S) Pte Ltd, Sentek Marine & Trading Pte Ltd, Lian Hoe Leong & Brothers Pte Ltd, Standard Oil & Marine Services Pte Ltd, Panoil Petroleum Pte Ltd, Ocean Bunkering Services Pte Ltd (owned by Hin Leong Marine International Pte Ltd), O.W. Bunker Far East Pte Ltd, The Barrel Oil Pte Ltd, Fratelli Cosulich Bunkers (S) Pte Ltd, Prestige Marine Services Pte Ltd, Gas Trade (S) Pte Ltd, Wired Bunkering Pte Ltd, Cockett Marine Oil (Asia) Pte Ltd, Ignition Point Pte Ltd, Prosperbiz Petroleum (S) Pte Ltd

cargo handling with the majority of growth coming from container cargo, which had a 12 percent increase to 9.3 million TEUs between 2004 and 2005. General cargo was up 7 percent, or 7 million tonnes, to a total of 110 million tonnes in 2005.

Rotterdam is also the largest bunker port in Europe. Bunker turnover in 2004 for the port was 12.5 million cubic meters (m^3). In 2002 and 2003, bunker turnover was 10.6 and 11.4 million m^3, respectively (Port Authority of Rotterdam, 2004a). These volumes include heavy fuel oil, light gas oil, distillate oil, and lube oils (heavy fuel oil represents the majority of overall bunker turnover). Russian oil imports represent a significant share of total refined oil product supply. Between 2002 and 2003, Russian imports of crude and refined oil products grew by 17 percent (Port Authority of Rotterdam, 2004b).

Refineries

The Port of Rotterdam has a significant petroleum refinery presence (in 2004, oil refineries represented 6.5 percent of the 58,000 workers directly employed by the Port). However, due to environmental regulations and European fuel market conditions, refineries in the region around Rotterdam are producing much less heavy fuel oil (3-3.5% sulphur), which typically dominates bunker markets. Consequently, the local refinery output can no longer cover the Rotterdam bunker demand.

This shortage has led to increased reliance on fuel oil from import sources. Fuel oil imports are estimated to be 300 to 400 thousand metric tonnes per day. As mentioned earlier, Russian fuel oil products typically dominate the market. Venezuelan fuel oils are also a common import in the Rotterdam bunker market.

The local refineries that still produce bunkers sold in the Rotterdam market include:

- **The Pernis Refinery** , owned by Royal Dutch/Shell;
    - Capacity approximately 416,000 b/d.
- **NEREFCO** (Netherlands Refining Co.), owned by BP (69%) and Texaco (31%).
    - Capacity in excess of 380,000 b/d.
- **Q-8 refinery**, owned by Kuwait Petroleum Corporation.
    - Capacity about 75,500 b/d.
- **The Esso Refinery** (ExxonMobil) does not produce fuel oil, but the company sources from a plant in Antwerp, Belgium with capacity of 225,000 b/d.

Bunker Traders

Bunker traders secure bunker volumes for their shipping clients in local supply markets or in their own refined-products distribution channels. Traders include both major oil companies as well as independents. Both types perform the functional service of in the timely procurement of bunker fuel orders. Traders act as midway between local customers and refinery suppliers, where the majority of transactions occur under long term contracts.

Traders in the Rotterdam market include oil majors, such as Shell Marine Products, and Lukoil. Shell Marine Products utilizes the majority of its' Pernis refinery's marine fuel output for its own clients (Bunkerworld, 2000), while the majority of NEREFCO's output is purchased by independent traders in the local fuel-barge market.

Independents typically purchase their bunker fuel on the local barge market. In addition, it is common for traders to import cargos of bunker fuel and store the fuel in rented storage tanks in the petroleum zones of the port. Vitol, Allround Fuel Trading/Chemoil, and the oil majors, especially Texaco, BP and Elf (TotalFinaElf), are the largest bunker traders of import oil product cargos (Bunkerworld, 2000).

Bunker Suppliers

Physical supplying of bunker fuel to ships is conducted by barge in the bunkering designated zones. Europort and Botlek areas are two primary bunkering areas within the port of Rotterdam. In 2000, over 90 percent of the bunkers in Rotterdam were delivered by barge (Bunkerworld, 2000).

Barges are loaded at various fuel-terminal facilities owned by Vopak and the oil majors. Most suppliers, including the oil majors, do not own or operate their own barges. Most majors and some independents have specially dedicated barges or barges on exclusive time charter. Among many independents, it is common practice to pool barge transportation services (Bunkerworld, 2000).

Due to the nature of physically supplying bunkers, large storage capacity is needed to enable flexibility in the suppliers' ability to respond to sudden fluctuations in bunker demand. The most recent example of traders enlarging storage capacity is the partnership of Lukoil and Fuel Transport Services (FTS)/Hofftrans (a local barge operator) partnering to build a bulk terminal named the Service Terminal Rotterdam (STR). STR is designed for better bunkering and ship-ship transhipment. This expansion is estimated to increase total storage capacity to 120,000 m^3. Another expansion is currently under way by the Vitol Group, which is constructing a 278,000 m^3 storage tank terminal in the Europort area. The Vitol facility is expected to begin operations in 2006 and will provide jetties capable of accommodating vessels ranging between bunker barges and very large crude oil carriers (VLCCs).

Barge Operators

The biggest barge operator is VT/Unilloyd, which works exclusively in transportation and owns more than 20 barges. FTS/Hoftrans has around 10 barges of up to 2000 mt capacity. A group of companies, which includes the suppliers Atlantic/Postoils, operate their own fleet of 21 barges ranging from 300-3,900 mt capacity. These barges also deliver on behalf of other suppliers (Bunkerworld, 2000).

Additionally, some suppliers own their own fleet of barges. One example is Argos Bunkers BV, which has its own fleet of six barges ranging from 200 to 1,400 mt capacity, plus the company charters three more barges ranging from 700-2,000 mt. Ceetrans/Ceebunker Services BV is owned by Argos and has access to the same barges. Frisol Bunkering BV has three time-chartered barges totalling 4,270 mt in capacity. NIOC (Netherlands Independent Oil Co.) has access to the 23 strong barge fleet of its Belgian parent company, Wiljo Bunkering NV (Bunkerworld, 2000).

2.3.3 Fujairah

Fujairah is the third largest bunkering port in the world, supplying over 12 million mt of bunker fuel annually (Gulf News, 2006). The Fujairah bunker market is comprised of three port areas, which include the United Arab Emirates (UAE) ports of Khor Fakkan, Fujairah and Kalba. Fujairah is situated in the middle of these three ports, with Khor Fakkan to the north. The three ports and their offshore counterpart in the Gulf of Oman, constitute "the Fujairah bunker market" – although there are some local differences, unless otherwise stated, "Fujairah" is seen as incorporating the entire area (Bunkerworld, 2002). Fujairah is located in the outer Gulf, just outside the Straits of Hormuz, which are the gateway to the Arabian Gulf (the inner Gulf). Because of their proximity to Middle Eastern oil production, Fujairah's bunker customers are predominately VLCCs, which are often anchored in the Gulf of Oman waiting for cargo in the inner Gulf.

While official data regarding the turnover of bunker fuel in the Fujairah market are not available, industry experts have estimated the annual volume to be over 12 million metric tons (mt) in 2002, with an average monthly supply volume of bunkers of around 1 million mt. Because tankers are the major customers in the Fujairah market, large bunkers rather than numerous small deliveries are the norm. The average supply volume varies between 2,000 mt to 15,000 mt (Bunkerworld, 2002). Assuming an average volume per vessel, this implies that approximately 120,000 bunkering transactions take place in the Fujairah market each year.

Several estimates exist regarding the market share of each bunker fuel grade. IFO 380 is estimated to account for between 80-95 percent of total bunkers supplied. The remaining 5-20 percent are split between IFO180 and MGO, but exact shares are not available. Typically, Fujairah is host to the most competitive pricing of bunker fuel in the Arabian Gulf. However, the price differences between IFO 380 and 180 cst grades in Fujairah are typically higher than those found in Singapore or Rotterdam (Bunkerworld, 2002). The significant price difference between IFO 380 and 180 is due to a lack of cheap cutter stock typically used in blending to create lighter fuel grades in the Arabian Gulf. As a result, Fujairah's bunker suppliers are forced to use MGO in blending activities. This, more expensive, alternative makes purchasing lighter grades of residual fuel such as IFO180 less attractive in the Fujairah market (Bunkerworld, 2002).

Refineries

Fujairah itself has only one refinery facility – the Fujairah Refinery Company (FRC) (Nakamura, 2005). The FRC plays a vital role in supplying straight-run fuel oil to the Fujairah bunker market and has been attributed as what enabled the port to emerge as a leader in the region. Metro Oil Corporation ran the facility until the late 1990s when it was shutdown. The FAL Energy Company took over the facility in 2004 to utilize its 460,000 m^3 of storage capacity (Nakamura, 2005). The Fujairah government in 2005 announced a desire to revitalize the facility and update processing technologies. Currently, the FRC refinery does not contribute a huge amount of bunkers to the local market.

The Abu Dhabi National Oil Company (ADNOC) operates two refineries in the UAE, including the Umm Al Nar and Ruwais refineries. The two refineries produce over 23 million mt of products annually, which are sold to both international and local markets (Bunkerworld, 2002). The Umm Al Nar refinery processes 150,000 bpd of crude oil, and the Ruwais refinery has two units with a total design capacity of 350,000 bpd. The Emirates National Oil Company Limited (ENOC) operates the 120,000 bpd Jebel Ali plant (Nakamura, 2005).

Other refineries located near Fujairah cover 14 major refineries and include: Bahrain National Oil Company's refinery, Aramco's five Saudi refineries, the National Iranian Oil Company's (NIOC) six refineries in Iran, and from Kuwait Petroleum Corporation's (KPC) three Kuwaiti plants (Nakarmura, 2005; Bunkerworld, 2002).

Bunker Traders

Through contracts with local suppliers, bunker traders arrange supply deliveries in the Fujairah bunker market. These firms provide services that ensure that bunker supplies are available and delivered in timely fashion. The Fujairah bunker market is presently serviced by approximately 11 trading companies that include FAL Energy Company, GAC Bunkers Co., and FAMM Middle East Ltd.

Bunker Suppliers

The offshore terminals in Fujairah make it an ideal bunkering stop-off for both inbound and outbound tankers leaving the Gulf (Bunkerworld, 2002). Typical bunkering entails bunker barges loading from storage tankers and supplying bunkers to passing vessel traffic that is moving through the Hormuz strait between the Arabian Gulf and the Gulf of Oman.

Most suppliers import their products and then store bunkers in large tankers that reside in the Gulf or in shore-based fuel terminals. The majority of companies purchase product from refineries in the UAE or other regional refineries. The port of Fujairah is serviced by 20 suppliers, representing a mix of local business as well as international bunker suppliers such as German based Bominflot, BP Marine Middle East located in Dubai, UAE.

EPPCO International, a joint venture between ENOC and Caltex, owns and operates some of the largest refined-petroleum terminalling facilities in the UAE. The terminals are spread between Jebel Ali and Fujairah, and represent 6.44 million barrels in storage capacity. In 2002, Vopak ENOC Fujairah Terminal Company had 30 tanks (10 tanks designed to handle fuel oil) with a total capacity of 1million m^3 storing fuel oil, gasoil, gasoline, naphtha, and jet kerosene. The Vopak terminal offers products to the local market via three berths capable of accommodating vessels up to 175,000dwt (Bluewater, 2002). Additional capacities are designed to serve the active fuel-oil market offshore, whether for cargo trading or for bunkering purposes.

Other examples of suppliers in the Fujairah market include FAL and EPPOC. The longest established bunker company in the UAE is FAL Energy Company, which leases storage capacity at the Fujairah Refinery (FRC) and has 24 tanks with a combined capacity of 422,000 cubic meters storing fuel oil, gasoil, naphtha, and jet kerosene. Finally, the Emirates Petroleum Products Co. (Eppco), a subsidiary of ENOC, expanded its existing storage capacity from 100,000 m^3 to over 150,000 m^3 in 2003. These investments in supplier infrastructure indicate the growing importance of this bunker market.

Barge Operators

The Fujairah market is largely served through off-shore deliveries by barge. For this reason, many suppliers operate their own barge fleet in the Gulf of Oman. In addition, there are eight independent barge operators offering service. The FAL Energy Company has a number of bunkering vessels operating in both the Arabian Gulf and the Gulf of Oman. Larger international suppliers such as ExxonMobile's Marine Fuels (EMMF) Company often contract with independent barge operators in the Fujairah market, following detailed certification by EMMF (EMMF, 2006).

2.3.4 Houston

The Port of Houston ranks second in U.S. foreign waterborne commerce and total tonnage. In 2004, 6,539 ships called at Houston (traffic is dominated by container ships, tankers and bulk carriers). Houston is a mix of private and public terminals. The areas controlled by the Port of Houston Authority can be divided into four main areas:

- The City Dock, also called the Turning Basin
- Barbours Cut Terminal, the main terminal for containers (940,000 TEU's in 1996)
- Jacintoport Terminal, a general cargo handling port
- Woodhouse Terminal, for ro-ro cargo vessels

Development of a new container terminal is now at the design stage at the Port. It is intended to alleviate pressure at the Barbours Cut Terminal, which was forecast to pass one million TEUs by 1998.

Refineries

Surrounding the port of Houston, local refineries include (among others) ExxonMobile's Baytown Refinery, BP's Texas City Refinery, Marathon Ashland's Texas City and the Valero Refinery. While these refineries represent a significant share of the U.S. capacity in refined products, they do not produce marine fuels. Typically, marine fuel is imported from countries in the western hemisphere where refinery production of heavy fuel oil is greater than in the United States. These imports most often come from Venezuela, Aruba, and Mexico.

Bunker Traders

Iso Industry Fuels and Chemoil Corporation are the two bunker traders associated with the Port of Houston bunker market. In addition, there are several international trading groups conducting transactions in the Houston bunker market.

Bunker Suppliers

There are between six and 15 major suppliers operating in the Houston Port area. Major suppliers to the area include Shell Marine Products, Valero Marketing and Supply Co., Chemoil Corp., BP Marine Fuels, and Bominflot Atlantic LLC.

In addition, there are several smaller suppliers that have storage terminals in or near the port area and operate barge delivery services. Houston Marine Services and Midstream Fuel Services operate storage terminals, bunker supply vessels, and fleets of barges along the Gulf coast. Matrix Marine Fuels, Enjet, and Difco Fuel Systems are examples of smaller suppliers in the Houston bunkering market. Suncoast Resources delivers primarily by truck at local berths, supplied by a network of fuel terminals in the Houston area (Bunkerworld, 2000).

Barge Operators

Currently, only very limited information is available on the barge market in Houston. Most existing barge operations appear to be conducted by local suppliers.

SECTION 3
DEMAND FOR BUNKER FUELS IN THE MARINE INDUSTRY

This section discusses the demand side of the marine fuels market. The analysis of current and expected future shipping activity in this section is used to estimate regional and world-wide projections of future marine bunkers demand through the year 2020. These consumption forecasts then provide a baseline for the WORLD model, against which the shipping industry's possible response to the adoption of a U.S. or North American SECA regulation could be evaluated.

3.1 Summary of the Modeling Approach

In general, the approach used to estimate marine bunker-fuel use can be described as an "activity-based" approach with a focus on the international cargo vessels that represent the majority of fuel consumption. Components of the estimation include:

- identifying major trade routes,
- estimating volumes of cargo of various types on each route,
- identifying types of ship serving those routes and carrying those cargoes,
- characterizing types of engines used by those ships, and
- identifying the types and estimated quantities of fuels used by those engines.

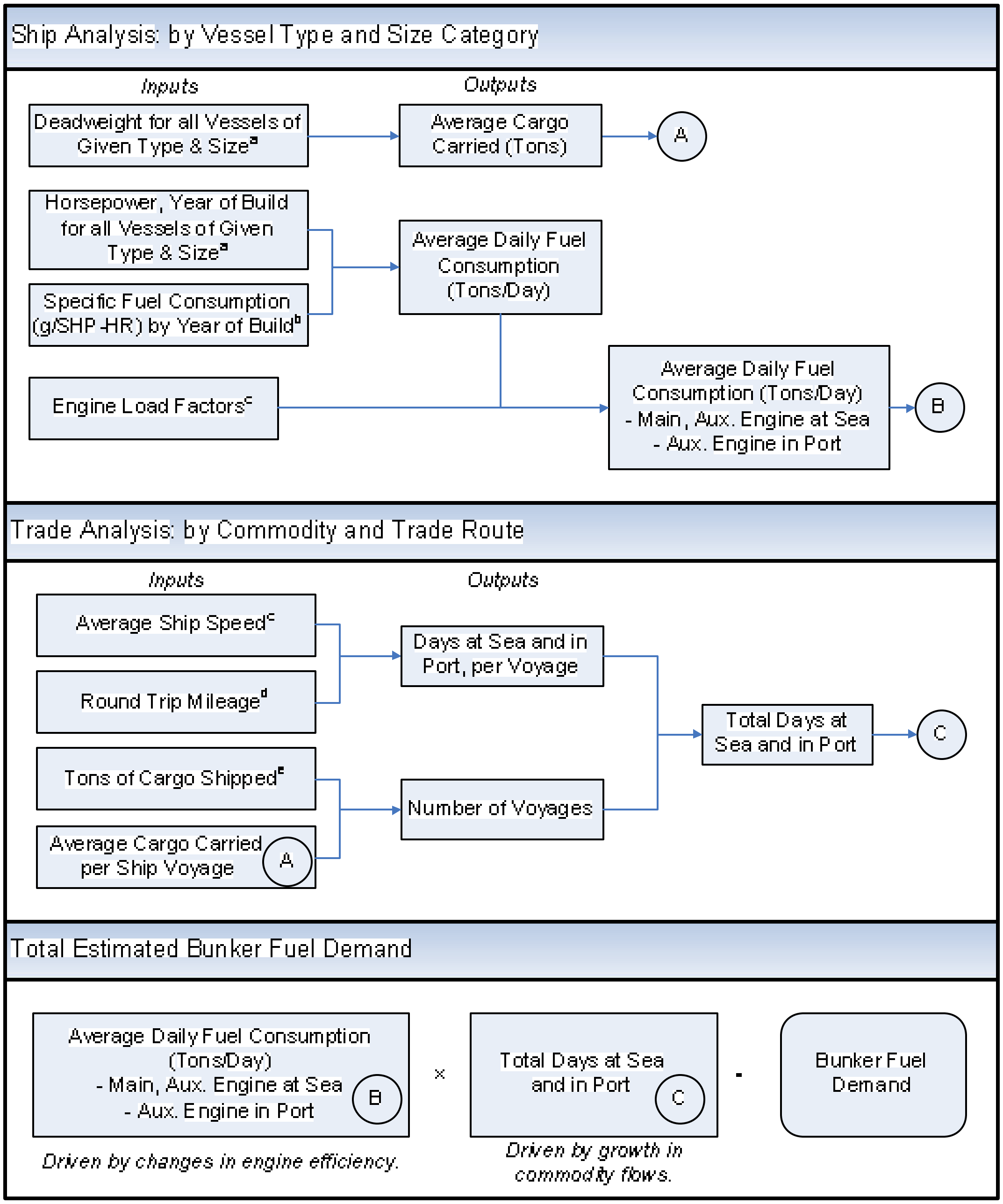
Implementing this approach involves combining information from a variety of sources: data on the existing fleet of shipping vessels from Clarksons (2005), information from Corbett and Wang (2005) and various industry sources on engine characteristics, and projections of future global trade flows from Global Insights (2005). The data on vessels and engines provide a characterization of fuel use associated with delivering a particular load of cargo, and the data on trade flows control how many times, and over what distances, these loads have to be delivered.

Estimating fuel consumption though an activity-based methodology that combines data on specific vessels with data on engine characteristics is similar to the approaches used in Corbett and Koehler (2003, 2004), Koehler (2003), Corbett and Wang (2005), and Gregory (2006). The approach in this report extends previous analyses by linking these ship data to projections of world-wide trade flows in order to determine the total number of trips undertaken in each year, and hence fuel use, rather than using estimates of the number of hours a ship/engine typically runs in a year.

Accordingly, the model developed in this section estimates fuel consumption based on an underlying economic model's projections of international trade by commodity category (Global Insights, 2005). Demand for marine fuels is derived from the demand for transportation of various types of cargoes by ship, which in turn is derived from the demand for commodities that are produced in one region of the world and consumed in another. The flow of commodities is matched with typical vessels for that trade (characterized according to size, engine horsepower, age, specific fuel oil consumption and engine load factors). Next, typical voyage parameters are assigned, including average ship speed, round trip mileage, tons of cargo shipped, and days in port. Fuel consumption for each trade route and commodity type thus depends on commodity projections, ship characteristics, and voyage characteristics.

Figure 3-1 illustrates the broad steps involved in developing baseline projections of marine fuel consumption. It is a multi-step process that relies on data and forecasts from numerous sources, some of which are listed above, to inform the projections. The flow chart in the figure illustrates the relationships to be profiled in characterizing baseline marine fuel consumption by cargo vessels.

Also, while the focus of this analysis of bunker-fuel forecasts is on projecting use by vessels carrying cargo among international ports, it includes other vessel types when estimating total demand for bunker fuels, as discussed below. These vessel types, discussed below, include passenger vessels such as ferries and cruise ships, service vessels such as tugs and offshore supply ships, and military vessels.



a – Clarksons Ship Register Database
b – Engine Manufacturers' Data, Technical Papers
c – Corbett and Wang (2005) "Emission Inventory Review: SECA Inventory Progress Discussion"
d - Combined trade routes and heavy leg analysis
e – Global Insight Inc. (GII) Trade Flow Projections

Figure 3-1. Method for Estimating Bunker Fuel Demand

3.2 Methods of Forecasting Bunker Fuel Consumption

Underlying the projections of bunker-fuel consumption by cargo vessels worldwide are projected flows of commodities between regions of the world. These are commodities produced in one region of the world and demanded in another.

3.2.1 Composite Commodities and Regions

The first step in analyzing trade flows was defining composite commodities as follows:

- liquid bulk – crude oil
- liquid bulk – refined petroleum products
- liquid bulk – residual petroleum products
- liquid bulk – chemicals (organic and inorganic)
- liquid bulk –gas (including LNG and LPG)
- dry bulk (e.g. grain, coal, steel, ores and scrap)
- general cargo (including neobulk, lumber/forest products)
- containerizable cargo

Next, countries of the world were grouped into approximately 20 larger regions. Table 3-1 shows the mapping of countries to regions. From Global Insight, Inc. (GII) World Trade Service, a specialized forecast was obtained that reports flows of each commodity among regions for the period 1995–2024. GII's forecast of shipments of these commodities among these regions drives the overall forecast of demand for shipping services and thus for marine fuels.

GII is a widely recognized macroeconomic forecasting firm. The GII World Trade Service provides annual macroeconometric analysis and forecasts of economic activity and trade for over 200 individual countries and for the global economy. GII provides integrated analyses and forecasts for individual countries and regions of the world and for the world economy as a whole, including an analysis of the relationship of each region's economy to the world economy. To facilitate integration of the fuel demand analysis with the fuel supply analysis, GII grouped its countries and regions into aggregate regions comparable to those used in EnSys Energy's WORLD model. The aggregate regions and associated source countries/regions are shown in Table 3-1.

Table 3-1. Aggregate Regions and Associated Countries

Aggregate Regions	**Containing GII Base Countries / Regions**
U.S. Atlantic Coast	U.S. Atlantic Coast
U.S. Great Lakes	U.S. Great Lakes
U.S. Gulf Coast	U.S. Gulf Coast
E. Canada[a]	Canada[a]
W. Canada[a]	Canada[a]
U.S. Pacific North	U.S. Pacific North
U.S. Pacific South	U.S. Pacific South
Greater Caribbean	Colombia, Mexico, Venezuela, Caribbean Basin, Central America
South America	Argentina, Brazil, Chile, Peru, Other East and West Coast of S. America
Africa – West	Western Africa
Africa-North/East-Mediterranean	Mediterranean Northern Africa, Egypt, Israel
Africa-East/South	Kenya, Other Eastern Africa, South Africa, Other Southern Africa
Europe-North	Austria, Belgium, Denmark, Finland, France, Germany, Ireland, Netherlands, Norway, Sweden, Switzerland, United Kingdom
Europe-South	Greece, Italy, Portugal, Spain, Turkey, Other Europe
Europe-East	Bulgaria, Czech Republic, Hungary, Poland, Romania, Slovak Republic
Caspian Region	Southeast CIS
Russia/FSU	The Baltic States, Russia Federation, Other Western CIS
Middle East Gulf	Jordan, Saudi Arabia, UAE, Other Persian Gulf
Australia/NZ	Australia, New Zealand
Japan	Japan
Pacific-High Growth	Hong Kong S.A.R., Indonesia, Malaysia, Philippines, Singapore, South Korea, Taiwan, Thailand
China	China
Rest of Asia	Viet Nam, India, Pakistan, Other Indian Subcontinent

[a] Canada is treated as a single destination in the GII base model. Shares of Canadian imports from and exports to regions of the world in 2004 are used to divide Canada trade into shipments to/from Eastern Canada ports and shipments to/from Western Canada ports. (Transport Canada, 2004).

The GII World Trade Forecasting Model is a non-linear multi-stage econometric switch model.(GII, 2005) It uses several data sources, economic theory, and multi-stage modeling linked by top-down control adjustment to capture and project commodity flows in the world. There is no single data source that provides a complete baseline picture of international trade. GII bases their model on UN historical international trade data (published by Statistics Canada). These data are supplemented with OECD International Trade by Commodity Statistics to reflect more realistic data for developing countries, and the U.S. Customs and IMF Direction of Trade data to calibrate and enhance historical commodity trade flows. Additional macroeconomic data (such as population, GDP, GDP Deflators, industrial output, foreign exchange rates, and export prices by country, and geographical distances are used as exogenous variables.

The general structure of the model for calculating trade flows assumes a country's imports from another country are driven by the importing country's demand forces (given that the exporting country possesses enough supply capacity), and affected by exporting country's export price and importing country's import cost for the commodity. GII then estimates demand forces, country-specific exporting capacities, export prices, and import costs. To arrive at each country's trade with each of its trading partners, non-linear multi-stage switch modeling is required.

Switch models are not continuous functions. Thus, they can not be estimated using conventional derivative methods; a direct search method is used instead. Although uncommon for economics, this method is widely used in other scientific fields. A direct search method estimates switch functions, while allowing one to define error minimization functions and set boundaries for model parameters. GII's approach to forecasting is unorthodox as well. GII contends that the three commonly used approaches—bottom-up, top-down, and manual (hybrid) approach—fail because of their limitations[1]. GII uses a system that could be referred to as controlled top-down approach.

GII defines four levels, with the bottom level being the most detailed: commodity flows between each pair of countries/regions. The third level is how much of each commodity each country exports/imports from the world. The second level is the total commodity flows that each country exports/imports from the world, and the first level is world trade of total commodities. The second, third, and fourth levels have their own behavioral equations, but individual forecasts at the lower levels are forecast under the constraint of their aggregate forecast at the higher level. Thus, if there is a discrepancy between the sum of individual forecasts and aggregate forecasts, the program identifies the items that could be adjusted and adjusts them step by step to eliminate the discrepancy.

---

[1] The bottom-up approach forbids forecasted items to be a subject to total resource constraints or equilibrium. For example, this approach would disallow the possibility of country's import limitations due to income constraint. The top-down approach requires forecasted items to have identical dynamic patterns. However, the historical data reveals it is rare to find a country's imports of a commodity from two different countries to exhibit identical dynamic patterns. The hybrid method solves the problems of the latter two, but is very time consuming.

GII's output for this project included detailed annual region-to-region trade flows for nine composite commodities, for the period 1995 to 2024. The projections for 2012 and 2020 are shown, along with baseline data for 2005, in Table 3-2. In 2005, dry bulk accounts for 41 percent of the total trade volume. Crude oil accounts for 28 percent, and containers account for 12 percent. Dry bulk and crude oil shipments grow more slowly over the forecast period than do container shipments; by 2020, dry bulk is 39 percent of the total, crude oil is 26 percent, and containers have risen to 17 percent.

Table 3-2. World Trade Estimates for Composite Commodities, 2005, 2012, and 2020

Commodity Type	2005 (in million tons)	2012 (in million tons)	2020 (in million tons)
Dry Bulk	2,473	3,051	3,453
Crude Oil	1,703	2,011	2,243
Container	714	1,048	1,517
Refined Petroleum	416	471	510
General Cargo	281	363	452
Residual Petroleum and Other Liquids	190	213	223
Chemicals	122	175	228
Natural Gas	79	91	105
Total International Cargo Demand	**5,979**	**7,426**	**8,737**

3.2.2 Ship Analysis by Vessel Type and Size

Different types of vessels are required to transport these different commodities to the various regions of the world. Profiles of these vessels were developed to provide a characterization of ships assigned to transport commodities of each type along each route. These profiles analyze data provided by the Clarksons Ship Register (Clarksons, 2005) on size, horsepower, age, and engine fuel efficiency to identify typical vessels of each overall vessel type and each size category. The main purpose of the analysis is to determine the average amount of cargo carried by and average daily fuel consumption of each vessel type.

First, the eight GII commodity categories were mapped to the type of vessel that would be used to transport them. These assignments appear in Table 3-3.

Table 3-3. Assignment of Commodities to Vessel Types

GII Commodity	Ship Category	"Type" Defined in Clarksons Register[a]
Liquid bulk – crude oil	Crude Oil Tankers	Tanker
Liquid bulk – refined petroleum products	Product Tankers	Product Carrier
Liquid bulk – residual petroleum products	Product Tankers	Product Carrier
Liquid bulk – chemicals (organic and inorganic)	Chemical Tankers	Chemical & Oil Carrier
Liquid bulk – natural gas (including LNG and LPG)	Gas Carriers	LNG Carrier, LPG Carrier, Chemical & LPG Carrier, Ethylene/LPG, Ethylene/LPG/Chemical, LNG/Ethylene/LPG, LNG/Regasification, LPG/Chemical, LPG/Oil, Oil & Liquid Gas Carrier
Dry bulk (e.g. grain, coal, steel, ores and scrap)	Dry Bulk Carriers	Bulk Carrier
General cargo (including neobulk, lumber/forest products)	General Cargo	General Cargo Liner, Reefer, General Cargo Tramp, Reefer Fish Carrier, Ro-Ro, Reefer/Container, Ro-Ro Freight/Passenger, Reefer/Fleet Replen., Ro-Ro/Container, Reefer/General Cargo, Ro-Ro/Lo-Lo, Reefer/Pallets Carrier, Reefer/Pass./Ro-Ro, Reefer/Ro-Ro Cargo
Containerizable cargo	Container Ships	Fully Cellular Container

[a] Vessel operators self-report these types to Clarksons Research Services for inclusion in their shipping databases.

Each of these vessel types were further classified by size in deadweight tons (DWT). Appropriate size categories were identified based on both industry definitions and natural size breaks within the data. Table 3-4 summarizes these subcategories, and provides other information on the general characteristics of vessels represented in the Clarksons' data. The size descriptions imply the size limitations as defined by canals or straits through which ships of that size can pass. Crude oil tankers (VLCC) are the largest by DWT; the largest container ships (Suezmax) are also very large. For each ship type and size category, data on typical ships' capacity in DWT, speed, and horsepower are used to estimate average daily fuel consumption.

Table 3-4. Fleet Characteristics in Clarksons Data

Ship Type	Size by DWT	Minimum Size (DWT)	Maximum Size (DWT)	Number of Ships	Total DWT (millions)	Total Horse Power (millions)
Container	Suezmax	83,000	140,000	101	9.83	8.56
	PostPanamax	56,500	83,000	465	30.96	29.30
	Panamax	42,100	56,500	375	18.04	15.04
	Intermediate	14,000	42,100	1,507	39.80	32.38
	Feeder	0	14,000	1,100	8.84	7.91
General Cargo	All	All		3,214	26.65	27.07
Dry Bulk	Capesize	79,000	0	715	114.22	13.81
	Panamax	54,000	79,000	1,287	90.17	16.71
	Handymax	40,000	54,000	991	46.50	10.69
	Handy	0	40,000	2,155	58.09	19.58
Crude Oil Tanker	VLCC	180,000	0	470	136.75	15.29
	Suezmax	120,000	180,000	268	40.63	5.82
	AFRAmax	75,000	120,000	511	51.83	8.58
	Panamax	43,000	75,000	164	10.32	2.17
	Handymax	27,000	43,000	100	3.45	1.13
	Coastal	0	27,000	377	3.85	1.98
Chemical Tanker	All	All		2,391	38.80	15.54
Petroleum Product Tanker	AFRAmax	68,000	0	226	19.94	3.60
	Panamax	40,000	68,000	352	16.92	4.19
	Handy	27,000	40,000	236	7.90	2.56
	Coastal	0	27,000	349	3.15	1.54
Natural Gas Carrier	VLGC	60,000	0	157	11.57	5.63
	LGC	35,000	60,000	140	6.88	2.55
	Midsize	0	35,000	863	4.79	3.74
Other	All	All		7,675	88.51	53.60
Total				26,189	888.40	308.96

Source: Authors' calculations based on data from Clarksons Ship Register (2005).

Fleet Average Daily Fuel Consumption

Average fuel consumption for each vessel type and size category was estimated in a multi-step process using individual vessel data on engine characteristics. Clarksons' Ship Register provides each ship's horsepower (HP), type of propulsion (diesel or steam), and year of build. These characteristics are then matched to information on typical Specific Fuel Oil Consumption (SFOC) from engine manufacturers and the technical literature. SFOC is measured in grams of fuel burned per horsepower-hour, so to determine the average daily fuel consumption of the fleet, the following equation is used:

$$\mathrm{FleetAFC}_{v,s} = \frac{1}{N}\sum_{i\in v,s}\left[\mathrm{SFC}_i \, x \mathrm{HP}_i \; x\left(.7457x\frac{24}{1{,}000{,}000}\right)\right] \qquad (3.1)$$

where *i* denotes an individual ship of vessel type *v* and size category *s*. This calculation results in a fleet average value for daily fuel consumption, measured in metric tons per day.

Key Assumptions Affecting the Forecast

The specific SFOC numbers used for this analysis are based on historical data provided by Wartsila Sulzer, a popular manufacturer of diesel engines for marine vessels. An additional 10% has been added to their "test bed" or "catalogue" numbers to account for the guaranteed tolerance level and an in-service SFOC differential.[2] Figure 3-2 shows data used in the model regarding the evolution of specific fuel oil consumption rates for diesel engines over time. (For steam engines, a fixed SFOC of 220 g/HP-hr is used)

Engine efficiency in terms of SFOC has improved over time, most noticeably in the early 1980s in response to rising fuel prices. However, there is a tradeoff between improving fuel efficiency and reducing emissions. Conversations with engine manufacturers indicate that it is reasonable to assume SFOC will remain constant for the 15 year time horizon of this study, particularly as they focus on meeting more stringent NOx emissions requirements, such as those imposed by MARPOL Annex VI.

---

[2] Overall this 10 percent estimate is consistent with other analyses which show variation between the "test bed" SFOC values reported in manufacturers' product catalogues and the actual SFOCs observed in service. The difference is explained by the fact that old, used engines consume more than brand new engines and that fuels used in-service may be different than the test bed ISO fuels. See Koehler (2003).

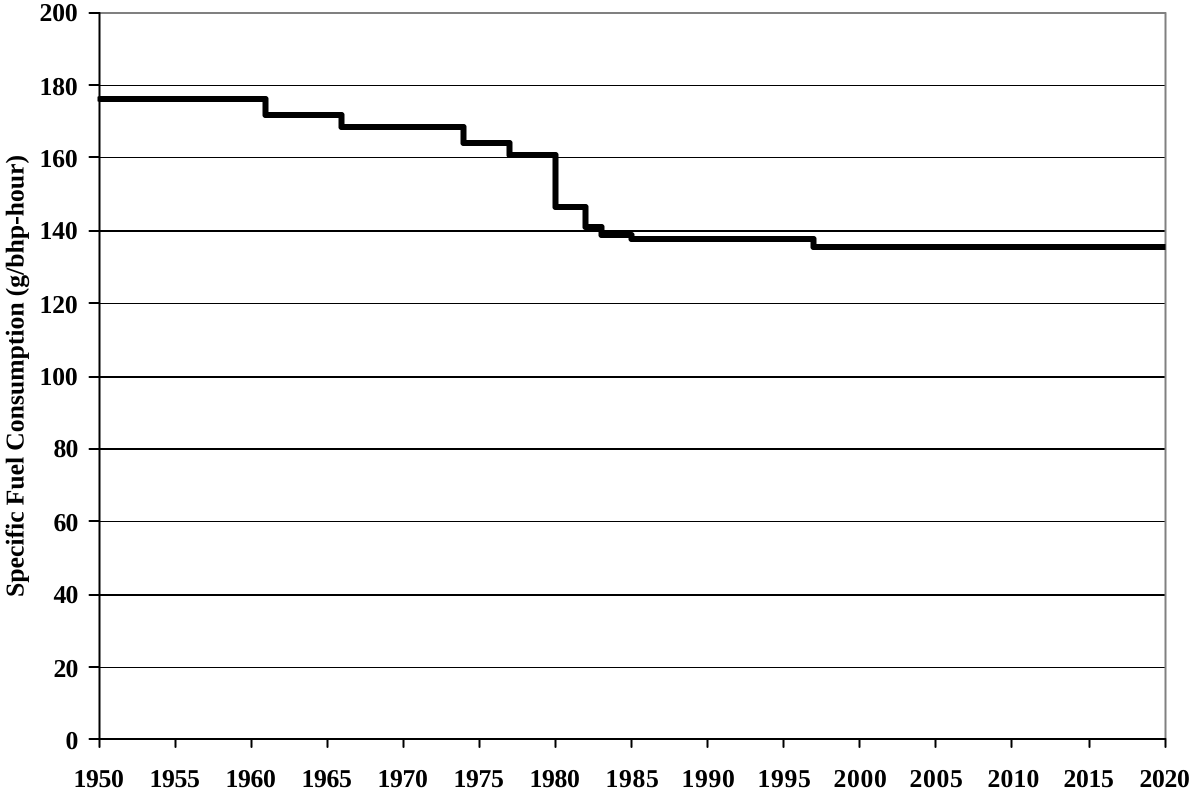


Figure 3-2. Specific Fuel Oil Consumption Over Time

Source: Authors' calculations based on communications with Wartsila Sulzer and other diesel engine manufacturers.

The values for fleet average daily fuel consumption calculated in Equation 3.1 are based on installed horsepower, and therefore they must be scaled down to reflect true engine loads. Engine load factors reported by Corbett and Wang (2005) are used to estimate average daily fuel consumption (tons/day) for the propulsion engine and auxiliary engines, both at sea and in port. These assumptions are summarized in Table 3-5.

Table 3-5. Assumptions Regarding Engine Loads

Vessel Type	Main Engine Load Factor	Auxiliary Engine as Percent of Main Engine	Auxiliary Engine as Percent of Main Engine at Sea
Container Vessels	80 %	22.0 %	11.0 %
General Cargo Carriers	80 %	19.1 %	9.5 %
Dry Bulk Carriers	75 %	22.2 %	11.1 %
Crude Oil Tankers	75 %	21.1 %	10.6 %
Chemical Tankers	75 %	21.1 %	10.6 %
Petroleum Product Tankers	75 %	21.1 %	10.6 %
Natural Gas Carrier	75 %	21.1 %	10.6 %
Other	70 %	20.0 %	10.0 %

Source: Corbett, James and Chengfeng Wang. October 26, 2005. "Emission Inventory Review SECA Inventory Progress Discussion." page 11.

Changing Fleet Characteristics

The population of vessels operating is assumed to change over time as older vessels are scrapped and new ones are built. In our analysis, vessels built over 25 years ago are retired and are assumed to be replaced by new ships of the most up-to-date configuration. Specifically, these ships are assumed to have a new engine (rated at the current SFOC) and are assumed to weigh as much as the average ship built in 2005. So even though improvements in SFOC over the next 15 years are not assumed, the fuel efficiency of the fleet as a whole is expected to improve over time through retirement and replacement. In the same way, even though specific increases in the size of ships being built are not projected, the total deadweight of the fleet will increase over time as smaller ships retire and are replaced. The analysis also reflects trends on the trade routes between Asia and North America or Europe for container ships to increase in size over time.

3.2.3 Trade Analysis by Commodity Type and Trade Route

Based on information from Navigistics Consulting, the distribution of ship size categories deployed on each of the trade routes were identified. For example, to serve the large crude oil trade from the Middle East Gulf region to the U.S. Gulf region, 98% of the deadweight tonnage is carried on Very Large Crude Carriers (VLCCs) while the remaining 2% is carried on the smaller Suezmax vessels. In addition to the volume of trade being moved, the limitations of the canals through which the vessels must pass determine the size categories deployed on each trade route.

Once a vessel type and size distribution have been assigned to each region pair and commodity trade type, a set of voyage parameters are estimated. Days at sea and in port are based primarily on ports called, sea distance, and ship speed. The number of voyages is based on the cargo volume projected by GII to move along a given route and the cargo capacity of the vessels on that route.

Days at Sea and Days in Port

Most trades are characterized by voyages that are essentially round trips, moving from a single port of origin to a single destination, and back. For these trades, Navigistics Consulting identified ports that were either in the middle of the trade region or ports through which the particular commodity was most likely to travel. For example, the Port of Singapore was selected as the port of origin for the Pacific High-Growth region for most commodities, but for dry bulk, Inchon was selected. Then, for each route, information was gathered on the distances between ports (NGA, 2001 and MaritimeChain, 2005).[3] Since carriers of crude oil, chemicals, petroleum products, natural gas, and dry bulk tend to travel full for a delivery and then return empty, round-trip distances were used to determine the length of the voyage. The days at sea are calculated by dividing the sea distance by the average vessel speed:

$$\text{DaysatSeaPerVoyage}_{\text{v,s,route}} = \frac{\text{roundtripdistanceroute}}{\text{speed}_{\text{v,s}}\ \text{x}24\text{x}1.1508} \tag{3.2}$$

Table 3-6 presents the values used for speed by vessel type (based on Corbett and Wang, 2005). These values are the same for all size categories and are assumed to remain constant over the forecast period.

Table 3-6. Vessel Speed by Type

Vessel Type	Speed (knots)
Crude Oil Tankers	13.2
Petroleum Product Tankers	13.2
Chemical Tankers	13.2
Natural Gas Carriers	13.2
Dry Bulk Carriers	14.1
General Cargo Vessels	12.3
Container Vessels	19.9[a]
Other	12.7

[a] Length of voyages by container ships estimated from additional sources. See below.

Source: Corbett, James and Chengfeng Wang. October 26, 2005. "Emission Inventory Review SECA Inventory Progress Discussion." page 11.

In addition to calculating the average days at sea per voyage, the average days in port per voyage are also estimated. It is assumed that most types of cargo vessels spend 4 days in port per voyage; however, this can vary somewhat by commodity and by port.[4] Tables 3-7 and 3-8 shows the results of these estimates of voyages lengths – focusing on U.S. trade routes. Table 3-7 presents average lengths across types of non-container vessels (these times are cargo specific

---

[3] http://maritimechain.com/ . This calculator provides nautical distances, which account for the particular routes vessels must take when traveling from port to port, e.g. movement through straights or canals.

[4] Some ports do not run as efficiently because of a lack of good shoreside facilities, labor problems, or other inadequacies. The maximum number of days in port for a non-container trade is 8 days.

and vary slightly based on the speed of the vessels – speeds are taken from Dr. Corbett's work). Two sources are used for non-container trades and voyage times in Table 3-7 - Worldscale (2002), and Maritime Chain (2005).

The Worldscale tables, based on underlying BP Shipping Marine Distance Tables, are the industry standard for measuring port-to-port distances, particularly for tanker traffic. The reported distances account for common routes through channels, canals, or straits. This distance information was supplemented by data from Maritime Chain, a web service that provides port-to-port distances along with some information about which channels, canals, or straits must be passed on the voyage. This distance information is then combined with Dr. Corbett's speed parameters to determine the length of a voyage in days.

As discussed above, voyage times for container trade in Table 3-8 are based on information from *Containerization International* (Degerlund, 2005), and calculations by Navigistics Consulting. This resource provides voyage information for all major container services. Based on the frequency of the service, number of vessels assigned to that service, and the number of days in operation per year, the average length of voyages for the particular bilateral trade routes in the Global Insights trade forecasts are estimated.

Table 3-7. Length of Voyages for Non-Container Cargo Ships (approx. average)

	Days per Voyage				
Global Insights Trade Regions	US South Pacific	US North Pacific	US East Coast	US Great Lakes	US Gulf
Africa East-South	68	75	57	62	54
Africa North-Mediterranean	49	56	37	43	47
Africa West	56	63	36	46	43
Australia-New Zealand	48	47	65	81	63
Canada East	37	46	7	18	19
Canada West	11	5	40	58	39
Caspian Region	95	89	41	46	48
China	41	36	73	87	69
Europe Eastern	61	68	38	45	46
Europe Western-North	53	60	24	32	34
Europe Western-South	54	61	30	37	37
Greater Caribbean	26	33	16	29	17
Japan	35	31	65	81	62
Middle East Gulf	77	72	56	65	83
Pacific High Growth	52	48	67	76	88
Rest of Asia	68	64	66	64	73
Russia-FSU	64	71	38	46	48
Rest of South America	51	30	41	46	44

Table 3-8. Length of Voyages for Container-Ship Trade Routes

Origin -- Destination Regions	Days per Voyage
Asia -- North America (Pacific)	37
Europe -- North America (Atlantic)	37
Mediterranean -- North America	41
Australia/New Zealand -- North America	61
South America -- North America	48
Africa South -- North America (Atlantic)	54
Africa West -- North America (Atlantic)	43
Asia -- North America (Atlantic)	68
Europe -- North America (Pacific)	64
Africa South -- North America (Pacific)	68
Africa West -- North America (Pacific)	38
Caspian Region -- North America (Atlantic)	42
Caspian Region -- North America (Pacific)	38
Middle East/Gulf Region -- North America (Atlantic)	63
Middle East/Gulf Region -- North America (Pacific)	80

Number of Voyages

The number of voyages along each route for each trade is computed by dividing, for each vessel type *v* and size category *s* serving a given route, the tons of cargo moved by the estimated amount of cargo per voyage:

$$\text{Numberof Voyages}_{\text{v,s,trade}} = \frac{\text{tonscargotomove}}{\text{FleetAvg.DWT}_{\text{v,s}}\ \text{x(utilizationrate)}} \tag{3.3}$$

The cargo per voyage is based on the fleet average ship size (in deadweight tons) calculated in the vessel profile analysis. For most cargo trades, a utilization factor of 0.9 is assumed to account for the fact that ships do not always run at full capacity. This factor is assumed to be constant throughout the forecast period. Lowering this utilization factor would increase the estimated number of voyages required to move the forecasted cargo volumes, which would in turn increase our estimated fuel demand.

Exceptions: General Cargo and Container Trades

The exceptions to the above approach for calculating voyage parameters are the general cargo and container trades. These routes tend to have multiple stops, with cargo loaded and discharged at each stop. Unlike the other types of vessels, these carriers rarely travel empty.

Thus, for each trade route, the focus only on the "heavy" leg of the journey, the direction with the highest trade volume.

For general cargo, port-to-port round-trip distances and the average vessel speeds are used to calculate days at sea. Days in port are estimated at 4 days per voyage. The difference is that the number of voyages is based only on the tons of cargo projected to be moved on the heavy leg of the journey. The assumption is that the projected trade volume associated with the "light" leg will be carried on the return trip of these round-trip voyages.

For the container trades, the voyage parameters are determined based on actual ship routings. Navigistics Consulting first identified major container trade lanes, to which the individual region pairs were assigned. For example, trade volumes from the Pacific High Growth region to the U.S. South Pacific and from China to the U.S. North Pacific are both included on a Transpacific trade route. Major shipping lines active on these trade routes are identified and their individual container services are analyzed, as recorded in the *Containerization International (CI) Yearbook 2005* and other sources. The *CI Yearbook* provides detailed information about each container service, including the ports visited, the frequency and length of the voyage, and the vessels deployed. It is assumed there is one day in port for each port visited, and then the days at sea are calculated by subtracting total days in port from the total length of the voyage.

The number of voyages for the container trade is again calculated by dividing the projected volume on the heavy leg by the estimated average cargo per voyage (i.e. average ship size times a utilization factor). The information about the vessels deployed is used to determine the average ship size. The utilization factor is calibrated so that the number of voyages implied by 2005 historical GII data matches the actual number of voyages recorded in the CI Yearbook. Our estimated factors, which average 0.51 across all trade routes, are generally lower than the utilization factor of 0.9 used on all other commodity trades. However, these estimates are consistent with what industry experts predict for capacity utilization. The main reason for the lower utilization rate is that container ships usually reach a maximum volume capacity well before they reach a maximum weight capacity. A vessel may be only 50% "full" in terms of deadweight, but still be unable to fit more containers on board.[5]

---

[5] The utilization factors estimated correspond to approximately 8-10 deadweight tons per Twenty-Foot Equivalent Unit (TEU), which is the volume measure most often used to describe a container ship's size. This is consistent with industry reports.

3.2.4 Calculating Total Estimated Fuel Demand for Cargo Vessels

As described in Figure 3-1, estimates from the vessel analysis and trade analysis are used to obtain an estimate of total fuel demand related to international cargo trade flows.

Total Fuel Demand in Year y, for y = 2005, 2012, 2020

For each year, total marine fuel consumed is computed as the sum of fuel consumed on each route of each trade (commodity). Fuel consumed in each route of each trade is in turn computed by summing the fuel consumed for each route and trade for that year by propulsion engines and auxiliary engines, both at sea and in port.

$$
\begin{aligned}
FC_y &= \sum_{trade}\sum_{route} FC_{trade,route,year} \\
&= \sum_{trade}\sum_{route}\left[AFC_{trade,route,yatsea} \text{ x } DaysatSea_{trade,route,y} + AFC_{trade,route,yatport} \text{ x} DaysatPort_{trade,route,y}\right]
\end{aligned}
$$

where

$$
\begin{aligned}
AFC_{trade,route,yatsea} &= \sum_{v,s,t,r}(Percentoftradealongroute)_{v,s}\left[FleetAFC_{v,s} \text{ x} \left(MELF + AEatseaLF\right)\right] \\
AFC_{trade,route,yatport} &= \sum_{v,s,t,r}(Percentoftradealongroute)_{v,s}\left[FleetAFC_{v,s} \text{ x} AE\ importLF\right] \\
DaysatSea_{trade,route,y} &= \sum_{v,s,t,r}(Percentoftradealongroute)_{v,s}\left[Daysatseapervoyage_{v,s} \text{ x } Numberofvoyages_{v,s}\right] \\
DaysatPort_{trade,route,y} &= \sum_{v,s,t,r}(Percentoftradealongroute)_{v,s}\left[Days\,atportpervoyagexNumberofvoyages\right]
\end{aligned}
$$

MELF: Main Engine Load Factor
AE at sea LF: Auxiliary Engine at-sea Load Factor
AE in port LF: Auxiliary Engine in-port Load Factor

The parameters used in these last four equations are all derived from the vessel and trade analyses discussed above. The *(Percent of trade along route)*$_{v,s}$ indicates the fraction of trade volume carried by each vessel size category, as discussed in Section 3.2. *Fleet AFC*$_{v,s}$ is the fleet average daily fuel consumption calculated using Equation 3.1. The main propulsion and auxiliary engine load factors are discussed in Section 3.2.2, and the specific values used are reported in Table 3-5. Days at sea per voyage and number of voyages are calculated using Equations 3.2 and 3.3, respectively.

3.2.5 U.S. Domestic Navigation

The GII forecasts are primarily designed to analyze international trade flows, so they do not include projected trade volumes for shipments within the U.S. In addition, these domestic shipments are primarily transported by carriers that are governed by the restrictions of the Jones Act. For these reasons, the methodology for estimating fuel demand by vessels transporting cargo domestically differs slightly from the methodology for international cargo vessels presented in Sections 3.2.2 through 3.2.4.

Ship Analysis by Vessel Type and Size

This analysis begins with a vessel profile. Navigistics Consulting helped compile a database listing vessels in the "Jones Act fleet." Four types of trade constitute a vast majority of the domestic cargo trade flows that are transported by ships through waterways: dry bulk trade on Great Lakes, crude oil trade (primarily from Alaska), petroleum product trade, and container trade. Accordingly, the four types of vessels that are utilized in these trades are considered: crude oil tankers, dry bulk carriers, container ships, and product tankers (which also carry chemicals).

As with international vessel fleet, vessel types of the domestic fleet were further classified by size in deadweight tons (DWT). Table 3-9 illustrates these breaks, along with summaries of deadweight and horsepower for each vessel type and size. As seen below, the Jones Act fleet composes only a small fraction of the international fleet. The Great Lakes bulk category makes up the largest share by the number of vessels, while the container category is the largest in terms of horsepower, and the crude oil tanker category is the largest in terms of deadweight. These four categories have a total of 151 vessels, with a combined deadweight of 7.9 million tons and a combined horsepower of 2.6 million.

Table 3-9. Jones Act Fleet

Vessel Type	Size by DWT	Minimum Size (DWT)	Maximum Size (DWT)	Number of Ships	Total DWT (thousands)	Total Horse Power (thousands)
Container*	Panamax	42,100	56,500	2	92.0	47.0
	Intermediate	14,000	42,100	35	924.0	890.4
	Feeder	0	14,000	1	13.9	22.9
Great Lakes Bulk**	Panamax	54,000	79,000	12	729.2	187.8
	Handymax	40,000	54,000	3	367.9	40.2
	Handy	0	40,000	33	800.1	218.8
Crude Oil Tanker***	VLCC	180,000	0	8	1,508.0	219.3
	Suezmax	120,000	180,000	10	1,289.4	299.1
	AFRAmax	75,000	120,000	4	367.9	98.0
	Panamax	43,000	75,000	1	57.7	17.0
Petroleum Product Tanker***	Panamax	40,000	68,000	24	1,112.4	300.4
	Handy	27,000	40,000	17	609.8	204.9
	Coastal	0	27,000	1	19.2	7.2
Total				**151**	**7,891.5**	**2,553.0**

Source: Authors' calculations based on data from Colton and Company (*), Greenwood's Directory (**), U.S. Maritime Administration (***)

Fleet Average Daily Fuel Consumption

Average fuel consumption for each vessel type and size category was estimated using the same basic approach that was used to estimate fuel consumption for international vessel fleet. The main difference lies in how fleet characteristics change over time through retirement and replacements.

U.S. Jones Act vessels are more costly to build, and therefore are kept in service longer than international fleet vessels, making their replacement age above the international fleet average. Replacement ages for Jones Act vessel categories are listed below:

- Containers – 35 years
- Great Lakes Bulk – 60 years (these ships are not a subject to salt water and thus last longer)
- Crude Oil Tanker – 35 years or OPA-90[6] requirement
- Petroleum Product Tanker – 35 years or OPA-90 requirement

The replacement ships are assumed to have a new engine (rated at the current SFOC) and are assumed to weigh as much as the average ship of a similar category and deadweight class (for example, a Panamax Size Container Vessel) built in 2005, based on the statistics from the international fleet database.

Voyage Parameters

Calculation of the voyage parameters was also slightly different. The average number of days required for a trip, as well as average number of days spent in port were estimated based on actual ship routings and calculated distances between Alaska, Hawaii, Puerto Rico and the continental U.S.

The number of days the ships will be engaged in trade (activity level) are then estimated for each ship category. For container, crude oil tanker, and petroleum product tanker categories activity levels are estimated at 350 days. The estimate of Great Lakes bulk vessels activity level was set at 290 days to account for winter weather conditions, when the lakes are frozen over. Given the activity level and the average number of days required for a trip at sea and in port, the total number of days at sea and in per port per ship per year are calculated as:

$$\text{Voyages per Year Per Ship} = \frac{\text{Activity Level}}{\text{Average Number of Trip Days}}_{s}$$

---

[6] Oil Pollution Act of 1990 (OPA-90) was introduced after the Exxon Valdez incident. OPA-90 requires all single-hull ships to be replaced by double-hull ships by certain date, based on deadweight and horsepower.

$$\text{Total Number of Days at Sea per Ship} = \frac{\text{Average Number of Days at Sea}}{\text{Average Number of Trip Days}_{s}} \text{ x Voyages Per Year Per Ship}$$

$$\text{Total Number of Days in Port per Ship} = \frac{\text{Average Number of Days in Port}}{\text{Average Number of Trip Days}_{s}} \text{ x Voyages Per Year Per Ship}$$

Total number of days in port and at sea per year per ship is then multiplied by the number of vessels in each category, to get the total number of days ships spend at sea and the total number of days ships spend in port each year. Given the average fuel consumption, the days at sea per voyage, and days in port per voyage for an average ship within each vessel category, the total estimated fuel demand is then calculated in the same way as for international vessel fleet.

3.2.6 Ship Analysis for Non-Cargo Vessels

As with domestic U.S. navigation, because the GII forecasts focus on international trade flows, they do not cover activities of several remaining types of vessels: passenger ships, fishing vessels, military vessels, and other support ships such as tugboats or supply ships. Data on fuel consumption by the ship categories have been based on available literature and information in the Clarksons database.

Historical fuel consumption by passenger ships, fishing vessels, and military vessels have been based on data from Corbett and Koehler (2003). Trends in passenger ships are based on a study by Ocean Shipping Consultants that projects increases in cruise-ship demands through 2020. Trends in fishing are based on data from the United Nation’s Food and Agriculture Organization (FAO) on world-wide fish capture trends between 1997 and 2002. Trends in military vessel energy use are based on forecasts from the U.S. Energy Information Administration’s *Annual Energy Outlook 2006*, which provides estimates of trends in future U.S. military distillate and residual consumption. Historical fuel consumption by other types of ships are based on data in the Clarksons database (the “Other” category shown in Table 3-4). These data on vessel characteristics are combined with engine load assumptions from Corbett and Wang (2005) and activity levels from Corbett and Koehler (2004) to determine fuel use. Trends in this fuel use are then assumed to follow patterns of economic activity as reflected in Gross Domestic Product (GDP) forecasts from EIA.

3.2.7 Bunker Fuel Grades

Fuel consumption by specific grades is evaluated as follows: information from Koehler (2003) on consumption of heavy fuel oil and marine distillate oil (MDO) and marine gas oil (MGO) by vessel type is used to assign overall fuel grades, this information is then combined with the main and auxiliary engine factors discussed in Section 3.2.4 – where main engines are assumed to use mostly Intermediate Fuel Oil (IFO) 380 and auxiliary engines use IFO180.

3.3 Results of Bunker Fuel Forecasts

This section presents estimates of bunker fuel consumption based on the methodology outlined above. The focus of the discussion and associated graphs is on: first, world-wide bunker fuel consumption estimates that can be compared to those by IEA and in other published works; second, U.S. regional fuel consumption estimates related to the cargo fleet engaged in international trade; and, finally, on growth rates in bunker fuel demand and the underlying factors.

Figure 3-3 shows estimated world-wide bunker fuel consumption by vessel type. Fuel consumption in year 2001 is equal to 278 million tons, which can be compared to the estimate in Corbett and Koehler (2004) of 289 million tons. By 2020, bunker fuel demand reaches 500 million tons per year. Note: the "historical" bunker fuel data shown going back to 1995 are also model estimates based on historical Global Insights trade flows. (Comparisons of these estimates to others in the literature are discussed in more detail in Section 4.2, given their importance to modeling of the petroleum-refining industry in the WORLD model.)

Figure 3-3. World-Wide Bunker Fuel Use

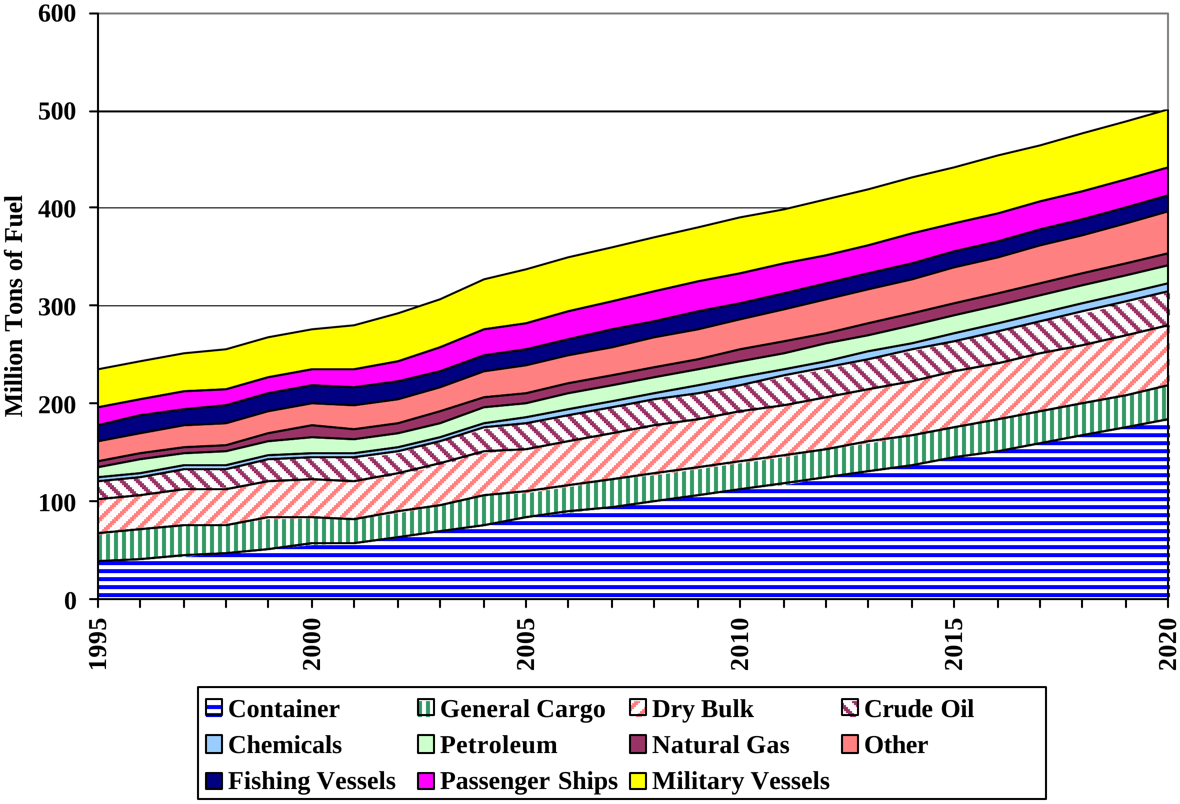
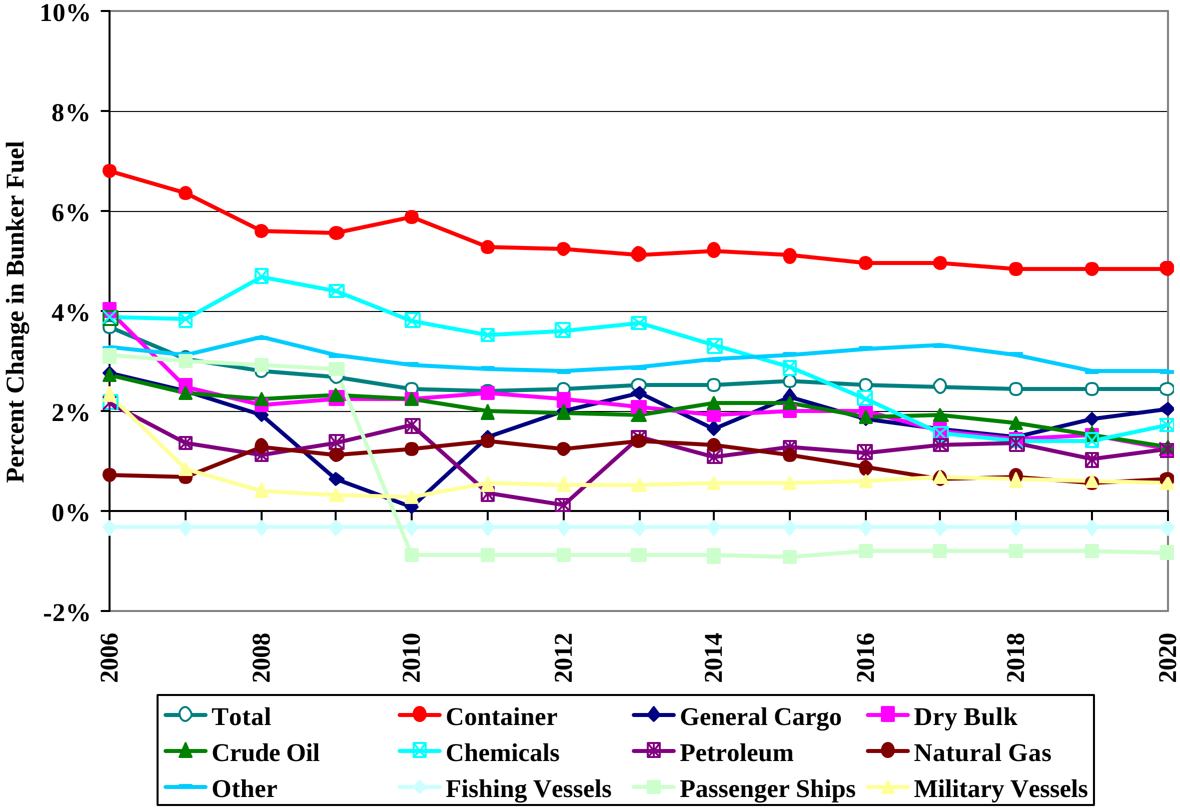


Figure 3-4 shows the annual growth rates by vessel-type/cargo that underlie the projections in Figure 3-3. Total annual growth is generally between 2.5 percent and 3.5 percent over the time period between 2006 and 2020 and generally declines over time, resulting in an average annual growth of around 2.6 percent. As shown in the "container" categories in Figures 3-3 and Figure 3-4, fuel consumption by container ships is the fastest growing component of world-wide bunker fuel demand – in 2004, consumption by container ships is around 75 million tons, growing to 87 million tons by 2006 and close to 180 million tons by 2020 (the historical estimates can be compared to Gregory (2006), which places container ship consumption in 2004 at 85 million tons, based on installed power). While overall growth is less than three percent a year, growth in container-ship demand remains above five percent a year on an average annual basis for the next 15 years. Across all vessel types, growth in bunker fuel consumption is somewhat lower than world-wide Gross Domestic Product (GDP) growth forecasts from EIA (*International Energy Outlook 2005*) of around 3.9 percent a year, but higher than IEA estimates of overall fuel consumption growth (around 1.6 percent in the *World Energy Outlook 2005*). The estimate of growth in marine bunkers over the next 15 years, however, is consistent with historical growth of 2.7 percent per year shown in IEA data from 1983 to 2003.

Figure 3-4. Annual Growth Rate in World-Wide Bunker Fuel Use



Growth in fuel use by container ships and the overall contribution by these vessels to world-wide demand is driven by several factors. The first is overall growth in world-wide GDP mentioned above. This growth leads to increases in international trade flows over time (shown in Figures 3-5 and 3-6 below). These figures illustrate that, although container trade is smaller in total volume than other categories, it is the fastest growing component of the trade flows. Measuring trade flows in tons of goods, as shown in Figure 3-5, also does not provide a good proxy for the fuel consumption needed to transport the goods. Liquids and dry bulk are much denser than container goods, for example. As mentioned in Section 3.2.3, it is estimated that utilization rates for container ships (comparing dead weight tons of capacity to actual cargo transported) are around 50 percent. Thus, it takes approximately twice as many ships to transport the same amount of container tons compared to liquid/dry bulk tons. This relationship tends to influence total bunker fuel use and weight it towards container trade. In addition, growth rates in particular trade flows such as Asia to the U.S. will also influence overall fuel consumption, especially as related to container ships as discussed in relation to U.S. regional trade flows below.

Figure 3-5. World-Wide Trade Flows (Global Insights)

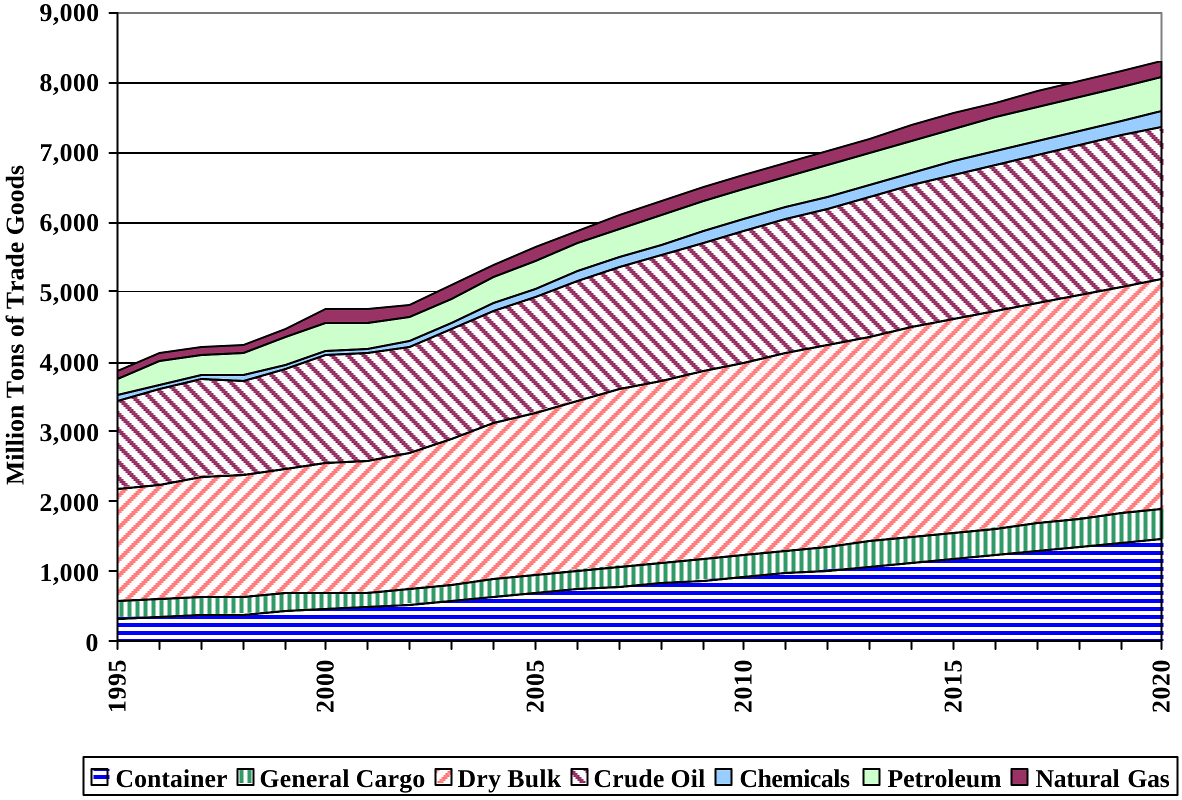
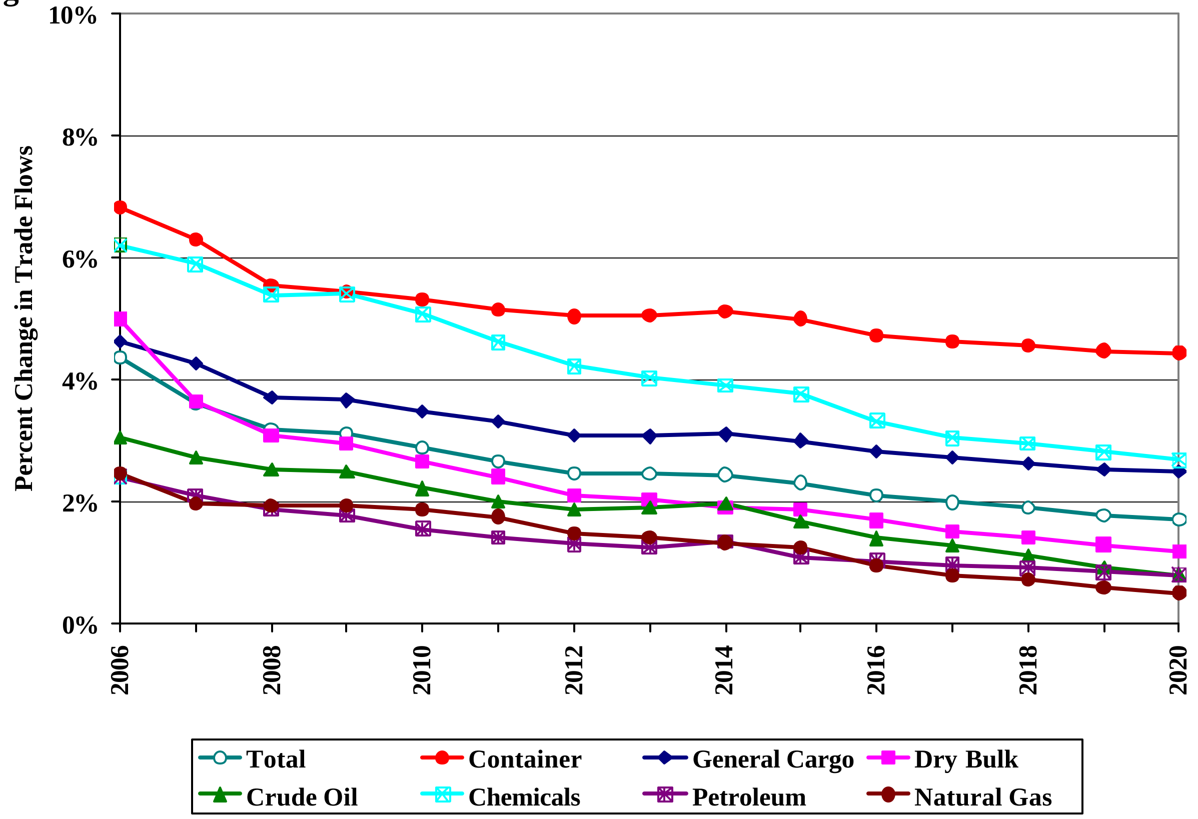


Figure 3-6. Annual Growth Rate in World-Wide Trade Flows



Figures 3-7 to 3-9 show estimated consumption of specific grades of bunker fuels from Figure 3-3.

Figure 3-7. World-Wide IFO380 Use

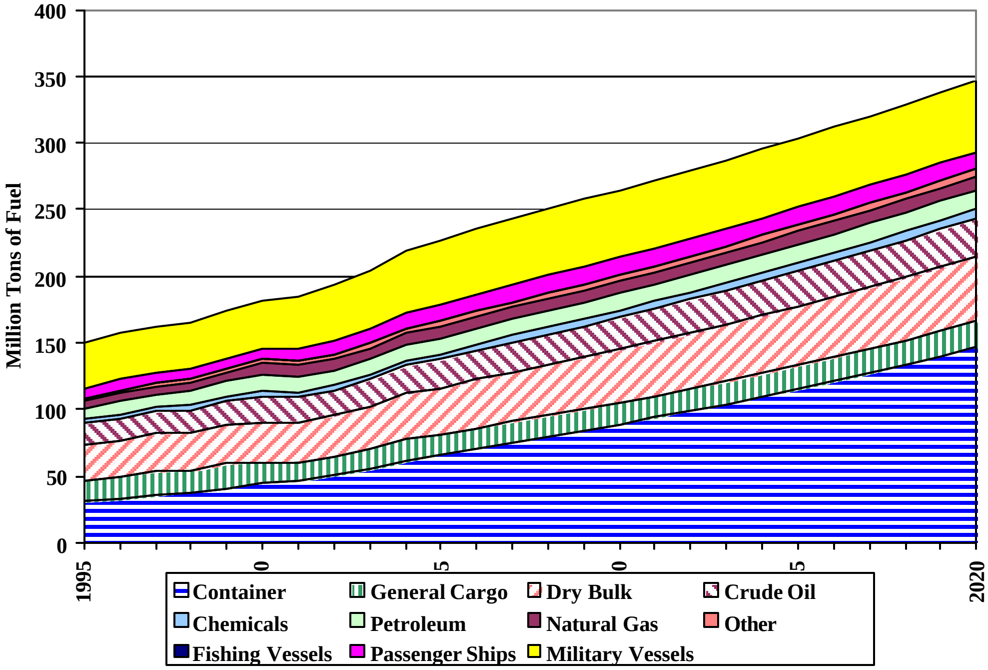


Figure 3-8. World-Wide IFO180 Use

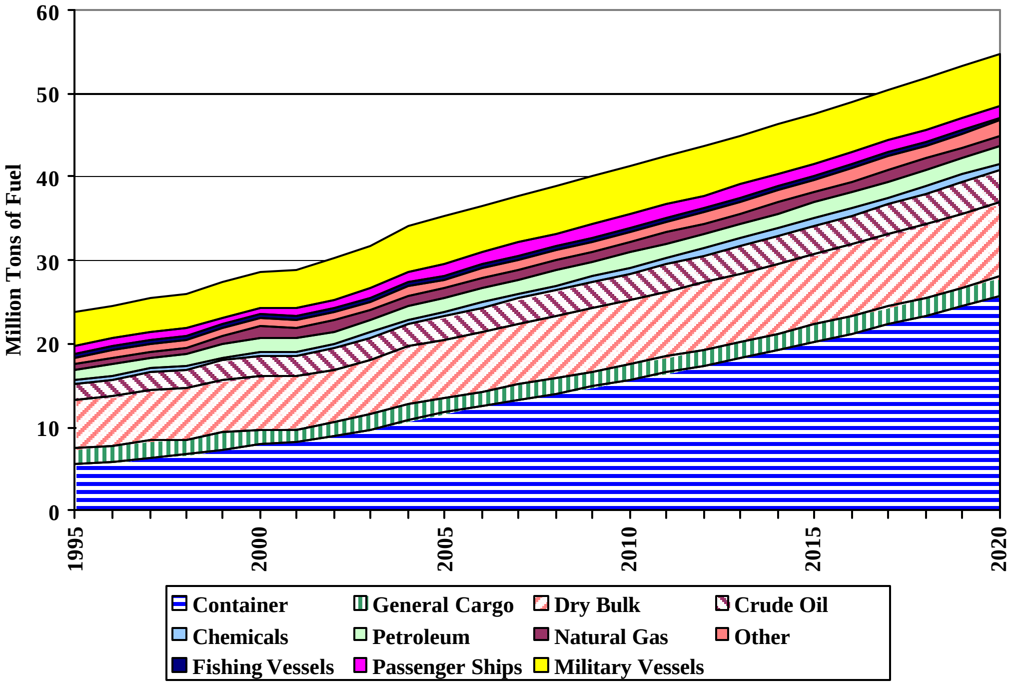
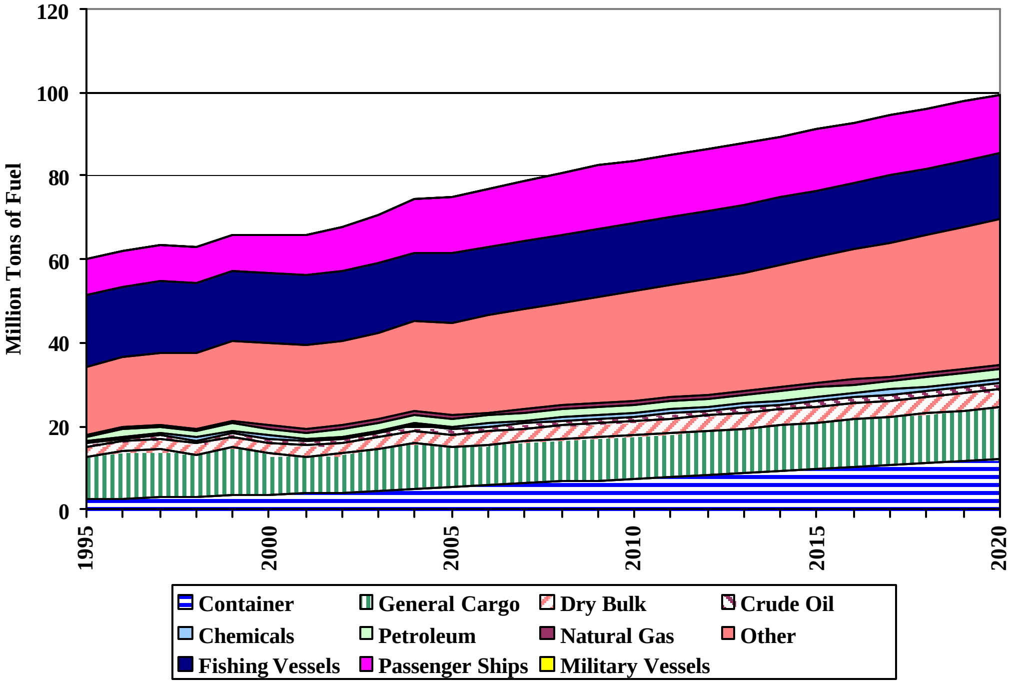


Figure 3-9. World-Wide MDO-MGO Use



Figures 3-10 to 3-13 present estimates of fuel use by the international cargo fleet engaged in delivering trade goods to and exporting trade goods from the United States. These estimates comprise part of the total world-wide bunker fuel use shown in Figure 3-3 and do not include fuel used for domestic navigation. The results in Figure 3-10 show estimated historical bunker fuel use in year 2001 of around 47 million tons (note: while this fuel is used to carry trade goods to and from the U.S., it is not necessarily all purchased in the U.S. and is not all burned in U.S. waters). This amount grows to over 90 million tons by 2020 with the most growth occurring on trade routes from the East Coast and the "South Pacific" region of the West Coast.

Figure 3-10. Bunker Fuel Used by the International Cargo Fleet Importing To and Exporting From the United States (by Region)

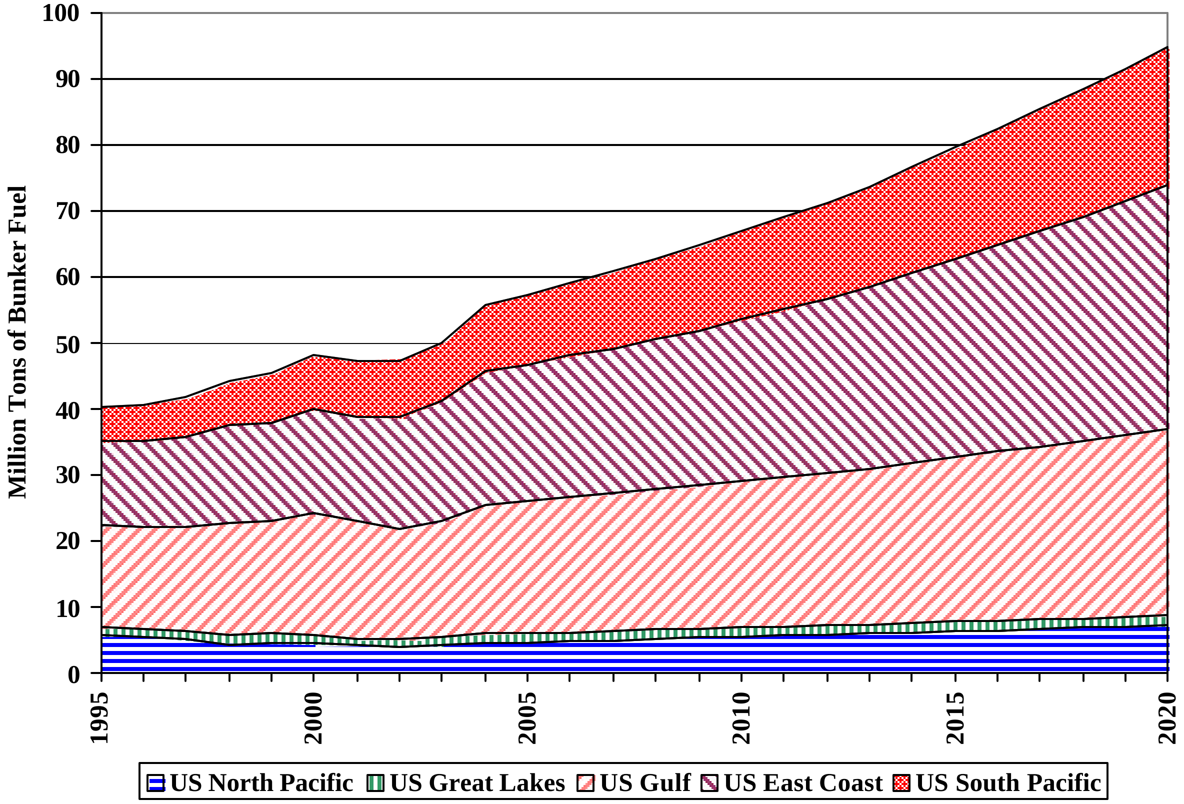
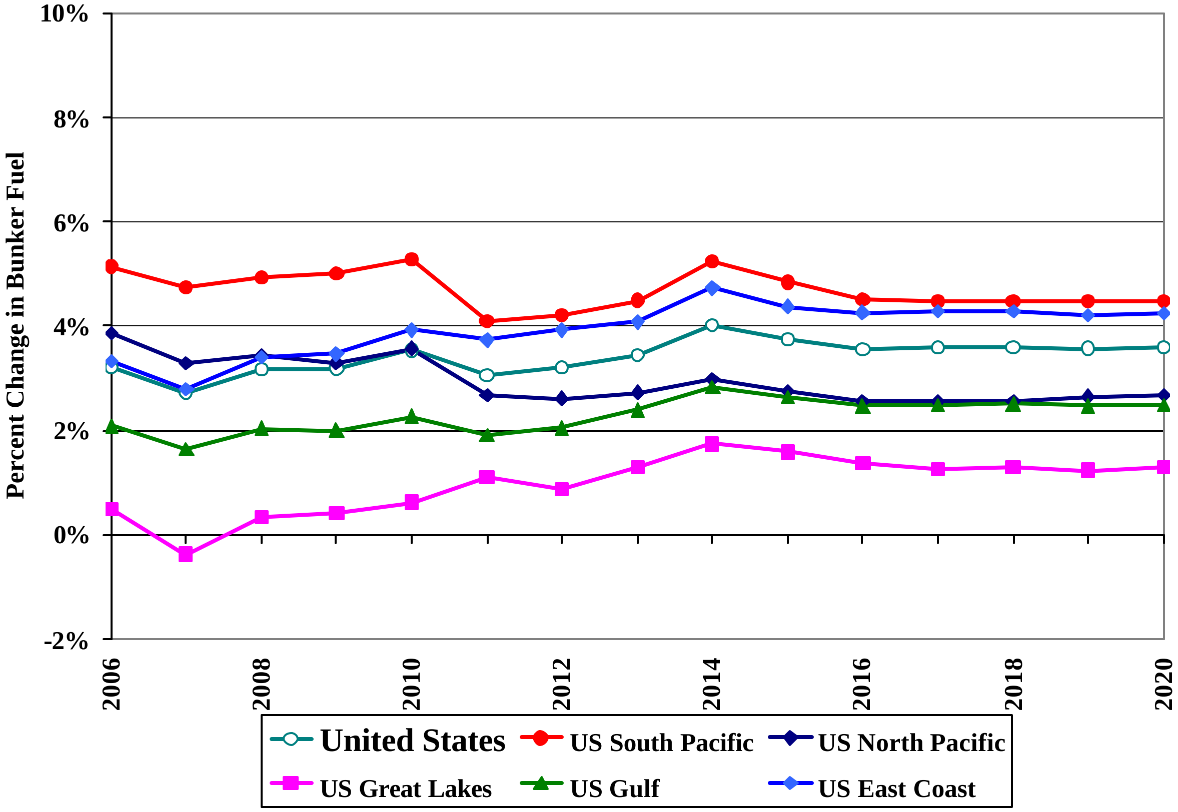


Figure 3-11 shows the annual growth rate projections for the fuel consumption estimates in Figure 3-10. The South Pacific and East Coast regions of the United States are growing the fastest, largely as the result of container ship trade (see Figures 3-12 and 3-13). Overall, the average annual growth rate in marine bunkers associated with future U.S. trade flows is 3.4 percent between 2005 and 2020. This growth rate is somewhat higher than world-wide totals, but is similar to estimated GDP growth in the U.S. of 3.1 percent between 2005 and 2020 (EIA, 2006) and is influenced by particular components of U.S. trade flows.

Figure 3-11. Annual Growth Rate in Bunker Fuel Used by the International Cargo Fleet Importing To and Exporting From the United States (by Region)



The growth rate in bunker fuel consumption related to U.S. imports and exports is driven by container ship trade (see Figure 3-15), which grows by more than four percent a year. U.S. trade volumes are also influenced by high world-wide growth in GDP and resulting demands for U.S. goods. Along with the fact that container ships use a disproportionately large amount of fuel to move a given number of tons of cargo (as discussed in Section 3.2.3), fuel use by container ships is also influenced by shifts in trading routes over time. In the future, trade is expected to shift to the Pacific region (an increase in Asia - U.S. routes), which causes the average distance per voyage to increase. Thus, while ship efficiency is increasing over time as older ships retire, this effect to dominated by the increase in voyage distance, leading to higher bunker fuel growth.

Figure 3-12. Bunker Fuel Used by the International Cargo Fleet Importing To and Exporting From the United States (by Vessel/Cargo Type)

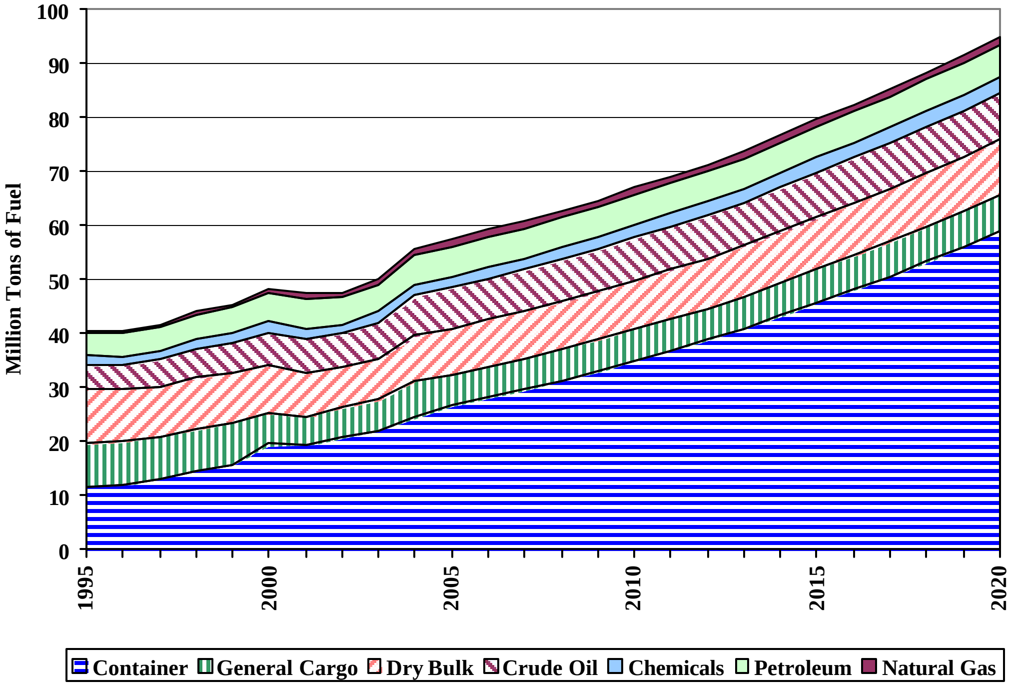


Figure 3-13. Annual Growth Rate in Bunker Fuel Used by the International Cargo Fleet Importing To and Exporting From the United States (by Vessel/Cargo Type)

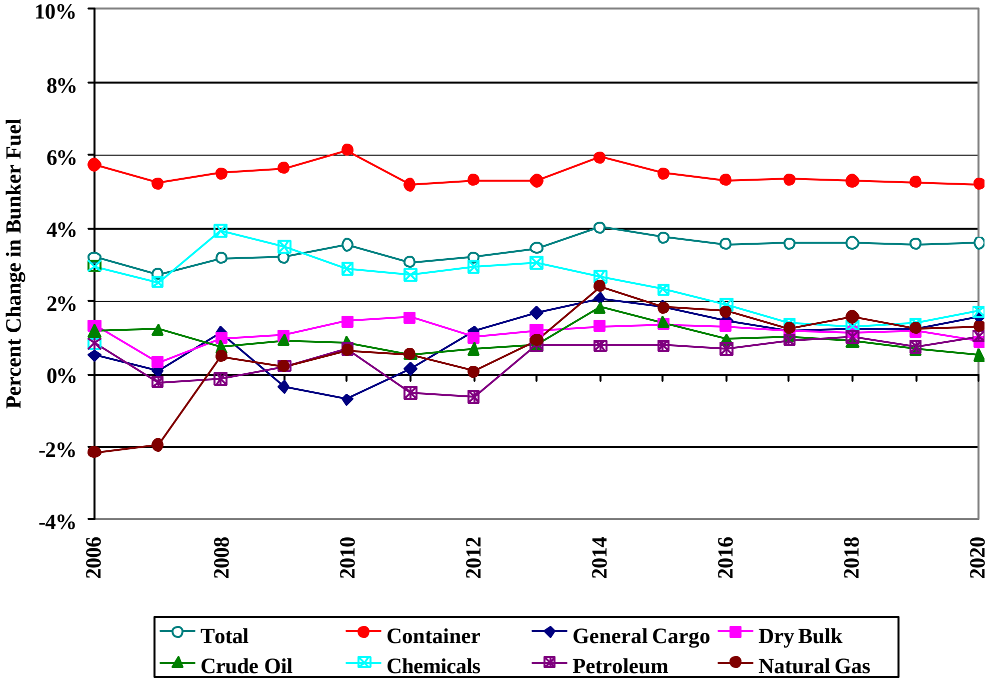


Figure 3-14. U.S. Trade Flows – Imports plus Exports (Global Insights)

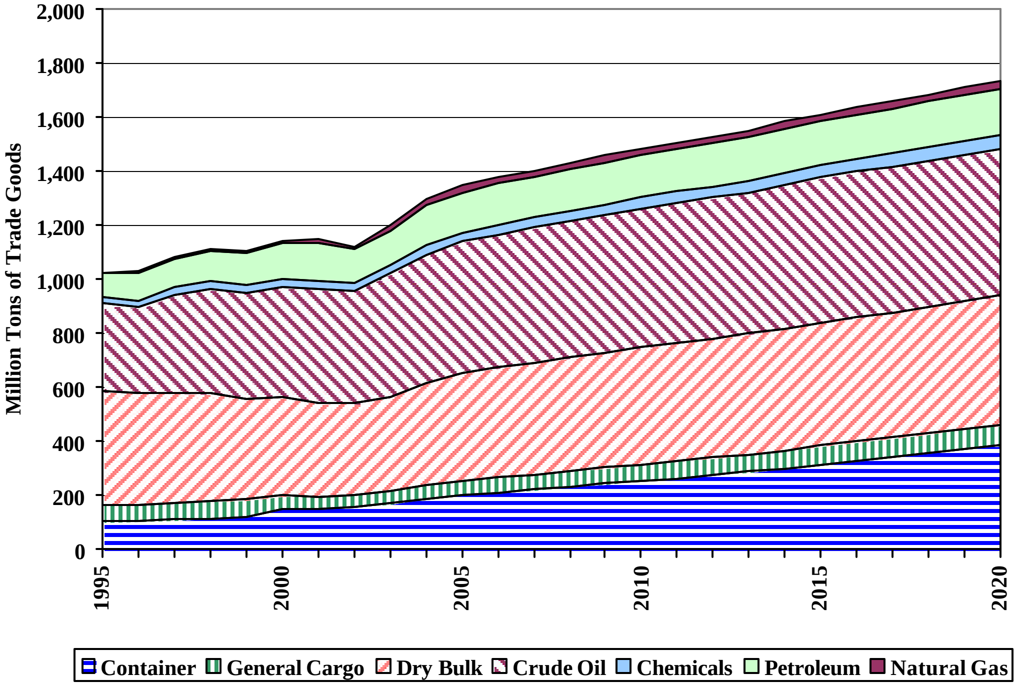


Figure 3-15. Annual Growth in U.S. Trade Flows – Imports plus Exports (Global Insights)