

Potential Market for LNG-Fueled Marine
Vessels in the United States

by

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S.B. Ocean Engineering
Massachusetts Institute of Technology, 2006

Submitted to the Department of Mechanical Engineering in
Partial Fulfillment of the Requirements for the
Degree of

Master of Science in Ocean Systems Management

at the

Massachusetts Institute of Technology

June 2008

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Abstract

The growing global concern over ship emissions in recent years has driven policy change at the international level toward more stringent vessel emissions standards. The policy change has also been an impetus for innovation and increased attention being paid to existing technologies in marine engineering that lessen ship emissions. It is estimated that the share of emissions from shipping to total global emissions is increasing, as world trade grows, and land-based emissions sources become cleaner. Shipping currently accounts for 2-4% of CO₂, 10-20% of NO_x and 4-8% of SO₂ global emissions. Gas turbines and gas engines, hybrid diesel-gas systems, and dual fuel diesel electric engines are examples of the existing engine system technology that can burn natural gas as a fuel and lessen ship emissions. Liquefied Natural Gas (LNG) fueled vessels in the gas burning mode result in the elimination of all SO₂ emissions, and reduced NO_x, CO₂, and particulate matter emissions compared to the emissions from a typical vessel powered by marine diesel. While the capital costs for the LNG-fueled systems are higher than for a typical diesel system, cost savings are generated due to the fact that LNG is historically less expensive than the other relatively lower-emissions fossil fuels, and the engine life is longer than a typical diesel engine. This study determines the feasibility of an LNG-fueled passenger and/or commerce market in the United States by analyzing the success of the current LNG-fueled activity around the world, incorporating the complexities of promoting LNG facilities in the United States, and the current LNG successes, both land-based and shore-side, in the United States.

Thesis Supervisor: Henry S. Marcus
Title: Professor of Marine Systems

Acknowledgements

It has been an honor to work with my advisor, Prof. Henry Marcus, over the past years. Prof. Marcus has been very supportive of my interests and endeavors, since I expressed my interest in the Ocean Systems Management Master's program during my sophomore year of my undergraduate studies in Ocean Engineering at MIT. He encouraged me to apply to the Master's program, and I was accepted my junior year in Fall 2004 into the Department of Ocean Engineering's graduate program. I began taking classes within the program and with Prof. Marcus that year and continued to enroll in graduate level courses my senior year.

In January 2005, the Department of Ocean Engineering was merged into the Department of Mechanical Engineering. While this merger had little impact on my undergraduate studies, it has had a definite impact on my graduate studies and life, upon my return to MIT for the 2007-2008 academic year after working thirteen months at a consulting firm. This academic year is the last the Master of Science in Ocean Systems Management (OSM) degree will be offered. The program is now within the Department of Civil & Environmental Engineering as a Master of Science in Transportation with a focus in marine systems. My understanding is that myself and one other student are the last students to receive the OSM degree, when we graduate in June 2008. Since I had returned to MIT with many of my OSM degree requirements complete, I took this year as an opportunity to grow my business knowledge through five Sloan courses.

My family and friends have been instrumental in my final year here at MIT (and in Boston). For a third year now, my sister and I have been enrolled at MIT simultaneously. And, ironically, she is enrolled in the Master of Science in Transportation program, though not with a focus in marine systems. It has been great to share our educational experience, and also nice meet up for lunch and a workout at the gym. Lastly, I give a special thanks to everyone for embracing my passion for ocean shipping.

My thesis topic is inspired by my upcoming professional career where I will be working for an energy company in their natural gas business.

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1 Nomenclature

MGO: marine gas oil
MFO: marine fuel oil
HFO: heavy fuel oil
LSHFO: light sulfur heavy fuel oil
MDO: marine diesel oil
FO: fuel oil
DO: diesel oil
NG: natural gas
LNG: liquefied natural gas
CNG: compressed natural gas
LCNG: liquefied compressed natural gas
BOG: "boil off" gas
DFDE: dual fuel diesel electric
CODLAG: combined diesel electric and gas
CODAG: combined diesel and gas
COGES: combined gas and steam
GHG: greenhouse gas
CO₂: carbon dioxide
SO₂: sulfur dioxide
NO_x: nitrogen oxides
PM: particulate matter
LNGC: liquefied natural gas carrier
LR: Lloyd's Register
DNV: Det Norske Veritas
ABS: American Bureau of Shipping

MMBtu: million British thermal units
PSV: oil platform supply vessel
RoRo: roll-on/roll-off vessel
RoPax: RoRo & passenger vessel
MARAD: US Maritime Administration
FERC: Federal Energy Regulatory Commission
EIS: environmental impact statement
ARB: California Air Resource Board
EPA: Environmental Protection Agency
EIA: Energy Information Administration
R/P: reserves to production ratio
EU: European Union
US: United States
SE Asia: Southeast Asia

1 barrel of oil energy equivalent =
6000 cubic feet of gas (Davis)

2 Introduction

Liquefied Natural Gas (LNG) has served as a marine fuel for many years, but primarily on LNG carriers (LNGCs) as the “boil off” fuel. It is only within the past decade that the growth of the LNG-fueled vessel market has really taken hold in Europe. The growth of the LNG-fueled vessel market in Europe is mainly due to the strict environmental regulations in coastal areas, and Europe’s dependence on ferry transportation for commuters in these same areas. This LNG-fueled vessel market reached South America, but has yet to be developed in other parts of the world. Realistically, any coastal area is a potential market, but the most viable markets are those where environmental regulations are likely to drive the need for cleaner, more fuel efficient vessels and there is little opposition to LNG infrastructure. The move toward these cleaner vessels is also driven by the price differential between the typical marine fuels and LNG, and is an important variable to consider.

Pressure is being placed on the International Maritime Organization (IMO) to tighten emissions regulations for new and recently constructed vessels already in service. Given that onshore industries have been cutting emissions, ship emissions are becoming a proportionally more significant part of total emissions. It is estimated that shipping emissions account for 2-4% of global CO₂ emissions, 10-20% of global NO_x emissions, and 4-8% of global SO₂ emissions (Einang²).

The United States is a potential viable market for the LNG-fueled vessel technology, given the combination of growing coastal commerce and a growing

cruise and ferry industry, in combination with growing maritime-related emissions concerns. LNG imports to the US will continue to increase through 2030, and while the price of the fuel is also likely to increase given the global demand for LNG, it is likely that typical “clean” marine fuels will continue to be more expensive for an equivalent energy content, relative to this cleaner burning fossil fuel (Drewry). LNG is currently available in the US as a transportation fuel for vehicles like trucks and city buses, but LNG has yet to be made readily available to the marine market beyond LNGCs (Clean Energy). The US Environmental Protection Agency acknowledges LNG as an alternative “clean fuel” solution for ports in the United States (EPA).

3 Overview of Marine Fossil Fuels

3.1 Marine Fuel Grades

3.1.1 Types

There are at least four main grades of marine fuels including marine gas oil (MGO), marine fuel oil (MFO or FO), heavy fuel oil (HFO), and marine diesel oil (MDO or DO). If vessels are not sailing, or at port, in an emissions restricted area, then the vessels will likely burn the least expensive fuel option for which they have access.

3.1.2 Prices

The price movements of FO and DO are relatively correlated, as are the price movements for these fuels across different regions (Arabian Gulf, N. Europe, Med, US Gulf, Caribbean, and Singapore). The price of DO is generally higher than the price of FO around the globe. The price of DO in the Caribbean has historically been the most expensive across these regions and is forecasted to continue to top the bunker fuel price for DO (close to \$630 USD per ton) and FO (close to \$320 USD per ton) through the year 2011. In contrast, the Mediterranean is the least expensive region for these bunker fuels. The next most expensive regions are the Arabian Gulf and Northern Europe. The mid to low range for bunker fuel prices is in Singapore, the US Gulf, followed by the Mediterranean (Drewry, 115).

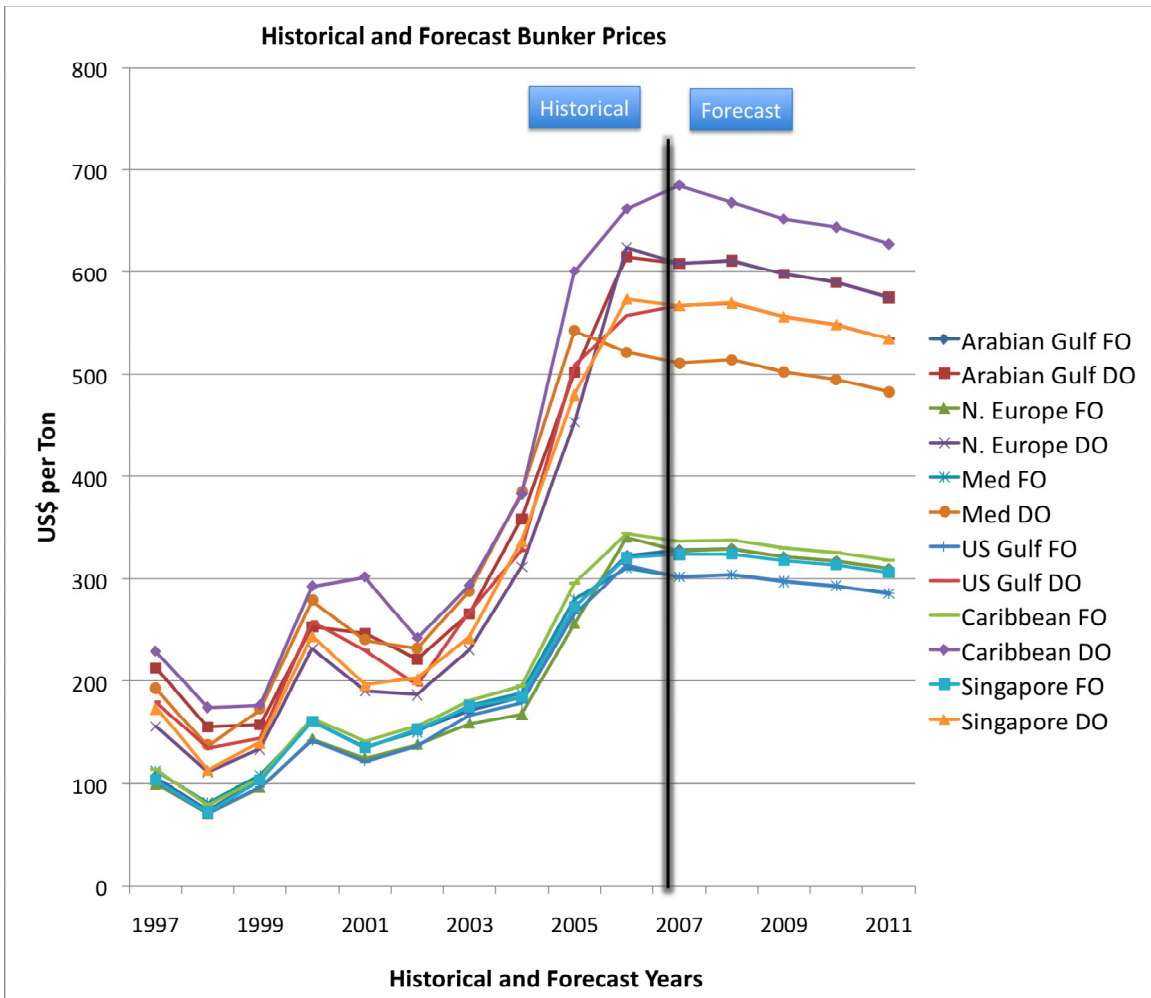


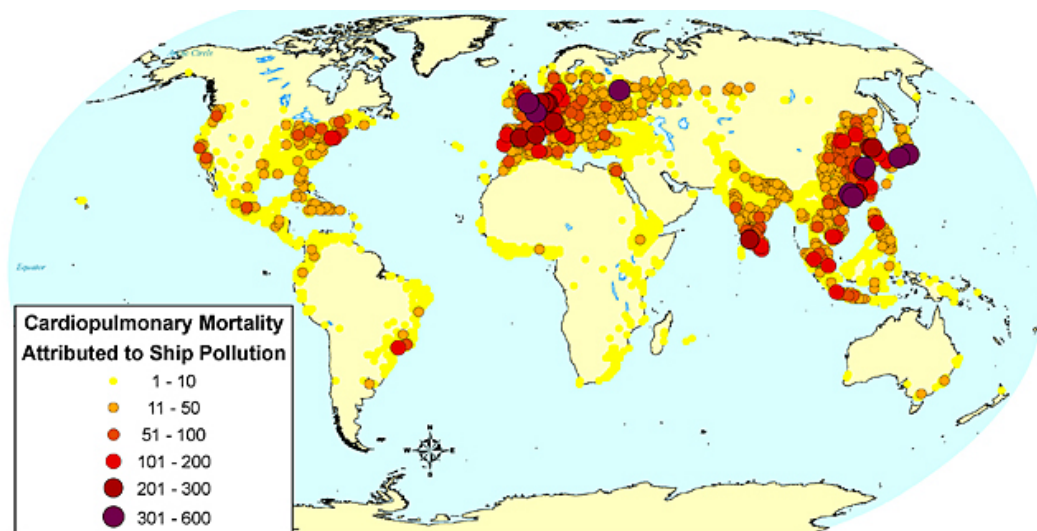
Figure 3-1: Global bunker fuel prices - historical and future (1997-2007). Global examples of historical (1997-2007) and forecast (2007-2011) bunker prices for fuel oil (FO) and diesel oil (DO) (Drewry).

3.1.3 Emissions

Typical marine fuel is a fossil fuel, a heavy fuel with high emissions of SO₂, NO_x, CO₂, and particulate matter (PM) when burned. A study conducted by researchers from two American universities found that each year, the emissions from high-sulfur fueled, oceangoing ships contribute approximately 15% of global NO_x emissions and 5-8% of global SO₂ emissions. The PM emissions from

these high-sulfur fuels are correlated with increased incidences of mortality due to heart disease and lung cancer in exposed populations.

The global impact of shipping-related PM emissions is estimated to be in the range from about 20,000-60,000 deaths annually. The wide range estimated is due to the uncertainty of the effects of PM exposure (Lubick). The majority of these deaths occur in the coastal regions along major trade routes. The yearly deaths due to PM ship-related emissions in the chart below are highest in regions in South Asia, East Asia, and Europe. Given the international ship emissions standards as of November 2007, and the projected growth in shipping, the study estimates that annual deaths due to ship emissions could increase 40% by the year 2012. The researchers see the study's findings as an impetus for the International Maritime Organization (IMO) to revisit the policy surrounding ship emissions (Boyle).

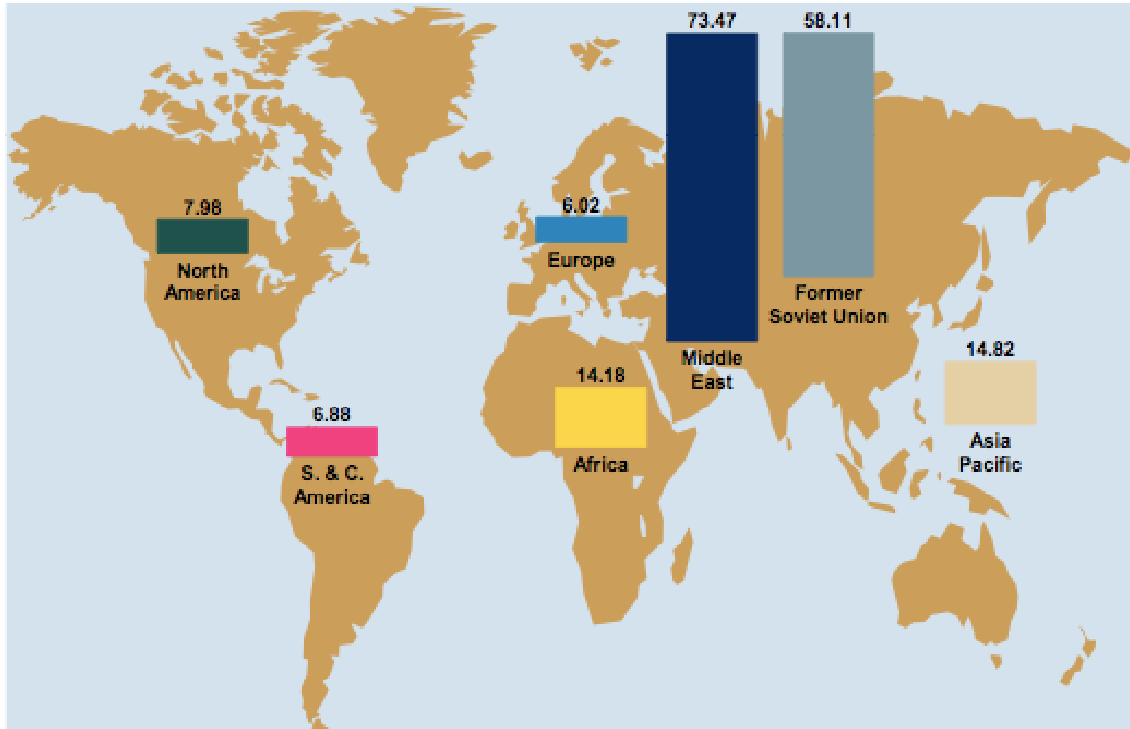


**Figure 3-2: Global deaths from shipping-related emissions (2006).
Global shipping-related deaths annually due to particulate matter emissions (Boyle).**

3.2 Natural Gas

Natural gas is also a fossil fuel and consists mainly of methane (CH₄), and has minor concentrations of ethane and propane. Natural gas is considered the cleanest burning of the fossil fuels because it has a high ratio of hydrogen to carbon. Therefore, it contributes less than the other fossil fuels to greenhouse gas (GHG) emissions, a well-proclaimed contributor to global warming. In the United States, natural gas primarily serves as a heating fuel for about 50% of homes, and accounts for 20% of the electrical power generated by utilities (Davis).

The world's natural gas reserves are greater on an energy basis than the known oil reserves. While natural gas is a fossil fuel spread throughout the world, the majority of the reserves are located in Asia; over 130 trillion cubic meters of natural gas reserves are in the Middle East and Former Soviet Union combined. North America's reserves are close to 8 trillion cubic meters (Drewry, 17).



Source: BP

Figure 3-3: Global natural gas reserves (2006).

Global reserves of natural gas in trillion cubic meters as of the year 2006 as calculated by BP (Drewry, 17).

BP estimates that the world's natural gas reserves-to-production (R/P) ratio is over 60 years. The R/P ratio is lowest for North America and the Asia Pacific region (BP4). Both regions are expected to be growing importers of natural gas (or LNG) over the next few decades.

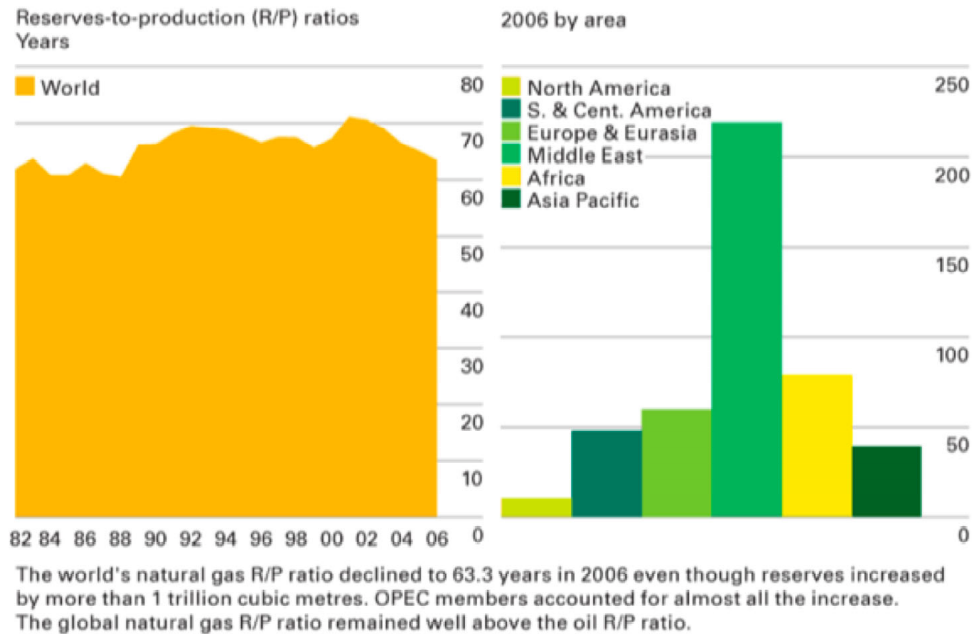


Figure 3-4: Global natural gas reserves to production (2006).
 Natural gas reserves to production ratios as of the year 2006 calculated by BP (BP4).

3.3 Compressed Natural Gas

Natural gas can also be compressed to serve as a transportation fuel. This compressed natural gas (CNG) is common for city transportation, where a refueling station is within close proximity. While CNG takes up less volume than natural gas, it is only a small reduction in volume. CNG is inherently more dangerous than natural gas or liquefied natural gas, as CNG is at a high pressure.

3.4 Liquefied Natural Gas (LNG)

Natural gas is in the gaseous form at ambient temperatures, and is a liquid when it is cooled to -162°C and held near atmospheric pressure. In its gaseous form, natural gas is distributed to markets via pipelines (Davis). In liquid form, the same energy content of the gas takes up $1/600^{\text{th}}$ the amount of space. It is this

liquid form that created the economies of scale and sparked the LNG global trade that moved the commodity outside of its regional markets, beginning in around the year 2003 when large investments were made in LNG liquefaction (export) facilities around the world (Davis). LNG now accounts for about 28% of the global trade of natural gas (i.e. the remaining 72% of natural gas is transported via pipeline) (Drewry, 19). Trade of LNG is growing in Asia, Europe, and the Americas. Asia dominates the LNG trade, followed by Europe, and then the Americas (Drewry, 1).

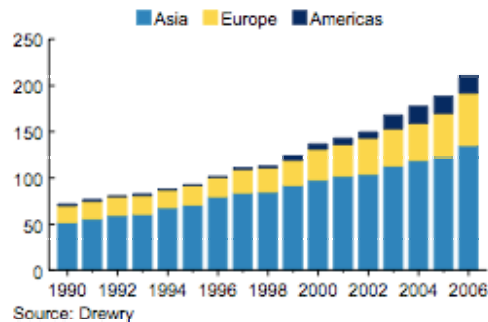


Figure 3-5: Historical LNG trade growth in Asia, Europe, Americas (1990-2006). LNG Trade development in the Asia, Europe, and Americas market from 1990-2006 (Drewry, 1).

3.4.1 Emissions

In terms of emissions benefits, the process of liquefying natural gas removes sulfur from the gas. Hence, SO₂ emissions are not present when the fuel is burned. A comparison of the emissions of natural gas to typical marine fuels results in reductions of four pollutants: SO₂, NO_x, CO₂, and PM. As mentioned previously, SO₂ emissions are completely eliminated, NO_x emissions are reduced by up to 90% (Howie, 25), CO₂ by 20%, and PM is also reduced.

4 LNG Market

4.1 Growth

The growth in world population along with growth in economies around the world contributes to an increase demand for energy. The Energy Information Administration (EIA) expects that this growth in the demand of energy supplies will be 57% between 2004 and 2030 (Drewry, 125). The LNG market is one of the fastest growing in the energy sector, and is a small segment of the also fast growing natural gas market. Over the past ten years, the global demand for LNG grew about 8% per year. LNG exports from Southeast Asia have remained relatively constant from 1996 through 2006, while there was export growth later in the period for Africa, the Middle East, and the Americas (Drewry, 2).

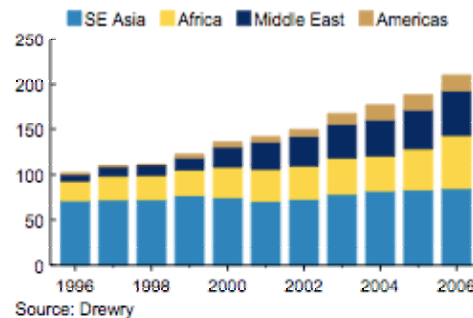


Figure 4-1: Historical LNG exports from SE Asia, Africa, Middle East, Americas. LNG exports from SE Asia, Africa, Middle East, and Americas from 1996 through 2006 (Drewry, 2).

The largest import markets of the commodity in the year 2006 include Japan, South Korea, and Spain. These top three markets account for close to 70% of the total import volume among the top 10 LNG importers. Following these three countries is the United States with an import volume of 16.56 billion

cubic meters of LNG in 2006. Of these top importers by volume, the only country with a decrease in imports from the years 2005 to 2006 was the United States with a 7.3% decrease in import volume; Japan, South Korea, and Spain each saw positive growth in LNG imports during the time period (Drewry, 9)

Pos.	Prev.	Country	2005	2006	% Change
1	1	Japan	78.32	81.86	7.3%
2	2	South Korea	30.45	34.14	12.1%
3	3	Spain	21.85	24.42	11.8%
4	4	USA	17.87	16.56	-7.3%
5	5	France	12.83	13.68	6.2%
6	6	Taiwan	9.61	10.20	6.1%
7	7	India	6.04	7.99	32.3%
8	8	Turkey	4.88	5.72	17.2%
9	9	Belgium	2.98	4.28	43.6%
10	13	UK	0.52	3.56	584.6%

Figure 4-2: Global Top 10 LNG importers (2005 and 2006).
Top LNG importers in the world and the volume imported in units of billion cubic meters (Drewry, 9).

4.2 Price

The price of LNG in the world market is historically linked with the price of crude oil (Drewry, 43). While the prices of these commodities fluctuate over time, there was an upward trend in prices over the period from 2002 to 2006. In the year 2002, crude oil was at about \$4.80 US/MMBtu and more than doubled to \$10.66 in 2006. During the same time frame, LNG prices in the United States increased similarly from \$3.34 to \$6.76 US/MMBtu. By 2006, the price of crude oil was more expensive than LNG in Japan, the European Union (EU), and the United States. When there is a disparity between the price of crude oil and the price of natural gas in the US market, analysts predict that the price of natural gas will

rise to close that price gap. When a great amount of LNG liquefaction terminal capacity was added globally in 2003, the market opened to significant global trade and led to higher market prices (Davis).

The price of LNG in the EU and the US is historically different from the price of LNG in Japan. One such explanation for the price discrepancy is that Japan's suppliers have a lower transport price than the EU's suppliers.

Furthermore, the price for LNG in the EU is held low due to the competitively priced pipeline gas from Russia in the same market (Drewry, 43)

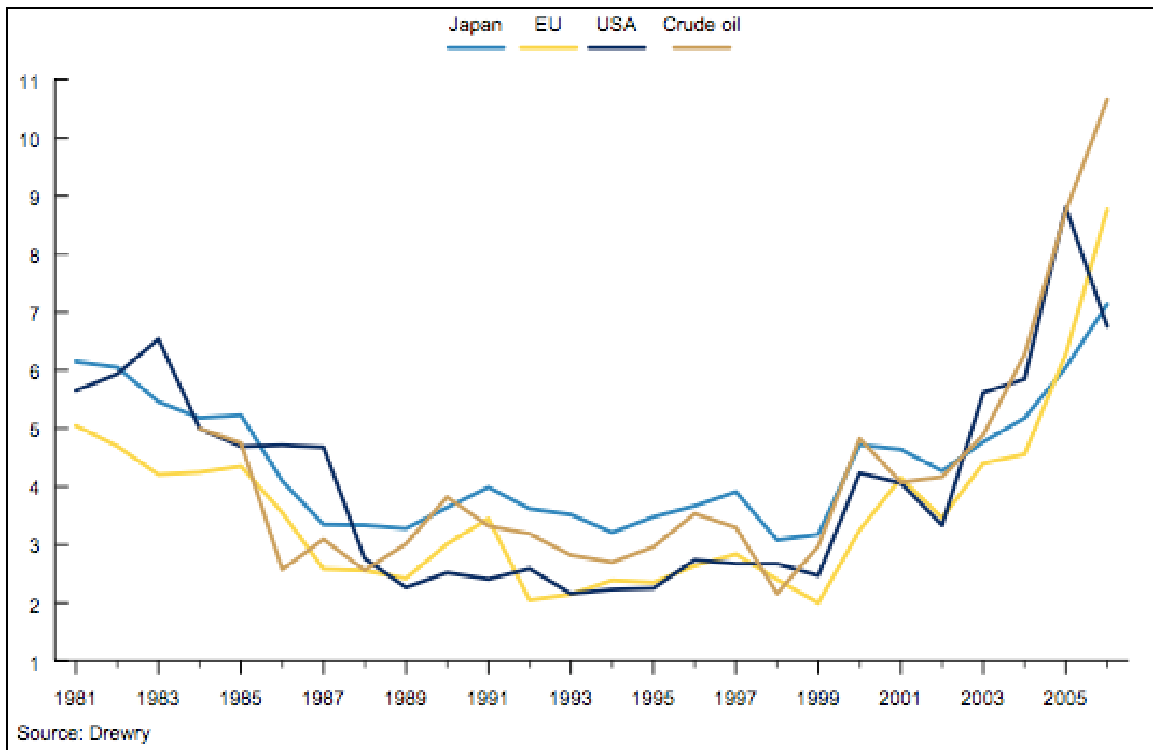


Figure 4-3: Historical LNG prices in Japan, EU, USA compared to crude oil price. LNG prices in US\$/MMBtu Japan, EU, USA compared to crude oil in US\$/MMBtu from 1981-2005 (Drewry, 44).

During the beginning of the year 2007, the US imported record amounts of LNG. However, the price for natural gas remained relatively stable as a result of

increased domestic production and the excess natural gas storage capacity available in the US at that time (FERC, 5).

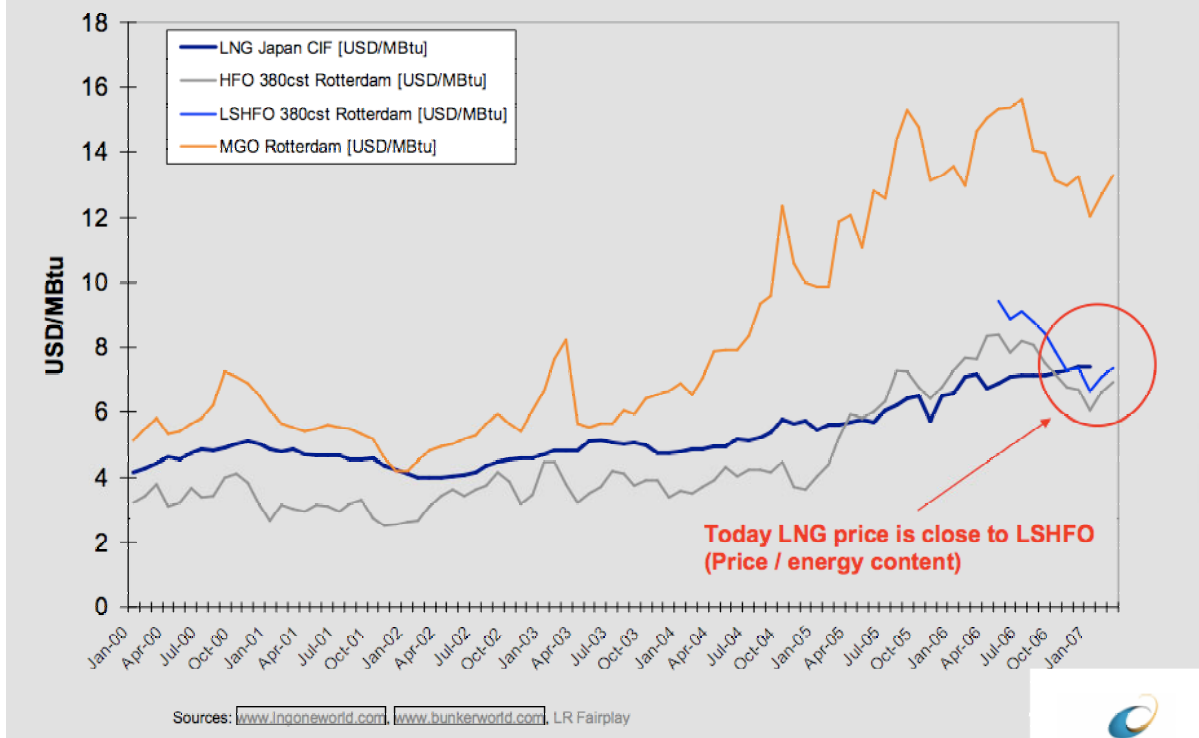
The price for LNG as reported by the OECD is slightly different than that reported by Drewry. In the year 2006, LNG prices were lower in the EU than in Japan, South Korea, and the United States.

	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Belgium	2.82	2.56	2.08	2.98	3.89	3.15	3.73	4.10	5.95	8.55
EU	2.84	2.40	2.00	3.10	3.68	3.17	3.62	4.01	5.27	6.58
Japan	3.91	3.08	3.18	4.73	4.84	4.32	4.82	5.23	6.05	7.12
South Korea	3.85	2.86	3.15	5.04	4.95	4.41	5.03	5.74	7.23	8.81
Spain	2.96	2.39	1.99	3.33	3.52	3.14	3.58	3.87	4.95	6.52
USA	2.67	2.67	2.47	3.34	4.22	3.38	4.68	5.21	7.40	6.83

Figure 4-4: Historical LNG prices (1997-2006). LNG prices in US\$/MMBtu across six selected regions from 1997-2006 (Drewry, 43).

The engine manufacturer Wärtsilä compiled bunker prices for four fuels to provide a price comparison over the time period from January 2000 through mid 2007. The four fuels selected were LNG (Japan CIF), HFO (Rotterdam), Light Sulfur HFO (Rotterdam), and MGO (Rotterdam). At the latest time point in the series, the price of LNG was closest to the price of the LSHFO and only slightly higher than the price of HFO. MGO was the most expensive bunker fuel of the four.

LNG price



7 © Wärtsilä
Figure 4-5: Historical LNG prices compared to HFO, LSHFO, and MGO prices (2000-2007). LNG price in Japan compared to HFO, LSHFO, and MGO prices in Rotterdam from 2000-2007. All units are US\$/MMBtu (Levander, 7).



4.3 Trade

The lead exporters of LNG in the year 2006 were Qatar, Indonesia, and Malaysia. These three countries each engaged in significant trade with Japan and South Korea in the same year these importing countries saw some of the highest average prices for the fuel. The US exports LNG via a liquefaction facility in Alaska to the Japanese market. The import trade for the US is mainly from Trinidad & Tobago, but the US supplements these imports with LNG from Africa (Drewry, 46).

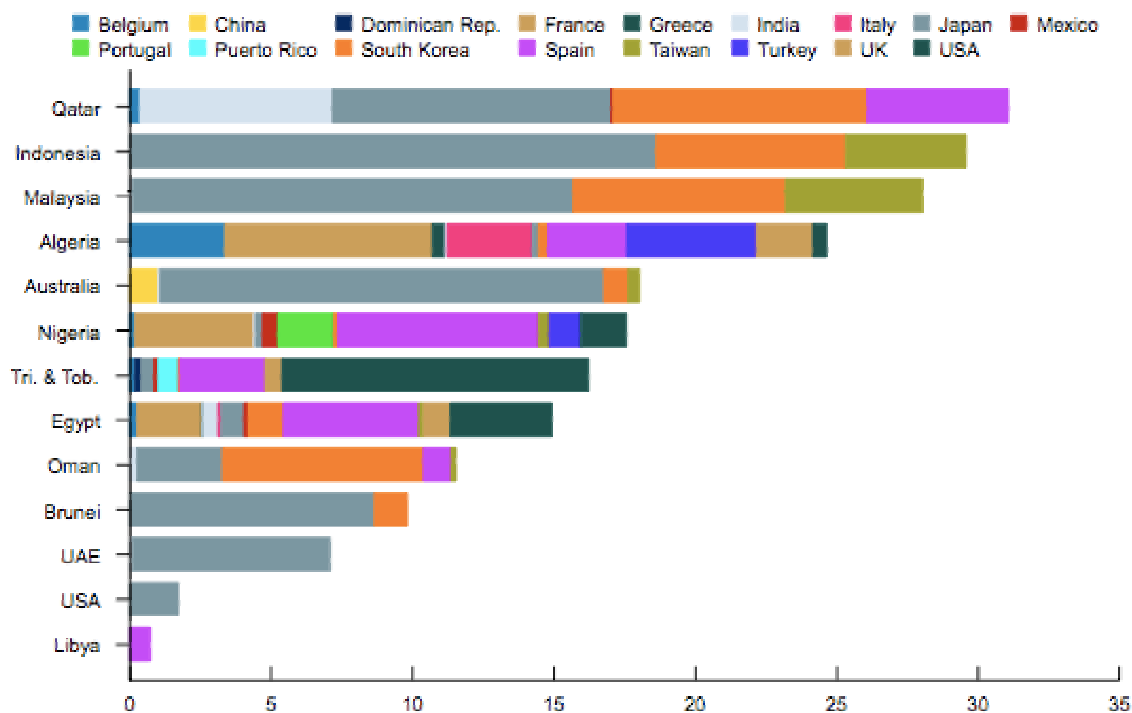


Figure 4-6: LNG exporters and their markets (2006). LNG exporters and the markets to which they export by volumes in billion cubic meters in 2006 (Drewry, 46).

Japan is the clear lead importer of LNG worldwide. In 2006, Japan imported over 80 billion cubic meters of the liquid, about four times that of the United States (Drewry, 57). Given that Japan has no fossil fuels of its own, and it is not in close proximity to natural gas producing areas such that the gas can more efficiently be piped into the country, Japan is forced to rely on these imports from LNGCs (Ackerman). The top importers in 2006 each had a diverse supply base including countries from various continents, evidence that LNG is truly a global commodity.

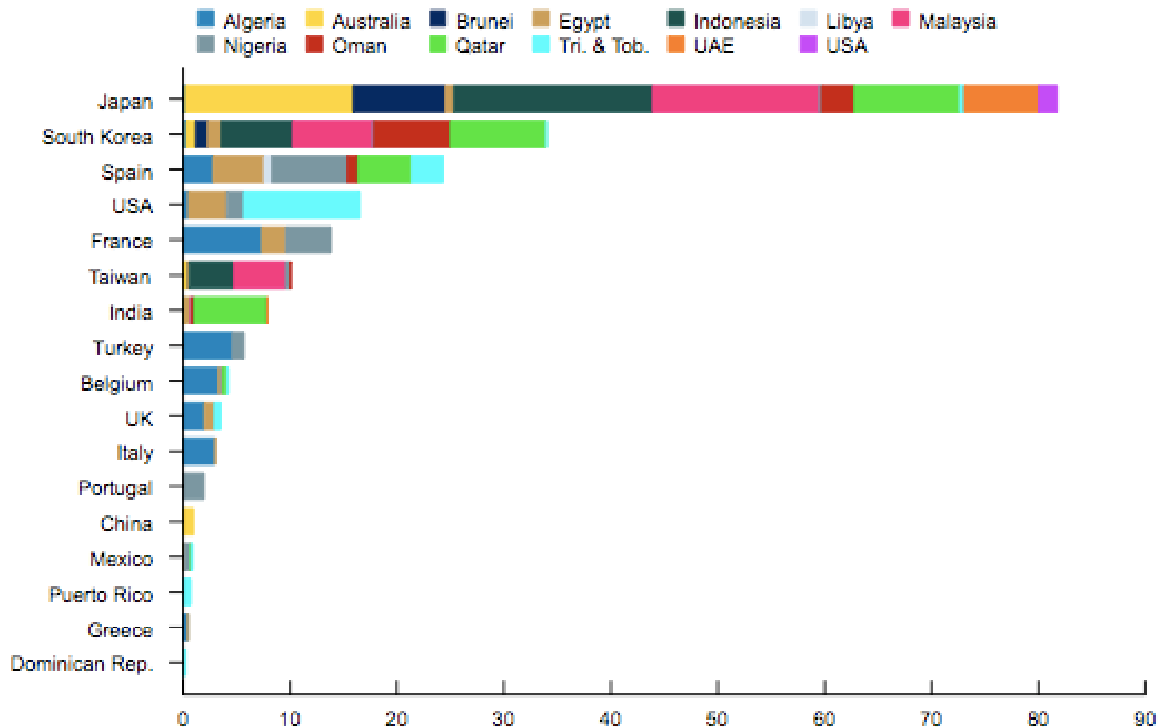


Figure 4-7: Global LNG importers and their markets (2006).
LNG importers and the regions from where they import volumes in billion cubic meters in 2006 (Drewry, 46).

4.4 United States

4.4.1 LNG Capacity

The total capacity of the LNG terminals in the United States in operation by the beginning of 2008 is about 6 billion cubic feet per day. However, these terminals have collectively received far less than this total capacity - less than 1 billion cubic feet per day (on average) so far in 2008. Plans for additional terminal capacity are underway and could reach 13 billion cubic feet per day by the end of the year (Ackerman). Director of Global LNG at Cambridge Energy Research Associates (CERA), Michael Stoppard, concludes that the US will need to build as much capacity in the next eight years as it has in the past forty years.

ExxonMobil, BP, and Royal Dutch Shell – a few of the energy majors – are all willing to invest the necessary funds to meet the demand here in the US, and have already begun investing (Forest).

As of April 17, 2008, there are six onshore LNG receiving terminals in the Continental US. Of the seven LNG terminals in the United States below (excludes Puerto Rico), only one is an export facility – Kenai, Alaska (FERC).

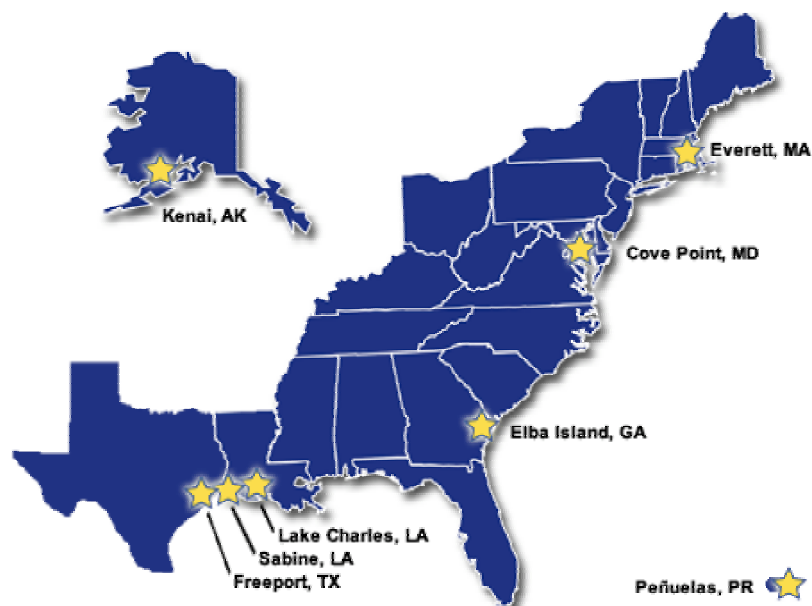


Figure 4-8: LNG facilities in the United States (April 2008).
Existing LNG facilities in the United States and territories as of April 2008. The Kenai, Alaska terminal is the United States' only LNG exporting facility (FERC).

LNG imports into the United States in 2006 and 2007 were to the following receiving terminals: Gulf Gateway/Excelerate; Lake Charles, LA; Cove Point, MD; Elba Island, GA; and Everett, MA (FERC, 4).

The Gulf Gateway terminal only received imports beginning in 2007. The first two thirds of 2007 were record importing months of LNG for the US. Lake Charles and Cove Point were the two terminals that managed to secure the

majority of this import growth. Imports of LNG were mostly steady for Elba Island and Everett in the period of high imports compared to 2006.

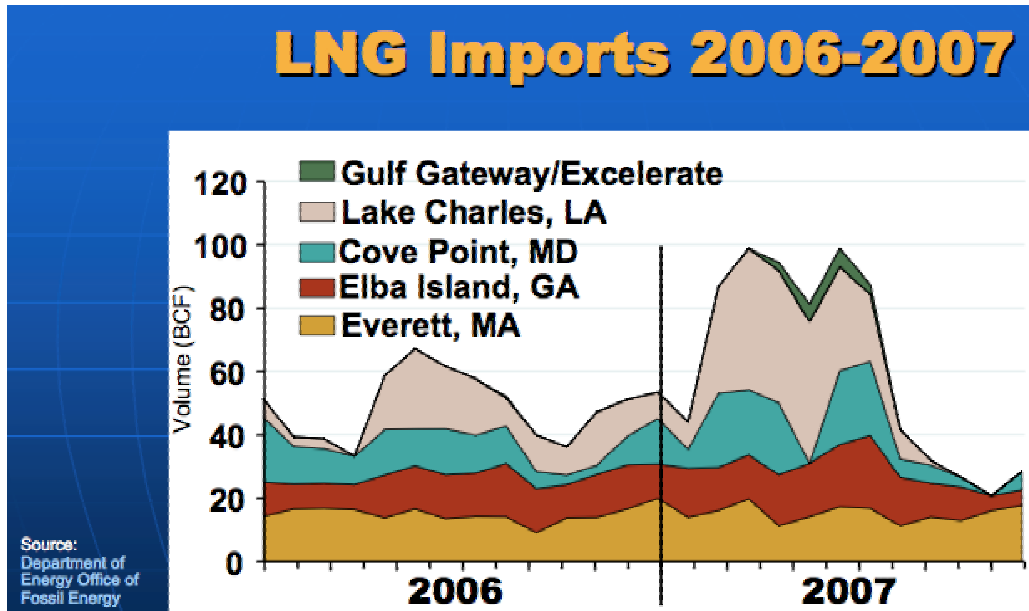


Figure 4-9: LNG imports to major receiving terminals in the United States (2006-2007). LNG imports into the five major LNG importing facilities in the United States: Gulf Gateway/Excelerate (offshore terminal), Lake Charles, LA; Cove Point, MD; Elba Island, GA; and Everett, MA. Volume of imports is in billion cubic feet for the years 2006 and 2007 (FERC, 4).

While the United States is growing its LNG terminal capacity, it is having difficulty gathering imports of LNG. From mid 2007 through the beginning of 2008, US LNG imports declined to reach the lowest point in the last five years. Meanwhile, the price of natural gas in that time frame in the US rose about 90%. The demand for LNG in the United States faces a competitive global market, particularly from Japan where prices of LNG imports neared \$20.00/MMBtu in 2008 (Davis).

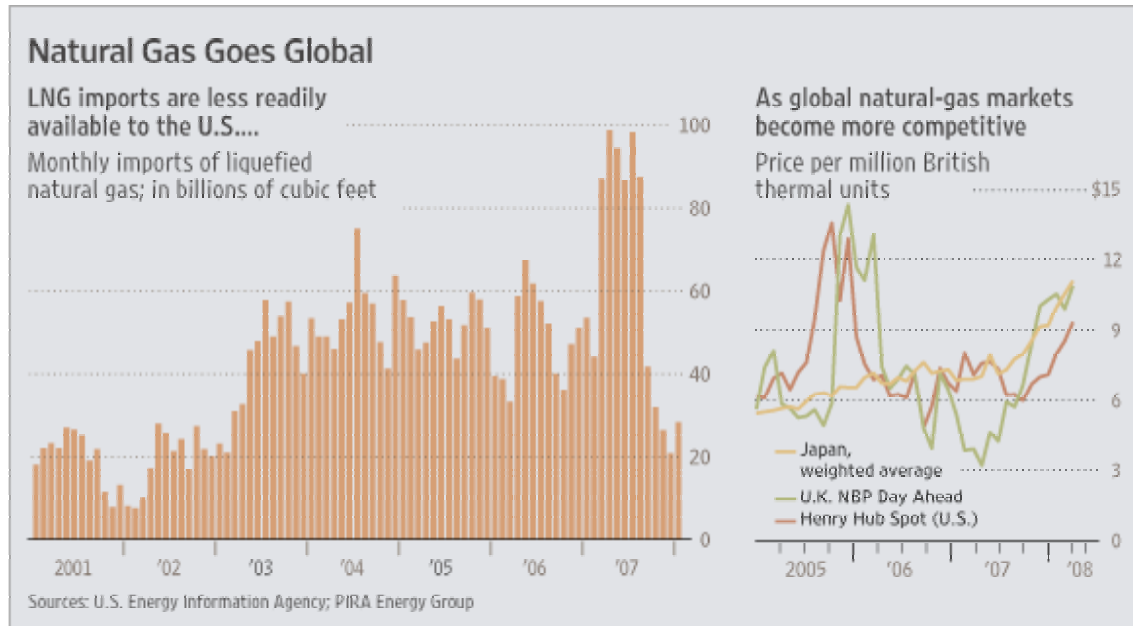


Figure 4-10: Historical LNG monthly imports to US (2001-2007) and natural gas prices in Japan, UK, and US (2005-2008). LNG monthly imports in volumes of billions of cubic feet to the United States from 2001-2007 compared alongside the price in US\$/MMBtu for natural gas in Japan, the UK, and US from 2005-2008 (Davis).

4.4.2 Natural Gas Supply & Demand

LNG imports into the US over the last decade were derived from four main regions: Southeast Asia, the Middle East, Africa, and the Americas. The low prices for domestic natural gas resulted in two years of decreased LNG imports to the US, as LNG was sent to the more price competitive markets in Europe and Asia. Despite the lower demand from 2005-2006, the market saw record-breaking successive monthly LNG imports in the beginning of 2007 (Drewry, 3); imports were up over 50% from the same period a year prior (Drewry, 8).

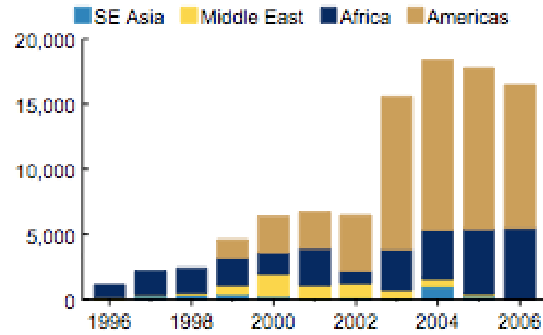


Figure 4-11: Historical LNG imports into the United States (1996-2006). LNG imports to the US in volumes of million cubic meters from 1996-2006 from SE Asia, Middle East, Africa, and Americas (Drewry, 2).

Royal Dutch Shell claims the domestic production of natural gas in the US in the year 2025 is likely to lag the demand by 15-20 billion cubic feet per day, necessitating LNG imports (Davis).

The forecast according to the Energy Information Administration (EIA) predicts a general increasing trend in the import of gas (either LNG or natural gas) to the US through the year 2030. Canada is expected to continue to supply natural gas to the United States through the year 2030, despite the increase of LNG imports (Drewry, 3).

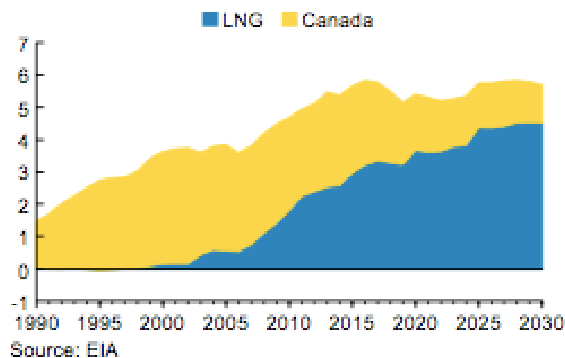


Figure 4-12: Forecast LNG imports and Canada's pipeline exports to the United States through 2030. Net natural gas imports forecast for the United States through 2030 compared to historical data beginning in 1990. Natural gas pipeline imports from Canada compared to supplemental gas from imports of LNG from around the world (Drewry, 3).

After the year 2015, the EIA forecasts that the net imports of natural gas into the United States will be dominated by LNG imports from around the world, and will for the first time be greater than the imports of natural gas into the US from Canada. The US has at times exported natural gas to Mexico, and is forecasted to continue to be a net exporter to Mexico in the future (Drewry, 129).

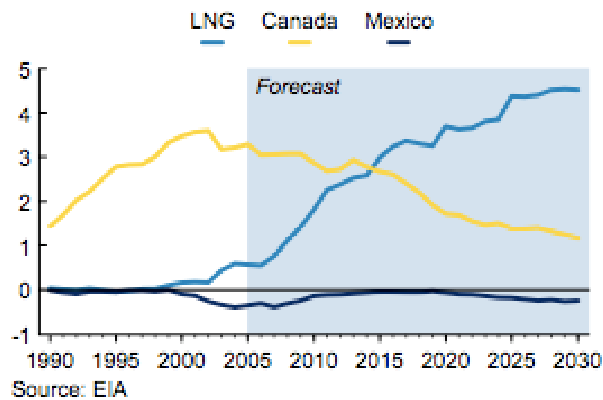


Figure 4-13: Forecast LNG imports to the United States through 2030 and shares of natural gas from Canada and Mexico.
Net natural gas imports forecast for the United States through 2030 compared to historical data beginning in 1990. Natural gas pipeline imports from Canada supplemented by LNG imports from around the world. The point at which LNG imports begin to overtake pipeline imports of natural gas is in the year 2015. The United States is a net exporter of natural gas to Mexico (Drewry, 129).

International oil company, ExxonMobil, is also in agreement with the long-term forecast for increased import demand for LNG around the world, especially in North America and Europe where ExxonMobil predicts the local production of natural gas will decline by 2030. ExxonMobil forecasts the “LNG market will change dramatically with a fivefold increase in volume to nearly 75 billion cubic feet per day.” The company also predicts that the supplies of LNG will shift from the Asia/Pacific region to the Middle East and West Africa (ExxonMobil).

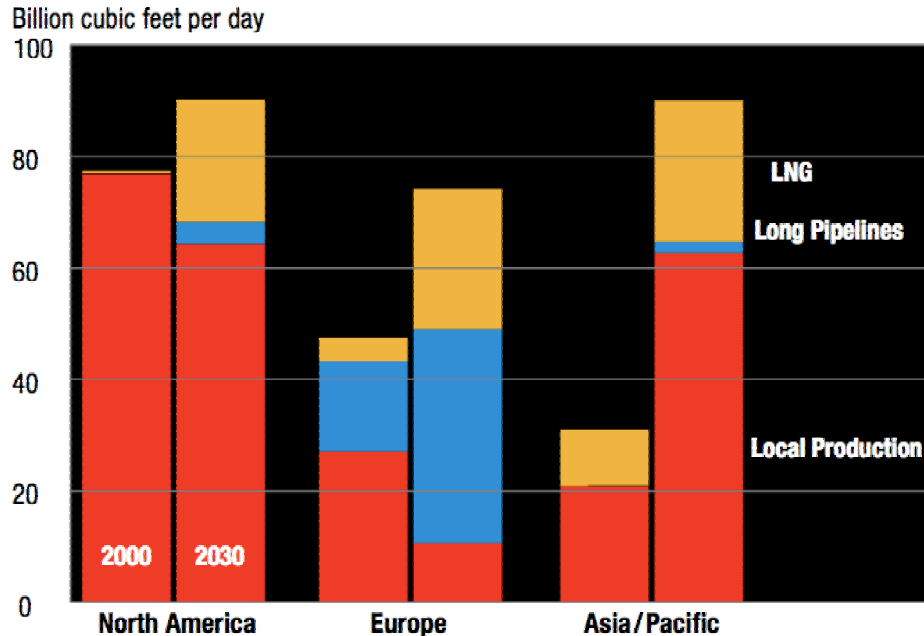


Figure 4-14: Forecast Natural Gas and LNG imports for North America, Europe, and Asia-Pacific for 2030.

The forecast for North America, Europe, and Asia/Pacific in 2030 is increased imports of natural gas over the volumes in the year 2000, whether the imports are via pipeline or transported as LNG. LNG imports are in yellow, pipeline imports are in blue, and local natural gas production is in red. The volumes are in billion cubic feet per day (ExxonMobil, 5).

4.4.3 Price Forecast of LNG to the US

The future demand for LNG imports in the US can be investigated under four different cases of the LNG market: low price, high price, low growth, and high growth. The base case assumes 8.2% growth between 2005 and 2030. The biggest differences in the import volumes occur between the low price and the high price cases. The forecasted import volume in the low price case at close to 8 trillion cubic feet (tcf) is almost four times that for the high price case (at 2.2 tcf) by the year 2030. The import growth in the high growth stage results in an import volume in 2030 that is approximately two times that of the low growth case (approximately 5.5 tcf vs. 2.5 tcf) (Drewry, 129).

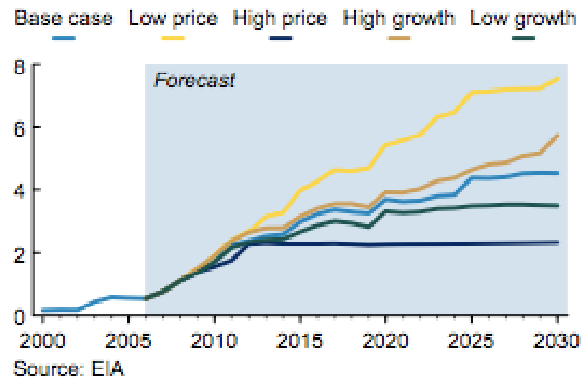


Figure 4-15: Forecast LNG import scenarios through 2030. Four scenarios for imports (volume in trillion cubic feet) to the United States of LNG are considered in a forecast from 2006-2030. The forecasts color codes as follows: at a low price (yellow), at a high price (dark blue), at high growth (brown), and low growth (green), and the base case (light blue) (Drewry, 129).

5 LNG-Fueled Marine Vessels

5.1 Introduction

There are a few configuration options for LNG-fueled vessel technology. Each of these engine propulsion options can be designed, or is designed, to burn natural gas. For each option investigated, natural gas could be stored on the vessel as CNG or LNG. However, LNG is the storage method for natural gas on the vessel to be discussed; LNG requires significantly less tank volume compared to CNG, and only LNG achieves the 0% emissions of SO₂ (given that sulfur is removed in the liquefaction process).

The first LNG-fueled configuration is a vessel that is powered by marine gas turbines or gas engines. These gas turbines or gas engines can be combined with steam turbines; a combined gas turbine and steam system is referred to as COGES. A marine gas turbine can be designed to burn natural gas, but is historically designed in the marine industry to burn other liquid fossil fuels. Marine gas turbines, with the appropriate fuel purification systems, can burn fuels on the spectrum from jet fuel to heavy fuel oil (Mars Tech). In 2006, Siemens conducted a test on their *SGT-500* gas turbine, designed to burn a variety of fuels. The *SGT-500* gas turbine test run on HFO proved there was no significant effect on the maintenance for the turbine, there was no visible smoke for as low as 20% loads, and there was high efficiency. Given the tripling in price of marine distillate fuels in recent years, there is a potential market for purification

systems for marine gas turbines to allow the systems to burn HFO (PEI). Marine gas engines are specifically designed to burn natural gas.

The second option is a hybrid diesel-gas vessel; these vessels have separate diesel engines and marine gas turbines or gas engines. The systems are referred to as Combined Diesel Electric and Gas (CODLAG) and Combined Diesel and Gas (CODAG) systems. If the system employs gas turbines, the turbines can be designed to burn natural gas, as in the case of COGES.

The third vessel type is powered by a dual fuel diesel electric (DFDE) engine. This engine type is designed to burn both diesel and natural gas.

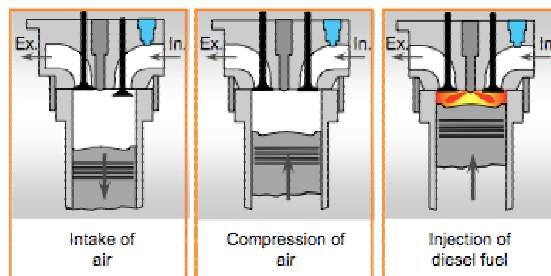
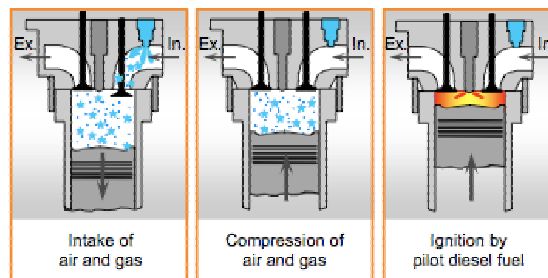
The gas turbine for marine applications is promoted by the major marine engine manufacturers Rolls-Royce and GE, along with Siemens mentioned previously. The power generation manufacturers have designed the power systems for hybrid vessels that can be configured to burn natural gas. Although, it is unlikely Siemens would configure their *SGT-500* system to burn natural gas, given that it is marketed as a gas turbine to burn HFO. Rolls-Royce also has designed a gas engine for marine applications that burns natural gas.

The Dual Fuel Diesel Electric (DFDE) propulsion system for marine vessels combines diesel and steam technology for an engine that can be powered either by diesel fuel or natural gas (stored as LNG on the vessel), as well as “boil off” gas in the case of LNG carriers (LNGCs). Wärtsilä, one of the manufacturers of DFDE engines terms these engine operating functions as “gas mode” and “diesel mode” (Levander, 16).

DF Engines - Operating modes

Gas mode:

- Otto principle
- Low-pressure gas admission
- Pilot diesel injection



Diesel mode:

- Diesel principle
- Diesel injection

16 © Wärtsilä



Figure 5-1: Dual Fuel engine operations.

There are two operating modes for the dual fuel (DF) engine: gas mode and diesel mode. The natural gas operating mode of the DF engine is low pressure with a diesel injection for the pilot. The diesel operating mode of the engine is with diesel injection (Levander, 16)

The system is an important innovation for the LNG industry (Drewry, 64). DFDE is more thermally efficient than a steam turbine by 15% and reduces daily fuel consumption by 30-40 tons compared to a steam engine (RasGas). The DFDE system is not to be confused with the Combined Diesel Electric and Gas (CODLAG) and Combined Diesel and Gas (CODAG) systems.

The CODLAG and CODAG systems, while sometimes referred to as dual-fuel systems are inherently different from a DFDE system. Namely, the CODLAG/CODAG systems incorporate separate diesel and gas turbines or gas engines on the same vessel; these systems do not have a single engine that can bunker both diesel and natural gas, besides diesel serving as a pilot fuel for a

gas engine designed to burn natural gas (Bailey, 5). Hence, the DFDE systems are inherently more flexible than the COGES, CODLAG, and CODAG systems that have engines that are tied to burning a specific fuel. The benefit of burning only one fuel (whether it is diesel or natural gas) is the simplification of bunkering, as only a single fuel needs be bunkered.

There is a higher initial capital cost for a ship propulsion LNG-fueled system compared to a diesel engine. LNG-fueled systems require new equipment not aboard typical diesel powered vessels including a large, gas combustion unit (RasGas). LNG-fueled systems are a proven technology with many operating hours. Specifically, the DFDE vessels have over 700,000 hours (including marine and power plant applications) of running time logged (Thijssen).

5.2 Manufacturers

There are four main manufacturers of technology that can be used for LNG-fueled vessels (Note: Siemens' *SGT-500* technology is excluded, as it is promoted as an HFO burning marine gas turbine). These four engine manufacturers include Rolls-Royce, GE, Wärtsilä, and MAN Diesel.

5.2.1 Rolls-Royce

Rolls-Royce developed the *Bergen K* (including *KVGS -12G4*) gas engine. The medium speed engines have similar components to the *Bergen* diesel engines.

The company claims its engine reduces emissions by the following: 90% less

NO_x, 20% less CO₂, no particulate matter emissions and no SO₂ emissions (MarineLink1). The gas engine has been designed and implemented to burn natural gas (Rolls-Royce).

The *MT30* is Rolls-Royce's gas turbine and was selected for the US Navy's DD(X) multi-mission destroyer (Corkhill) in a CODAG system (Rolls-Royce), and is considered the most power-dense solution available with ratings of over 40MW. The *MT30* is ABS certified and intended for larger LNGCs. However, the *MT30* gas turbine has not yet been modified to burn natural gas as a primary fuel. Rolls-Royce states that one of the benefits of its gas engine and turbine solutions for marine vessels is the need to only have one bunker fuel - LNG (Corkhill).



Figure 5-2: Gas turbine that can potentially burn natural gas. The *MT30* engine developed by Rolls-Royce has two designs. The design on the left is for smaller vessels (typically naval vessels) and the design on the right is for larger commercial vessels (Ingjerd).

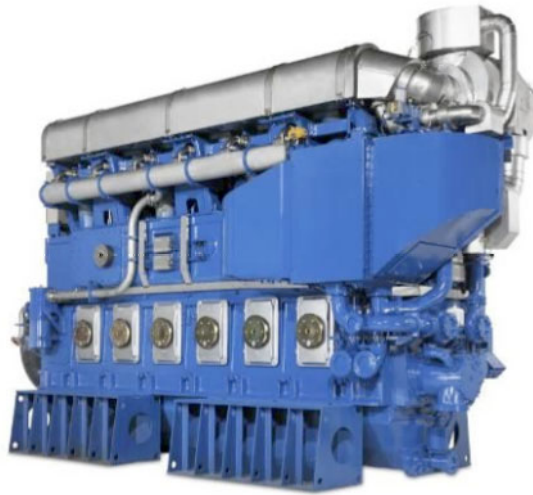
5.2.2 GE

The GE Marine Engine group developed the *LM2500*, *LM2500+*, and *LM6000TM* ('L' meaning land and 'M' meaning marine), "aeroderivative gas turbines", based on aircraft engine technology (Eser; MarineLink2). Not only limited to commercial industries, the Royal Norwegian Navy and the German Navy have

both adopted the CODAG system for propulsion systems for some of their naval vessels (MarineLink2). GE's main market is LNGCs. GE claims that "the space-saving gas turbines also offer ease of use, flexible operation, and lower maintenance costs that will ultimately translate into increased revenues for LNG carrier owners and operators", as stated in an October 2005 article in MarineTalk. Lloyd's Register provided the approval of the *LM2500* for LNG ships (MarineTalk). The marine applications of the *LM* gas turbines have been limited to diesel-fueled systems. However, these gas turbines have been adapted to bunker LNG for land-based applications (Eser).

5.2.3 Wärtsilä

Wärtsilä's DFDE engines include the *50DF*, *34DF*, and *32DF*. Wärtsilä is the only manufacturer with a known tri-fuel technology. The *50DF* engine can burn LFO, HFO, and NG. The engine allows for continuous operation, as there is no interruption to the engine service during a fuel switch. The technology utilizes the "lean-burn" combustion principle that leads to a high compression ratio. The high compression ratio results in improved efficiency, reduced peak temperatures of the engine, and even greater reduced NO_x emissions. This engine calls for a highly advanced automated control system (Wärtsilä1). Wärtsilä claims that its engine reduces emissions by the following: 85% less NO_x, 30% less CO₂, very low particulate emissions, and 100% less SO_x. Other benefits of the DFDE system while burning natural gas include no visible smoke from the vessel's smokestack and no sludge deposits (Levander).



Wärtsilä 6L50DF

**Figure 5-3: Dual fuel diesel electric engine.
The Wärtsilä 50DF dual fuel diesel electric engine (Levander).**

The 34DF and 32DF are dual-fuel technologies (Wärtsilä2). The 32DF is the engine that Wärtsilä markets for its passenger cruise-ferry concept. The primary fuel for the 32DF system is natural gas (LNG) and the backup (and pilot) fuel is MDO.

5.2.4 MAN Diesel

The 51/60 DF is the dual fuel technology produced by the manufacturer MAN Diesel. The engine received “type approval” from classification societies in November 2007 (MAN Diesel), which puts MAN Diesel behind Wärtsilä’s progress to date in adopting the LNG-fueled DFDE technology. “Gaseous fuels will play an increasingly vital role in the global energy economy,” said Dr. Stefan Spindler, member of the MAN Diesel Executive Board. “With the 51/60 DF we have the high efficiency, low emissions gas engines needed by the marine market (Wilson-Roberts2).”

5.3 Existing and Potential Fleet

Norway dominates the LNG-fueled vessel fleet. As of March 2008, its ship inventory was as follows:

Existing Fleet: Six ferries and three offshore platform supply vessels

Fleet On-Order: Six ferries, one offshore platform supply vessel, and three coastguard vessels

Possible Orders: Two ferries

The company that manufactures the LNG containment tanks for the LNG-fueled vessels has had an inquiry from a US-based tug owner (Lennerås). There is also an LNG-fueled ferry operating in Brazil (Roueche1), and numerous LNG-fueled LNGCs operating around the world.

5.3.1 Ferry

According to an executive from Canada's BC Ferries, global ferry market growth is 55 ships annually at a cost of more than \$5 billion. The ferry industry is "superheating" and the current four-year minimum window from order to delivery of ferry newbuilds is evidence cited by BC Ferries, and agreed upon by Aker Yards who sees an even longer delay. There is such a backlog in orders, that there is estimated to be a three-year wait for the main engines alone (Roueche2).

5.3.1.1 Gas Engine

Ferry operator *Fjord1* (owned by county authorities in Norway) put the world's first LNG-fueled ferry, *Glutra*, into operation in the year 2000 (Roueche3). The Rolls-Royce *Bergen K* gas engine designed to burn natural gas is used on some *Fjord1* ferries. Norway both produces and exports natural gas and currently has

low domestic consumption of the gas (MarineLink1). Rolls-Royce entered the LNG ferry market in Norway with two goals for its vessels: to operate in an environmentally sound manner, and to help “create a base load demand for LNG around which a broader local gas distribution network can be” created (Howie, 25). *Fjord1* shares the same sentiments (Kleppe). In the words of Chief Operator Hallgeir Kleppe at *Fjord1*, commenting on the success of their LNG-fueled ferries in service at the annual Interferry Association conference in Stockholm, Sweden,:

“In their first five months, the ferries have operated 51,000 port calls averaging seven or eight minutes a time,” he reported. “Full redundancy makes them much safer than conventional ferries, NOx emissions are down 90% and maintenance can be carried out at sea with only a few days a year off hire. Build costs were about 10% more expensive and operating costs are a little higher, but there are no taxes on LNG as compared with diesel” (Roueche2).

Rolls-Royce views the impetus for a developed LNG refueling network to be the development of the demand – a growing LNG-fueled vessel network. The ferries are refueled via tanker trucks (MarineLink1), “except in the case of Halhjem, near Bergen, where Chart-Ferox [has] a dedicated bunkering facility” (Roueche3).



Figure 5-4: LNG semi-permanent refueling station for LNG-fueled ferry (Norway). LNG refueling station for the *Fjord1* ferry. The ferry operates on a fixed route to Halhjem, Norway. The refueling facility is a semi-permanent LNG tank structure (Skjervheim, 16).

The ferries can carry up to 240 cars at 23 knots (Roueche2), and have a passenger capacity of 590 persons (Einang). The Rolls-Royce *Fjord1* vessels are classed by DNV (MarineLink1) and built by Aker Yards (Roueche2). Emissions reduction estimations are CO₂ by 25%, NO_x by 90%, SO₂ by 100%, and particulate matter by 100% (Kleppe).



**Figure 5-5: LNG-fueled ferry vessel (Norway).
A *Fjord1* LNG-fueled ferry with a symmetrical design for ease of loading and unloading of passengers along its Norway routes (Fjord1).**

Operating in Norway, this ferry vessel has the range to sail for one week with no refueling necessary. The ferry has two possible unloading platforms (one at the bow, the other at the stern), and the gas engines are safely stowed at the middle of the vessel. LNG is the *Bergensfjord's* primary fuel and MDO serves as the secondary (backup) fuel (Hannula, 4).

5.3.1.2 DFDE

In March 2008, the Brazilian shipbuilder and ferry operator, TWB, launched a DFDE vessel in Salvador, Brazil. Designed by Australian *Sea Transport Solutions*, the vessel is a 53' RoPax catamaran named *Ivete Sangalo*. The

vessel travels at 18 knots and has a capacity of over 600 passengers and close to 75 automobiles. The vessel is powered by four, dual-fuel converted Caterpillar diesel engines. TWB Group has plans to for a sister DFDE vessel (Roueche1).



Figure 5-6: LNG-fueled RoPax vessel (Brazil).
The design concept for the new dual fuel diesel electric (DFDE) catamaran RoPax vessel for TWB Group in Brazil. The vessel was launched in March 2008 (TWB).

5.3.2 Cruise

Beyond the ferry market for LNG-fueled vessels, the other important potential market for this “clean” technology is the cruise industry. Like ferries, cruise ships are mainly sailing in coastal areas, and often happen to be in regions that are environmentally sensitive.

There are various cruise vessels that utilize alternative engine systems like CODLAG, CODAG, or COGES technology including Royal Caribbean International, Celebrity Cruises, Holland America, Cunard Cruise Lines, and Princes Cruises (Bailey, 5). However, there are currently no known examples of natural gas burning cruise vessels in operation (Bakker).

5.3.2.1 COGES

The first cruise ship to use gas turbines was Celebrity Cruise's *Millennium*. The vessel has a COGES configuration and debuted in the summer of 2000. The vessel passenger capacity is 1,950 and the COGES system meets both the power and propulsion requirements for the ship. The vessel is powered by two GE LM2500+ gas turbine-generator sets.

Since the *Millennium's* debut, COGES vessels have been added to Royal Caribbean International's (*Radiance of the Seas*, *Brilliance of the Seas*, *Serenade of the Seas*) and additional vessels to Celebrity Cruises (*Infinity*, *Summit*, and *Constellation*). The total operating hours for Royal Caribbean's and Celebrity's vessels combined was 187,000 hours as of December 2003 (GE1). All of these vessels burn diesel fuel in the gas turbines (Bakker).

5.3.2.2 CODAG

The first instance in which a CODAG system was utilized was in January 2004, when the *Queen Mary II* sailed its maiden voyage. GE developed the system where there were both diesel generator sets and the LM2500+ gas turbine-generator sets on the same vessel. The vessel's maximum speed is 30 knots and the drive configuration is electric. Power derived from the system is used for propulsion and onboard power. Holland America also has the CODAG system installed on four vessels: *Noordam*, *Westerdam*, *Oosterdam*, and *Zuiderdam*. Princess Cruises has the technology on the *Coral Princess*, *Island Princess*, and *Diamond Princess* (GE2). All of these vessels burn diesel fuel in the gas turbines (Bakker).

5.3.3 LNG Carriers

LNG carriers (or LNGCs) have traditionally been propelled by steam boilers that function from a combination of diesel and “boil off gas” (BOG). Steam engines are heavy and require more space than a gas turbine alternative. The increasing popularity of LNG-fueled engine technology has now created a market for gas turbines, gas engines and dual-fuel engines for the LNGC market (Ingjerd).

5.3.3.1 COGES

Gas turbine technology or the Combined Gas Turbine and Steam Electric System (COGES) can save about 12% additional space for cargo compared to a steam boiler propulsion system. The system operates with a mechanical drive; though, the LNG community tends to prefer an electric propulsion system that is available in the dual fuel diesel technology (Ingjerd).

5.3.3.2 DFDE

DFDE is popular among LNGC ship-owners and shipyards, empirical evidence that LNG-fueled, and in particular dual-fuel system technology, is economically beneficial. Thirteen different ship-owners and six different shipyards have invested in ordering thirty-one new DFDE LNGCs. In 2006, 20% of the LNGCs ordered were DFDE powered vessels. However, low speed diesel and traditional steam turbine systems continue to dominate the LNG carrier orderbooks. Compared to a steam turbine propulsion system, the DFDE system has lower operating costs, requires less space, and has more efficient redundancy (Drewry, 64).

At the end of 2006, the first LNGC with the DFDE technology to be delivered was Gaz de France's *Gaz de France Energy* (Drewry, 64). Gaz de France utilizes four Wärtsilä 50DF engines in the vessel *Provalys* for a combined 40MW of power (Mattas).

BP also has a DFDE LNGC that utilizes HHI technology named the *British Emerald*. The vessel was the largest LNG carrier when released in July 2007 and was classed by Lloyd's Register.



Figure 5-7: LNG-fueled LNGC dual fuel diesel electric vessel (BP Shipping). From the “Gem” series of BP Shipping’s LNGCs, the British Emerald is a dual fuel diesel electric vessel selected for its relative clean environmental performance to diesel LNGCs (Society of Petroleum Engineers).

Mr. Adrian Howard, Vice Chairman of Technical Management with BP explains the selection of the DFDE technology: “The biggest reason we chose the DFDE propulsion system was for the environment. But it was a big adventure when we ordered it (HHI). Namely, BP hopes to set “new standards for safety and environment performance (Robinson).” At a vessel speed of 20 knots, the vessel burns 140 tons of fuel per day – 40 tons of fuel less than a vessel powered by a steam turbine (HHI).

“Typically, a steam-powered LNG carrier burns around 90 tonnes per day (tpd) of heavy fuel oil and 90tpd of LNG - 180tpd in all, which equates to around 530 tonnes of carbon dioxide (CO₂) and seven tonnes of sulphur oxides (SO_x) emitted to atmosphere. British Emerald's DFDE system, by comparison, is burning fuel at a rate of 140tpd, equivalent to 386 tonnes of CO₂ and extremely low levels of SO_x” (BP5).

BP believes that *British Emerald* will produce fewer CO₂ emissions than comparable-size LNGCs by up to 36,000 tons per year (BP1, 19) and 1,700 tons less SO_x per year (BP5). BP has plans to bring its DFDE LNGC total to four by the end of 2008 (BP2, 19).

As of the Fall 2006 issue of *LNG World Shipping*, 35 of the 142 LNGCs on order were DFDE systems – that accounts for 25% of the vessels on order (RasGas).

5.3.4 Offshore Supply Vessels

Another implementation of the LNG-fueled technology is for offshore oil platform supply vessels (PSVs). The *Viking Energy* is an example of this application and utilizes Wärtsilä's 32DF engine technology and was the world's first LNG-fueled PSV (Solutions).



Figure 5-8: LNG-fueled vessel LNG containment structure. The cryogenic containment vessel for LNG designed by CYRO and used on the Viking Energy, among other LNG-fueled vessels (Levander, 22).

The company that charters the vessel in Norway, Statoil, receives emissions credits that it uses to offset its other operations along the Norwegian coast where there are more strict regulations on NO_x emissions. The vessel is expected to use 7,000 tons of natural gas annually, which benefits the economics for developing a network of LNG bunkering facilities along the coast of Norway for the country's growth in LNG-fueled vessels (Bibik).

A Norwegian PSV had a recorded incident where the vessel accidentally collided with a quay; the LNG system, including the containment vessel, was undamaged (Lennerås).

5.4 Vessel Classification

Det Norske Veritas (DNV) and Lloyd's Register (LR) currently have classified the LNG-fueled vessels. A notable customer for LR includes Hyundai Heavy Industries (HHI), who had orders in the year 2005 for DFDE systems on two Teekay Shipping vessels and four BP Shipping vessels (Robinson).

5.5 Bunkering

There are various bunkering possibilities for an LNG-fueled vessel. The most feasible solution is vessel dependent as the tank capacities vary greatly, depending on vessel type. For instance, a ferry that travels a short distance from port to port can refuel often and does not likely have large tank capacities. However, cruise vessel itineraries are often for seven days, and traveling across countries where LNG refueling infrastructure may not exist. The vessels are also not at port each evening, but sometimes at sea for more than 24 hours. In this case, the vessel requires LNG tanks with larger capacities.

5.5.1 LNG Terminal

The first bunkering method would be refueling from an LNG terminal, where LNG cargoes are received from LNGCs. This option does not require additional infrastructure, as the permanent structure is already in place.

5.5.2 Tank

Another option is an onshore tank or an offshore, floating tank. The onshore tanks can either be above or below ground. An average onshore fueling station in the United States (that both stores and dispenses fuel) costs \$1 million (California Energy Commission). The company Clean Energy, the largest provider of natural gas (both CNG and LNG) for transportation fuels in the North America, has refueling stations located across the United States. For the purposes of an onshore, seaside refueling station, this established company in

the LNG refueling business is a possible partner for the design, operation, and maintenance of LNG fuel stations in the United States (Clean Energy).



**Figure 5-9: LNG onshore vertical storage tank (United States).
An onshore LNG vertical storage tank in the United States (California Energy Commission).**

In order to construct an onshore LNG facility in the United States, the Federal Energy Regulatory Commission (FERC) must approve the site and construction process, in addition to the proposed operations for the site. If FERC approves the application for the facility, then an Environmental Impact Statement (EIS) must be completed. The EIS is reviewed by FERC and the US Coast Guard and considers the following impacts: air quality, ecology, cultural, socioeconomic, safety, and security (U.S. Coast Guard).

5.5.3 Tanker Truck

Another bunkering method is an LNG tanker truck. The Rolls-Royce gas engine, LNG-fueled vessels with the ferry operator *Fjord1* utilize this bunkering method for most of its vessels (MarineLink1). The truck can position itself alongside the

vessel when it is at port. These trucks hold 10,000-12,000 gallons (38-45 m³) of LNG and are able to deliver the commodity to remote locations (FERC). There is no need for investment in permanent LNG storage or bunkering infrastructure.



Figure 5-10: LNG-fueled ferry vessel bunkering via tanker truck (Norway). The DFDE *Fjord1* ferry vessel, *Glutra*, is bunkered by a tanker truck at berth each evening (Einang1).

The tanker truck solution is convenient, as it does not require LNG to be stored on port premises. However, the volume per truck is limited, and the vessels rely on timely tanker truck deliveries. Depending on the refuel volume, more than one tanker truck may be needed. In the case of the *Fjord1* LNG-fueled ferries, approximately 6 tanker trucks would be needed to completely fill its two LNG tanks with 125 m³ capacity each to 95% capacity (Løseth). In comparison, if the LNG tanker trucks were used to bunker a cruise vessel with an

LNG total tank capacity of 1,900 m³ to 95% capacity, then approximately 46 tanker trucks would be required for the fueling (Levander).

5.5.4 Mobile Tanks

A niche market supported by Scandinavian Gas Logistics AS, a company with supply chain optimization for land-based LNG distribution, is LNG bunkering from mobile containment vessels. The main benefit of the mobile LNG units is that they can be brought by truck, rail, or ship, to a designated refueling area within a port. This LNG mobile containment industry is also developing in Germany and Japan.



Figure 5-11: LNG mobile storage containers for intermodal transport of the fuel. LNG mobile storage containers of standard ISO size. The picture on the left is transportation of the filled container via truck, the picture on the right is the same ISO container being loaded onto a rail car (Rostock, 67). The picture below is an extension to the possibility of these same intermodal containers loaded onto a small container vessel to transport port-to-port (SGL1, 5).



Unlike the gas housed in a dedicated LNG tanker truck, the mobile unit can be dropped off and picked up, at a transporter's convenience. The mobile units eliminate the need for any permanent LNG refueling infrastructure at the port (SG1). The US Environmental Protection agency is likely not aware of such a solution, as they state on their "Clean Ports" section of their website that marine applications (for transportation or otherwise) involving natural gas "may require fueling infrastructure (EPA)." The housings for the containment vessels can take on many shapes, depending on the requirements of the user. One specific housing is a forty-foot container - an ISO standard international, intermodal container size (SGL1). Each of the forty-foot containers house approximately 31.5 m³ of LNG (Paananen), less volume than a typical LNG tanker truck with a volume of 38-45 m³ (FERC).

Wärtsilä produced a hypothetical study on a container vessel with an LNG-fueled auxiliary engine operating on a Asia-California route and concluded the following in regards to fuel consumption: for every 108 tons of LNG burned by its dual-fuel engines, 240 m³ of LNG are consumed. If the RoPax ferry is refueled using the forty-foot mobile units with 31.5 m³ LNG, then 8 of these mobile units would be required (Paananen).

Another benefit of the flexibility surrounding a mobile unit is that small-volume users can also be served by the business (SGL1). The mobile units are either sold or leased to gas distributors who choose the customers. The Norwegian Coast Guard has two new patrol vessels that use LNG as a fuel, and

ordered a service from mobile units from a provider of LNG in the Barents region, Barents NaturGass AS, to refuel these ships (SGL2).



Figure 5-12: LNG-fueled coast guard vessel (Norway). LNG-fueled design of Norwegian Coast Guard vessel. The vessels will be supplied gas from Barents NaturGass AS (Skjervheim, 21). The vessels are powered by Rolls-Royce Bergen K gas engines and capable of 40 knots (Ingjerd).

Fjord1 ferries can refuel at a temporary land-based LNG tank area in Halhjem. These tanks are not permanent infrastructure, so they can be regarded as mobile tanks. The *Fjord1* bunkering station consists of two tanks each with a capacity of 500 m³ of LNG, enough to fully refuel the 250 m³ LNG capacity per vessel twice. The large ferries require refueling every third night. Hence, the tanks need to be replenished approximately weekly if one vessel bunkers at the tank area. The bunkering of the LNG takes place at night, and is transferred by a pump from the tanks to the vessel. The total fueling time is about 2 hours for the large ferries (Einang).

5.5.5 Barge

Another possible bunkering method is via a vessel-to-vessel transfer of LNG from a tanker vessel or barge. *Excelerate*, a company progressing the industry of deepwater LNG ports as well as regasification vessels, exhibited proof of concept of the transfer of LNG from one vessel to another. While this process was designed to transfer LNG cargo from a supply vessel to a regasification vessel, the same technology can be applied to the process of refueling an LNG powered vessel. The concept of offshore bunkering of LNG is likely to face the least opposition, as the “not in my backyard” (NIMBy) syndrome often expressed by inhabitants of coastal regions that oppose the installation of LNG onshore structures, is avoided. Offshore bunkering also provides the opportunity for a movable refueling station, such that the station can be fully utilized within a coastal region.

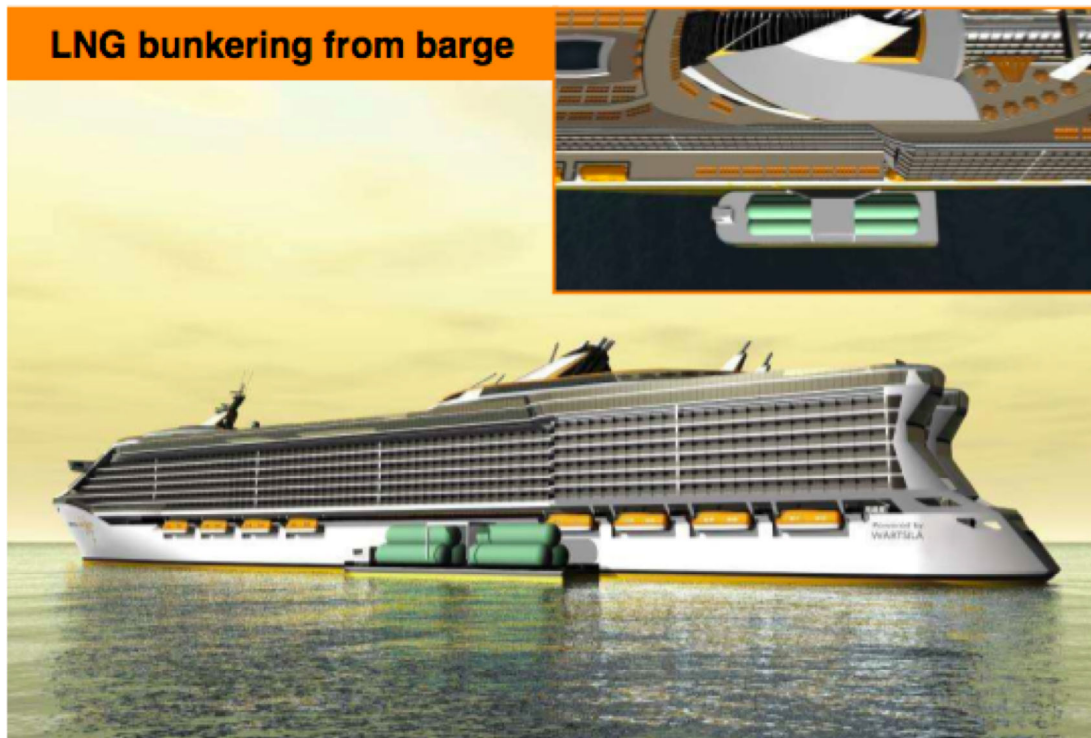


Figure 5-13: LNG bunkering concept from a barge. LNG-fueled vessels can bunker away from port, or while at port, via tanks on an LNG barge (Paananen, 42).

The LNG refueling vessel can also be built to a suitable capacity for its purpose in a given region. For instance, if the refueling vessel is to be mainly used to transfer LNG to cruise vessels, the refueling vessel tanks will reflect the fuel capacity required by cruise vessels. The LNG-fueled cruise vessel concept by Wärtsilä and Aker Yards requires 1,900 m³ of LNG total to fill its six tanks, at 95% fill rate. However, if the refueling vessel in a port region is to be used to refuel LNG powered ferries, the refueling vessel can be significantly smaller. A *Fjord1* LNG-fueled ferry vessel requires 250 m³ of LNG to fill its two tanks (Einang).

5.6 Vessel Safety

In its liquid form, LNG is neither explosive, nor corrosive, nor toxic. LNG in its gaseous form has three properties that contribute to the unlikely event of a fire, or explosion, of the gas. First, when LNG is first released into the air, it effectively “boils” upward, as it is less dense than air when above a temperature of -162° C. Furthermore, natural gas can only ignite once the temperature reaches 600° C and if the air concentration is between 5 and 15 percent.

The Wärtsilä Corporation incorporated an added safety measure in its LNG-fueled vessels called an “Emergency Shut Down”. In the case of a leak in one of the LNG tanks onboard, the supply of LNG to the engines ceases and the backup MDO is used (Hannula, 4-5).

In order to obtain certification for the original LNG-fueled vessel, the Norwegian shipowner proposed the idea to the Norwegian Maritime Directorate (NMD). The NMD issued a regulation for an LNG-fueled vessel after DNV conducted an extensive risk analysis on the dual-fueled vessel. DNV concluded that the risk level for an LNG-fueled vessel is no greater than that of a diesel vessel (Lennerås).

BP notes the tremendous safety record of LNGCs since the first voyage was made in 1964. “There has never been a major shipping incident in port or on the seas that resulted in a loss of containment. This record demonstrates a deep and lasting attention to safety detail (BP3).”

5.7 Cost of LNG-Fueled Systems

5.7.1 Cost

The cost for an LNG-fueled ship is the total of the fixed and variable costs. The fixed costs include the repayment of the capital borrowed to purchase the vessel (about 12% higher than the capital investment for a diesel vessel – in the case of DFDE), and the interest due on the loan (Lennerås). The variable costs include both operating costs and voyage costs. The price of the fuel to power the vessel is taken into account in the voyage costs (Drewry, 108).

5.7.1.1 Fixed Costs

The capital investment required for LNG-fueled vessels is higher than that for a typical diesel fueled vessel. Specifically, a DFDE vessel is an additional 2-4% more than a steam turbine. However, the DFDE system has 10% better fuel efficiency than a steam turbine. When considering the fuel savings for the DFDE system compared to a traditional steam turbine, Hyundai Heavy Industries estimates a five year payback period for the additional cost of the DFDE system (Society of Petroleum Engineers).

The space required in LNG-fueled vessels varies. For gas turbines replacing steam turbines in an LNGC, there is 12% additional cargo space generated (GE). And given that the LNGC is carrying LNG, this additional cargo space is also the fuel storage space. However, in the case of a DFDE ship, fuel storage is 2.3 times that what is needed in a MDO vessel (for the same energy content). The DFDE vessels store LNG in insulated cryogenic tanks. When the

additional space required surrounding the large LNG tanks in the DFDE vessels is taken into account, the space is 4 times that needed for the MDO fueled vessel. The LNG tanks are made of steel, and hence, also add to the weight of the storage unit. Compared to storage for MDO, LNG storage tanks are 1.5 times heavier.

It is difficult to retrofit vessels if the installed LNG system will occupy additional space than the current engine technology, which it does in any vessel case (excluding LNGCs). Given the difficulty of retrofit, the decision to include a DFDE system on a vessel needs to be made with the preliminary design considerations for the vessel (Hannula, 4).

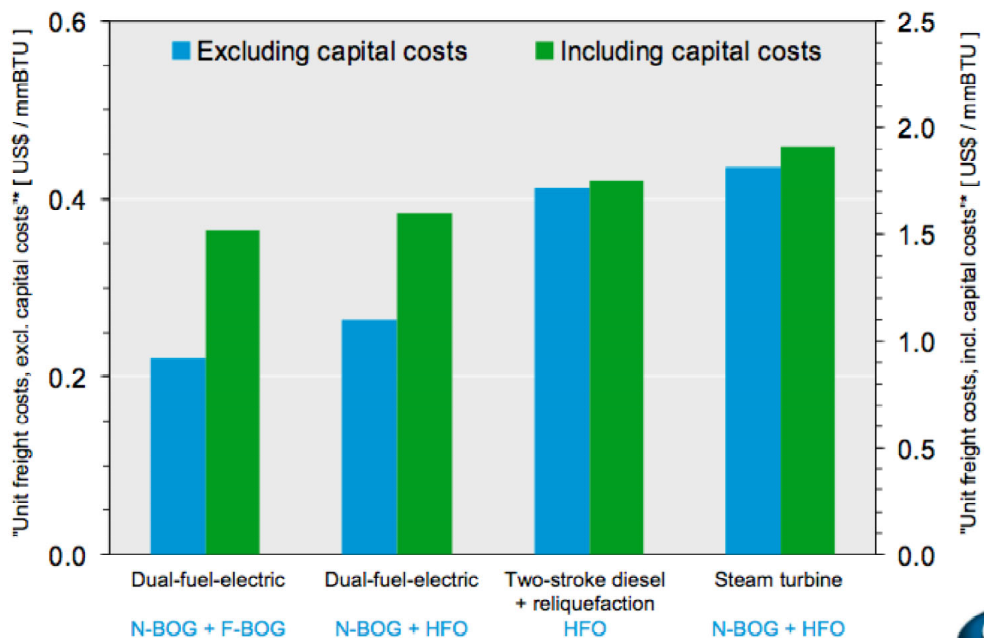
5.7.1.2 Variable Costs

The cost for manning a vessel with LNG aboard is higher than the crew costs for most vessels. The crew cost is a component of the voyage cost. The crew for such a vessel must be highly trained and competent, and as such these crews tend to be more expensive labor. There is also a shortage of such skilled crew, so the demand keeps the manning operating costs high (Drewry, 111).

The cost of fuel is also added into the voyage cost for a vessel. LNG is typically less expensive than the “clean” marine fuels for the same energy content. However, depending on the market, this may not be the case. If LNG is more expensive than the marine fuels available in a given market, then the DFDE LNG-fueled solution has its benefits, given that the engine can operate on both diesel and LNG.

The following three figures are cost breakdowns that compare DFDE systems to alternative power systems. The first figure compares DFDE to a steam turbine and diesel engine for LNGCs (Thijssen). The second two figures specify the capital expenditures and operating expenditures of the DFDE system onboard a 300 passenger cruise ferry concept created by Wärtsilä (Hatley):

“Unit freight costs”*

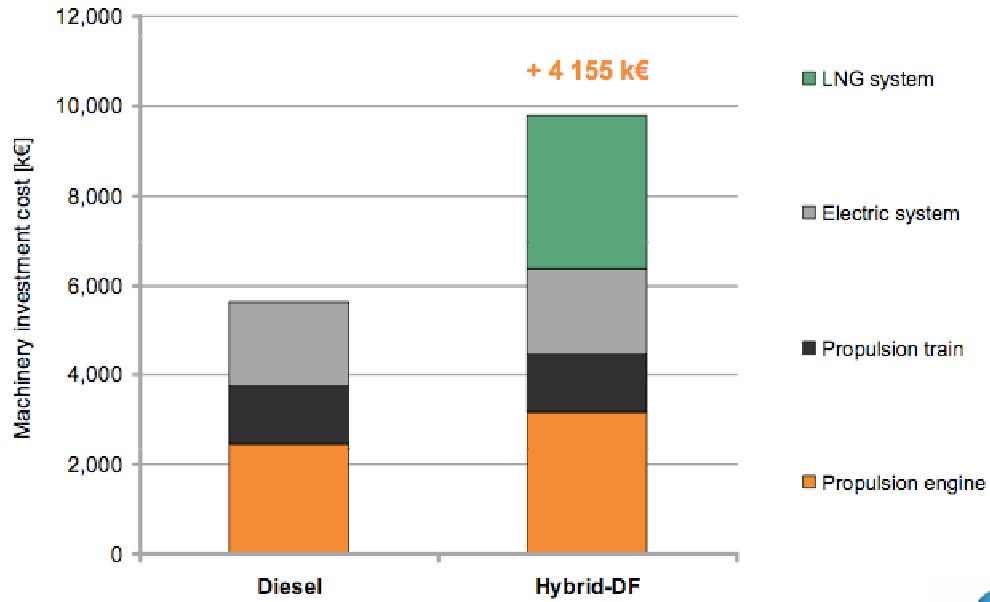


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Figure 5-14: Fuel cost comparison for "unit freight" for DFDE, steam turbine, and diesel engine. The “unit freight costs” for the DFDE system is less expensive than both the steam turbine and diesel systems investigated for LNGCs (Thijssen, 40).

Machinery CAPEX

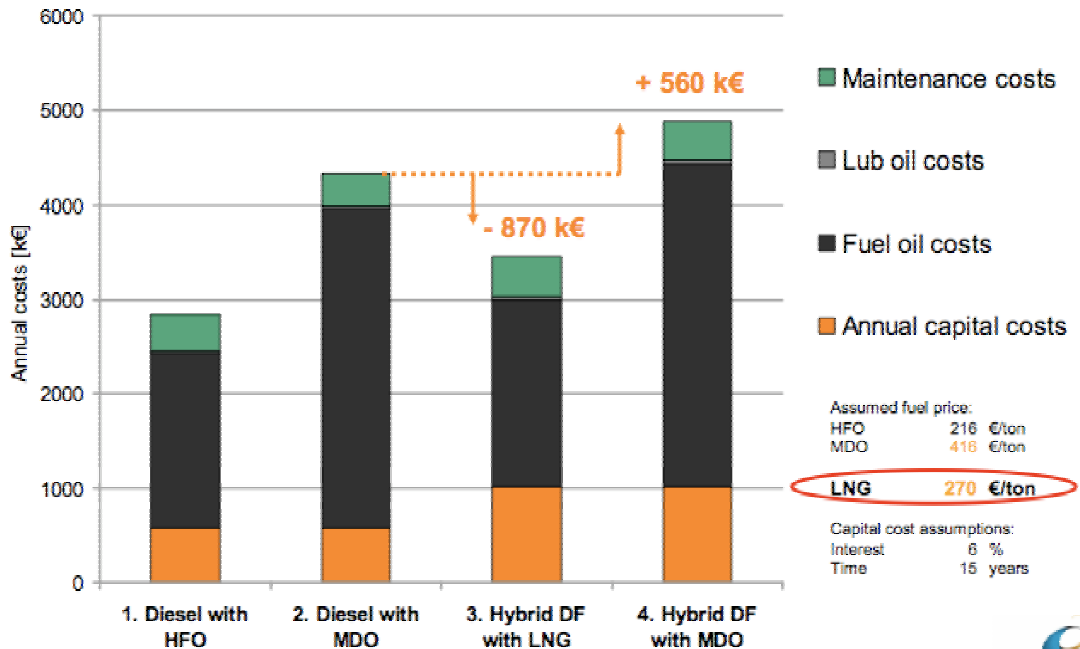


28 © Wärtsilä



Figure 5-15: DFDE and diesel engine machinery capital expenditure comparison. The DFDE machinery is approximately 1.7 times more expensive than the diesel engine system investigated for the Wärtsilä 300 passenger cruise ferry concept (Hatley, 28).

Machinery OPEX



29 © Wärtsilä



Figure 5-16: DFDE and diesel engine machinery operating expenditures comparison. The machinery operating expenditures (for the Wärtsilä 300 passenger cruise ferry concept) for the DFDE are greater than the diesel engines' when the DFDE is operating on MDO. However, when the DFDE is operating on LNG, the DFDE has lower machinery operating costs than the diesel engine operating on MDO. The least expensive operating cost is the diesel engine running on HFO (Hatley, 29).

6 Feasibility of LNG-Fueled Vessels in the US

6.1 Introduction

Three market forces customarily drive the impetus for change to an industry standard fuel-type: policy change, technological innovation, and price of fuel. While the two former forces are often slow changes, the later can be extremely volatile.

LNG-fueled system manufacturers have entered the ferry, offshore supply vessel, and government military vessel markets successfully in Europe, but have yet to enter the cruise and commerce segments. In the US marine market, LNG-fueled vessel technology has yet to make a significant entrance. On the other hand, the LNG vehicle market in the US totaled 3,000 vehicles in the year 2006 (ENGVA). Possible marine industries in which the LNG-fueled technology could prove beneficial in the United States are discussed in this section. The cost-benefit analysis of entering these industries will be considered. Finally, the trend toward market resistance in the US will also be discussed in this section.

6.2 Possible Industries

There are four possible marine industries (beside LNGCs) in the United States where the LNG-fueled vessel technology applies. These industries include ferry (both passenger & RoPax), cruise, harbor craft (including US Coast Guard patrol vessels), and Short Sea Shipping. The ferry and cruise market are geared

toward passenger services, while the harbor craft is for either government or commerce applications, and Short Sea Shipping for commerce applications.

6.2.1 Existing Application in Shore-side Power

It should be noted that beyond the LNG exporting facility (in Alaska) and receiving facilities in the US, LNG has also developed a presence at US ports to serve the purpose of cold-ironing, or providing shore-side power to vessels while vessels are in port. During the summer of 2007, the Port of Oakland (the nation's fourth busiest container port) successfully provided power to an APL, 863' container vessel by way of an LNG-fueled mobile electric generator. This was the first-ever successful demonstration of LNG cold-ironing (PG&E News). The project was approved by the US Coast Guard and the Port of Oakland Fire Department (CleanAirLogix).



Figure 6-1: LNG cold-ironing in the United States (Port of Oakland). LNG exists at ports in the United States that do not have an LNG receiving terminal. This picture shows shore-side clean power being provided to the APL *China* via LNG cold-ironing from a mobile containment unit at the Port of Oakland in the summer of 2007.

Connection from shore to ship occurs in about an hour. The ship was powered for about 8 hours (CleanAirLogix, 10).

The logistics were handled by the utility Pacific Gas & Electric (PG&E). The utility provided the fuel and the LNG generators were provided by Wittmar. Forging the connection between the vessel and the LNG station takes about an hour (CleanAirLogix). According to a PG&E executive, “at-berth ship emissions make up approximately 28% of all port emissions (PG&E News).” In order to create permanent cold-ironing infrastructure at the Port of Oakland, \$90 million would need to be invested, and the Port’s power grid would not even be able to handle the full load. The development of the new LNG cold-ironing alternative has only been a \$275,000 investment for the Port (Sandifur).

In comparing the emissions from APL’s vessel, the *APL China*, in a non cold-ironing vs. cold-ironing case, the emissions reductions provided by cold-ironing were at least 40% across all source categories. NO_x emissions were reduced by 95%, SO_x by 100%, CO₂ by 42% and PM₁₀ by almost 100%.

Emissions Comparison, LNG Cold Ironing of <i>APL China</i>			
Pollutant	On-board diesel power (0.5% sulfur marine diesel)	LNG cold-ironing	% reduction
NO _x	1,059 lbs	56 lbs	94.71%
CO	79 lbs	34 lbs	56.96%
PM ₁₀	15 lbs	.02 lbs	99.93%
SO _x	72 lbs	0	100%
CO ₂	42,651 lbs	24,430 lbs	42.72%

Figure 6-2: LNG cold-ironing emissions benefits (Port of Oakland). The LNG cold-ironing demonstration at the Port of Oakland in the United States had emissions reductions compared to the vessel burning on-board diesel for power in port of over 90% for NO_x, 100% for SO_x, and over 40% for CO₂ (GreenCarCongress/PG&E News).

Given the success of the Port's demonstration, Oakland hopes to cold-iron every incoming ship at its port by the year 2010. The Port of Oakland is subject to emissions reduction targets created by the California Air Resources Board, but this 2010 goal would be a decade before the Board would expect to witness such an achievement.

The Port of Richmond will conduct an LNG cold-ironing vessel demonstration similar to the Port of Oakland's in the second quarter of 2008. The Port of Los Angeles and the Port of Long Beach are highly potential customers for LNG cold-ironing, given that California is forcing reduced emissions for vessels at-berth by 2010; other potential users of the LNG cold-ironing technology are the Ports of Seattle, Houston, and Vancouver (CleanAirLogix).

6.2.2 Ferry

Despite the slow acceptance of an LNG-fueled vessel market in the United States, the world's first CNG-fueled passenger ferry is a commuter ferry vessel that operates in the Tidewater river region in the State of Virginia. The ferry began operation in the 1990s (HRT). In 1999, the ferry transported 500,000 people, and the vessel is still in operation today under Hampton Roads Transit. The vessel was developed via public funds from the Federal, State, and local governments. The vessel has a shore-side CNG fueling facility and runs on Caterpillar engines. The vessel CNG capacity is enough to operate on the normal vessel schedule for three days without refueling (MarineLink3). There are other examples of existing CNG-fueled ferry vessels around the world.

MARAD planned an economic feasibility study on a dual fuel ferry, in cooperation with Red & White Fleet, a San Francisco Bay ferry operator. The idea was to evaluate the conversion of a slow speed diesel ferry the *MV Harbor Queen* to a dual fuel engine. The study was encouraged by the existence of Canadian ferries *Klatawa* and *Kulleet* that were converted to dual fuel in the 1980s (Gore).

Ferries to Catalina Island in Southern California operated by Catalina Express are propelled with low-emission diesel engines. However, only NO_x and particulate matter emissions are reduced. This company accounts for significant service with 30 roundtrips from four points in the Los Angeles area to Catalina Island each day. The President of the company, Greg Bombard, is an important stakeholder for clean ferry industry developments, as he represents ferry owners from around the globe as President of the Interferry Association (Catalina Express).

6.2.3 Cruise

There are cruise vessels with gas turbine engines that have ports of call in the United States (such as Holland America's *Noordam* that calls Port Everglades), but all of these vessels are only configured to burn marine diesel (Bakker).

Cruise vessel operators take advantage of the fact that gas turbines can release various compositions of diesel emissions and cooling air mixtures to lessen emissions per volume of air when compared to a diesel engine. The ability to control emissions per volume of air allows cruise lines operating gas turbines to release apparently cleaner emissions when in and near ports with strict

environmental regulations. The EPA has not yet regulated the air mixtures in diesel emissions that cruise lines can release from operating gas turbines (Eser).

Cruise lines are witnessing the impact of diesel fuel prices on their profits. Carnival Corporation, the world's largest cruise operator, reported a 17% drop in its first quarter profits in 2008 and cited rising fuel costs. The fuel costs are predicted to be \$600 million above the costs in 2007 (Archer), and will lead to a lower expected profit yield for 2008 (Ruggiero). Carnival has modified its voyage itineraries in the Southern Caribbean to decrease distance traveled by swapping the "far-flung" ports with ports in close proximity (Dunham-Potter). Royal Caribbean International has taken steps to lower fuel costs including coating vessels with a special paint that reduces drag, and implementing various onboard power energy consumption reductions, such as the installation of new lighting that uses less energy than the current lighting (Ruggiero). Various cruise lines are slowing the transit speed and cold-ironing in ports that offer the service, in order to generate fuel savings (Dunham-Potter).

Carnival and Royal Caribbean (who together comprise 75% of the world's cruise vessel fleet) have instituted fuel surcharge programs (Dunham-Potter). However, Carnival expects these surcharges to only cover 25-40% of the additional \$600 million fuel costs for the year (Archer). Disney Cruise Lines announced a fuel surcharge on passengers that will go into effect at the end of May 2008. The fuel surcharge is \$8 per day for the first and second occupants of a room, and \$3 per day for the additional occupants (with a maximum of \$112 and \$42 respectively for a voyage), similar to Carnival's fuel surcharge. "A fuel

surcharge has become a necessary step due to market conditions,” said a Disney Cruise Line spokeswoman (Balancia).”

6.2.4 Harbor Craft

Crowley Maritime Corporation (headquarters in Jacksonville, FL) has designed a proposal for an LNG-fueled harbor tug vessel for the Port of Long Beach and the Port of Los Angeles. The “handy-sized” tug would not only have cleaner emissions compared to the current diesel-fueled tugs, but it would also have emissions well below the current EPA standards. Furthermore, the LNG-fueled tug would have more powerful engines than the San Pedro Ports’ current harbor tug vessels. The proposed harbor tug burns natural gas with Rolls-Royce gas engines. The natural gas is bunkered as LNG (readily available in the San Pedro Bay) in two tanks of capacity 21 m³ each at the bow of the vessel. In the San Pedro Bay area, LNG is less expensive per unit of energy than ultra low sulfur marine diesel, as is the case in many coastal markets.

Crowley Maritime’s LNG-fueled harbor tug emissions reductions tests yielded 89% less NO_x, 94% less SO₂, 90% less particulate matter, and 24% less CO₂ when compared to an ultra low sulfur marine diesel-powered harbor tug (Cavalier).

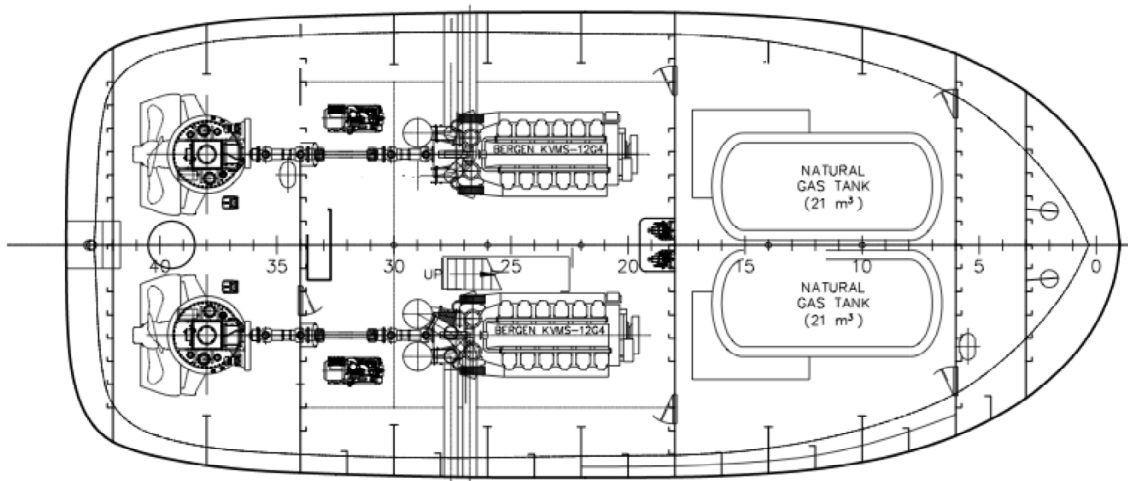


Figure 6-3: Proposed LNG-fueled Harbor Tug (United States).
The machinery configuration of a proposed LNG-fueled harbor tug to be used in the San Pedro Bay Ports area in the United States. Designed by Crowley Maritime.

Given the impetus for an LNG-fueled vessel to enter the San Pedro Bay Port area, it is likely that the introduction of other LNG-fueled vessel proposals in other US ports will be welcomed. The Norwegian Coast Guard’s new LNG-fueled patrol vessels also serve as an example for the application of LNG-fueled patrol vessels for the US Coast Guard and other government marine vessels.

6.2.5 Short Sea Shipping

Most of the commercial freight imported and exported through the seaports in the United States is transported domestically by rail or truck (Nagle). An alternative to distribution by land transportation is Short Sea Shipping. For imported cargo,

the concept is for commercial freight to be transported from major US ports closer to its final destination on small ships and barges via inland and coastal waterways (MARAD). The figure below is a small container ship proposed to operate in the US domestic trade in Hawaii. The company, Santa Maria, proposes to operate small, self-loading container vessels with a capacity of over 350 45' containers (Santa Maria).



Figure 6-4: Proposed Short Sea Shipping small container vessel (Hawaii). A proposed Jones Act small containership vessel for the Hawaii trade by Santa Maria Shipping. This vessel is the typical size for a Short Sea Shipping container vessel (Santa Maria).

While the concept is considered to be in its evolutionary stages in the US, proof of concept is in Europe where the industry is well developed (Sanford).

At a time when highway congestion is increasing, and trade is expected to at least double by the year 2020, the US Maritime Administration (MARAD) sees Short Sea Shipping as a viable option to alleviate the burden of commercial freight on the land transportation infrastructure. Deemed “The Wave of America’s Future” by the Administration, the benefits are clear: reduced

congestion on US highways, reduced emissions from the transportation of commercial freight, and an enhanced marine transportation system (MARAD). The benefits are especially clear when considering that the larger US ports (Los Angeles/ Long Beach; New York/New Jersey; Norfolk) are also located in urban regions that are already highly congested (Nagle).

According to the American Association of Port Authorities (AAPA), one of the major reasons that the domestic waterborne shipping industry has not developed in the US, despite the benefits acknowledged, is there is a harbor tax levied on cargoes moved domestically from US ports (Sanford). The Harbor Maintenance Tax (HMT) is an *ad valorem* tax that is collected for the US Army Corps of Engineers to support their port waterways dredging program. The AAPA made an appeal to the President's Advisory Panel on Federal Tax Reform for an HMT exemption on domestic cargo moves of mainly containerized and Ro/Ro cargo, and only for cargo that is not already a part of domestic waterborne commerce. Domestic cargo moves accounted for less than 5% of the HMT collected in the year 2002, so the monies raised by the HMT would not be impacted greatly (Nagle) with such an exemption.

The Short Sea Shipping Initiative is intended to “promote the use of the waterways as a method of easing traffic congestion and alleviating air pollution” (MARAD). While the Short Sea Shipping system would reduce highway miles (and congestion delays) for commercial freight, and hence truck emissions, moving the commercial freight from the highway infrastructure to coastal and inland waterways intensifies the emissions effects on the coastal regions. An

Initiative that incorporates LNG-fueled vessels for its Short Sea Shipping fleet is even more effective in reducing the impact of emissions, particularly in coastal regions.

In a testimony given to the US House Committee on Coast Guard and Maritime Transportation, the owner of a domestic containership company (Santa Maria Shipowning & Trading) made the case that a Federal Government investment in Short Sea Shipping would help develop “alternative power for ships that reduce emissions and fuel consumption”, citing natural gas as one of these alternatives for lower carbon emissions. The owner, Anastassis Margaronis, is one of the maritime industry promoters of Short Sea Shipping. According to the Margaronis’ testimony:

“Six 300 TEU vessels offer the potential to eliminate 1,800 trucks from the two ports at a total cost of about \$150 million. Currently, ocean carrier container demands require 14,000 trucks per day to serve the L.A./Long Beach ports. So \$150 million buys a 13% reduction in truck congestion. It is estimated that shippers will realize a 10% reduction on delivery charges compared to road transport (Margaronis).”

Horizon Lines, the largest US containership company operating in the domestic trade, is also in support of a Short Sea Shipping industry. “It is no longer a question of if our nation’s transport infrastructure will start to fail, but when,” said the Lines’ President and CEO. Opponents of the development of

Short Sea Shipping in the US cite that the substantial federal funding such a program would require is difficult to muster, given the growing federal deficit. Others cite that the development of “America’s Marine Highway” could be to the detriment of the trucking and rail industries (Salzano).

6.3 Availability of LNG

LNG is not widely available in the US. The large shore-side installations of LNG are located at the LNG receiving and exporting terminals in the US, and smaller installations are at refueling stations for land-based LNG-fueled vehicles.

6.4 Investors

Possible investors for LNG-fueled vessels and refueling stations in the United States include port organizations; the state, local and Federal Government; and large corporations.

6.4.1 Port Organizations

Port organizations have a vested interest in improving the air quality in their port region. The organizations serve to benefit the commercial interests of the region, but the long-term viability of the port is of utmost importance. A healthy population and clean region will continue to grow, as will the region’s ability to import, and possibly even export, goods. There are two types of port organizations: some are private entities and others are public. In the case of a private organization, private investors like venture capital firms could be considered. Carbon credits can be traded on the open market, and if the port

organization could build infrastructure (or arrange for semi-permanent refueling facilities, or mobile tank deliveries) for LNG-fueled vessels, and a carbon trading system was devised, such a trading program could encourage private investment.

6.4.2 Local, State, and Federal Governments

Cooperation from all levels of government is necessary in the success of an LNG-fueled vessel market in the United States. Local governments have a role in gaining community support for the endeavor, and in finding capable businesses to design and build the LNG infrastructure, if any is needed. Local funding is more likely for regional projects involving ferry systems and cruise vessels. While the local government can contribute to the funds for an LNG-fueled vessel project, it is likely that the majority of the funds will come from the state and Federal governments. For international and interstate commerce, state governments and the Federal Government are important stakeholders in allocating funds for the development of the infrastructure to spur this growth.

Involvement from the Federal Government is required in the case of LNG-fueled government vessels, and in the case of supporting the Short Sea Shipping Initiative. Vessels that operate in the US domestic trade (US port-to-US port) are classified under the Jones Act. The Jones Act requires these ships be US-built, have a crew comprised only of US citizens, and be owned and operated by US citizens. To accommodate the enhanced domestic trade that would result from the new industry, feederships would need to be built. The “establishment of a short sea fund through the U.S. Maritime Administration's Title XI loan guarantee”

for the public financing of a new, clean, national fleet of merchant vessels “should be a top legislative priority in 2007,” a US domestic shipowner, Anastassis Margaronis believes. “This will require a down payment of one billion dollars to the Title XI loan program. This will provide over \$20 billion in guarantees to finance new ships and shipyard upgrades (Margaronis).”

6.4.3 Corporations

Large corporations are looking to make their supply chain “green”. These corporations are becoming increasingly aware of their impact on global emissions. In the San Pedro ports area in California, Nike has voluntarily switched its fleet of trucks that bring its cargo to Los Angeles area facilities from diesel fueled to LNG-fueled. “Nike and our affiliate companies are committed to a 30 percent absolute CO₂ reduction for inbound logistics by 2020,” said the Director of Corporate Logistics Services at Nike, John Isbell. It is this “environmentally preferred alternative” that the multinational corporation has chose to move toward. Isbell recognizes that additional efforts beyond the “green fleet” of trucks will be needed to recognize his goal (Adkins).

Nike took a leadership position in its move toward a smaller carbon footprint for its Asia-Pacific to Southern California supply chain. The development of a “green fleet” of LNG-fueled vessels could be a future step for companies looking to reduce their contribution toward global CO₂ emissions.

6.5 Emissions Regulations

The impetus for environmental governing boards to revisit air emissions standards from marine engines is driven at many different levels by various stakeholders.

6.5.1 Examples on the US West Coast, and in Alaska and Canada

In the United States, California and the Pacific Northwest are regions whose environmentalists urge its policy makers to be ahead of national marine emission regulations. For example, some environmentalists in California coalesced to push the California Air Resource Board (ARB) to enact stricter emission standards for new marine engines, if the EPA were to not set Tier III Standards for new marine engines. The lobbyists also recommend a “non-diesel alternative standard for ferries” that would “require or incentivize conversion to natural gas and/or pure biodiesel.” Furthermore the charter ferries that “clock significant operation hours should also be required to switch to non-diesel fuels (Bailey, 2-3).”

Similar strict emissions standards were set by the San Francisco Water Transit Authority for its ferries. The requirements on the new ferry fleet are 85% below the EPA Tier II standards, evidence that stricter standards can be met (Bailey, 2).

Ports in the State of California and the Vancouver Port Authority in Canada have set regulations that force ships to use low sulfur (distillate) fuels while in port or in the surrounding regulated regions. Vancouver, Canada has also instituted incentives for marine vessels to use cleaner fuels. The environmental director of the Authority sees that this standard will be most easily

met by more recently constructed container vessels and cruise vessels, which will have newer engines that may already run on low sulfur fuels. Vancouver's policy is as follows:

“To qualify for a bronze award, and be charged the same harbor dues as 2006, a ship must burn 1-2% sulfur fuel. A silver award, receiving a 10% reduction in dues, requires the ship to use 0.5%-1% sulfur fuel. The highest award, the gold category, will require a ship to use less than 0.2% sulfur fuel and will receive a 20% discount on harbor dues (Wilson-Roberts).”

The Port of Long Beach (POLB) has a myriad of air emissions reduction programs, all intended to reduce NO_x, SO₂, and particulate matter. One of the POLB's efforts is cold-ironing, or the use of shore-side power for vessels in port to prevent the bunkering of diesel. The POLB recognizes that the cost for cold-ironing is high, about \$15,000 per ton of emission reduction. As a possible alternative to the cold-ironing emissions reduction project, one of the Port's suggestions is that ships use a cleaner fuel while in port – be it low sulfur diesel, MGO, or LNG (Mahier).

The San Pedro Ports Clean Air Action Plan addresses the emissions from port-related activity from both the POLB and the Port of Los Angeles (POLA). These two ports are working in cooperation to implement the following standards for ocean-going vessels: reduced vessel speed for transiting within 40 nautical

miles, cold-ironing for all vessels at berth, less than 0.2% sulfur MGO (or alternative with equivalent emissions reductions) in auxiliary engines and main engines for vessels at berth and transiting within 40 nautical miles, and diesel PM and NO_x control devices on auxiliary and main engines on new vessels and existing vessels that call the San Pedro Bay Ports frequently. The Clean Air Action Plan also addresses harbor craft. By the end of 2008, all resident harbor craft will meet EPA Tier II engine standards (or alternative with equivalent emissions reductions). By the year 2011, all existing resident harbor craft will be retrofitted with PM and NO_x emissions reduction technology. And finally, all resident harbor craft will be repowered to meet the EPA Tier III engine standards, within five years of the engine availability (San Pedro Bay Ports).

The NorthWest CruiseShip Association (NWCA) member cruise lines agreed in the year 2003 that cruise vessels in the waters of the Pacific Northwest be required to burn low sulfur fuel. Royal Caribbean and Celebrity Cruise Lines adopted gas turbine vessels powered by a 99% biodiesel blend for voyages in the Pacific Northwest (Puget Sound Air Maritime Forum). Alaska also instituted an extensive air quality control program that regulates cruise ship emissions in its waters (Murkowski). Clean cruise ship acts have been introduced to the US Congress in recent years, but have not made it past the “Committee on Commerce, Science & Transportation” to which they were introduced (GovTrack).

6.5.2 Port Region Marine Emissions In-Depth Study

The Puget Sound, a 16,000 square mile (20% of which is water) estuarine area in Washington State (Taylor), is the first area in the United States for which a detailed GHG emissions inventory has been generated. Encompassed in the region are the city of Seattle and the ports of Seattle and Tacoma. The Puget Sound Maritime Air Forum Executive Summary from April 2007 ascribed the contribution of various maritime activities in the Sound to its total emissions register (Starcrest). According to the group's website, the Maritime Air Forum is a "voluntary public/private partnership working together for healthy air through fact-based, cost-effective emission reduction strategies."

The study's primary findings are that ocean-going vessels account for over 80% of the SO₂ from maritime-related emissions, and they are also significant contributors to GHG, particulate matter, and NO_x emissions. Harbor vessels are the primary maritime contributors (from close to 50% for GHG, particulate matter, and NO_x, over 80% for volatile organic compounds (VOC) and CO) to all of the emissions source categories, with the exception of SO₂, where ocean-going vessels dominate. Lastly, the marine vessels in the Puget Sound Region contribute the majority of the maritime emissions, while the vehicles, locomotives, and equipment for maritime uses contribute less than 40% of the total emissions across all source categories (Starcrest, 23).

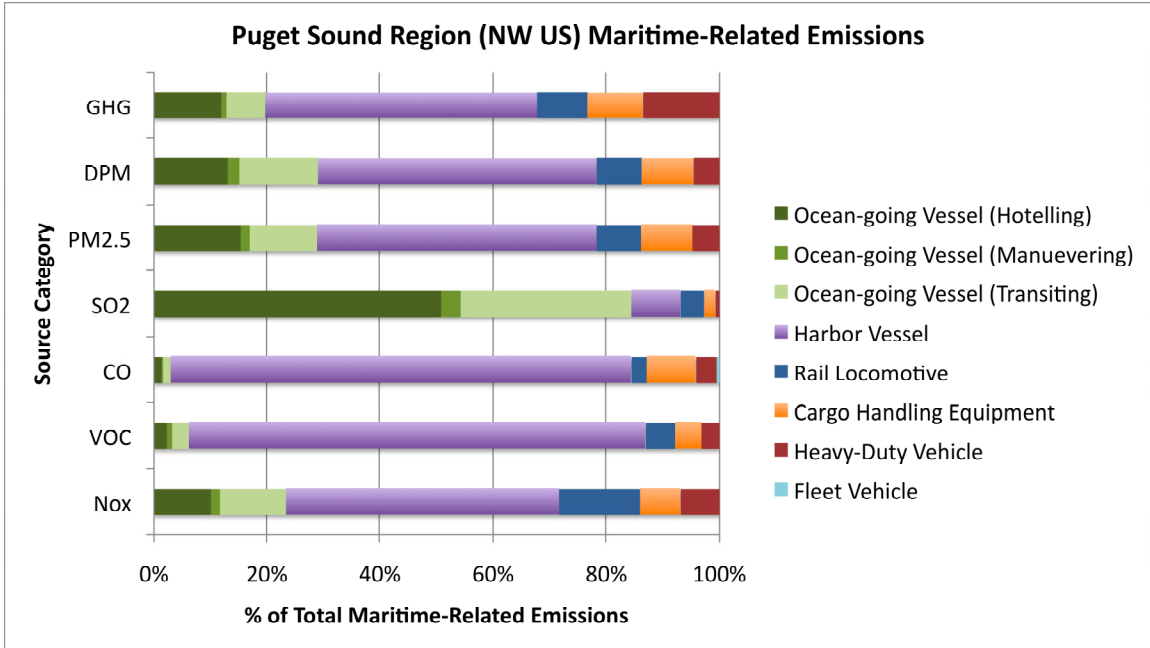


Figure 6-5: Emissions contributions from sources related to maritime industry (Puget Sound Region, United States).

The maritime-related emissions in the Puget Sound Region (located in the US Northwest) are compared across categories: ocean-going vessels, harbor vessels, rail locomotives, cargo handling equipment, heavy-duty vehicles, and fleet vehicles. The emissions from the ocean-going vessels (highlighted in three shades of green) are separated into three components: hotelling, maneuvering, and transiting, as the emissions from each contribute at least 5% of the total maritime-related emissions (Starcrest, 23).

Comparing the Puget Sound Region contribution of maritime emissions to the total emissions in the Region, SO₂ and DPM are the two most prominent emissions from maritime contributions (Starcrest, 23).

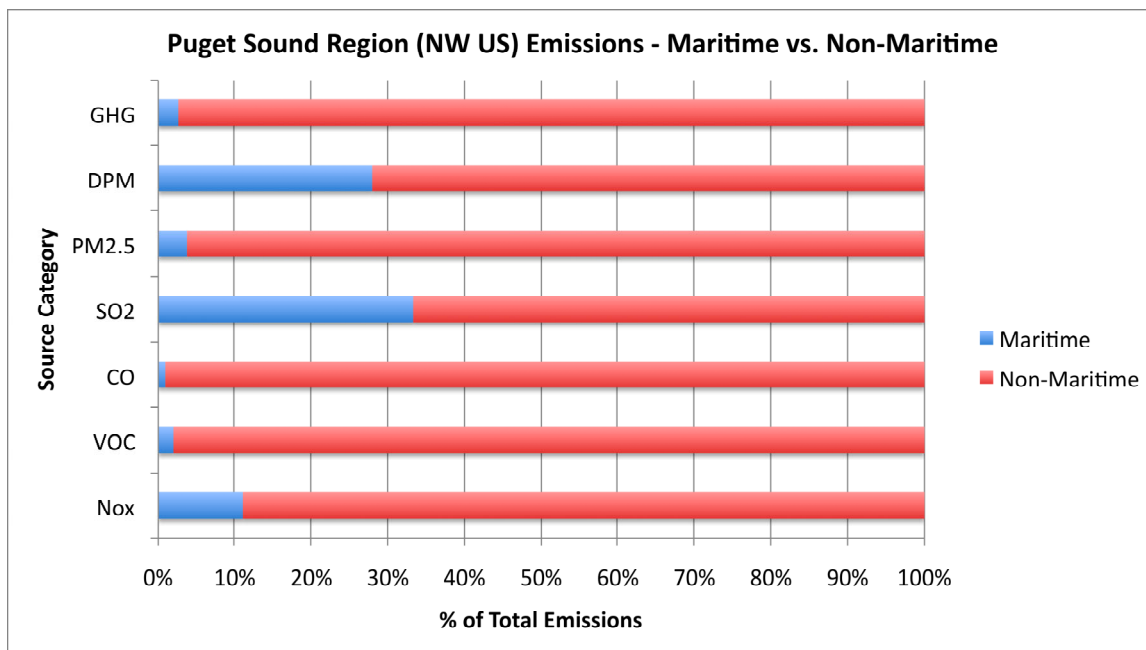


Figure 6-6: Emissions contributions from maritime vs. non-maritime sources (Puget Sound Region, United States). Maritime-related emissions to the total Puget Sound Region emissions are highlighted in blue and compared to the emissions contributions from non-maritime sources. Maritime-related emissions greatest emissions contributions are SO₂, particulate matter, and NO_x (Starcrest, 23).

6.6 Emissions Exemptions & Credits

The Swedish government supports an emissions trading scheme for both NO_x and SO_x with a plan to reduce emission levels in the North and Baltic Seas to sustainable levels by 2012. In general, reducing emissions generated by a ship is far less costly than reducing emissions from land sources. Hence, there is an emission credits trading market in Sweden; shipowners have a financial incentive to reduce their ship emissions by improving their engine technology in order to trade emissions credits with onshore industries (Roueche2). Such a trading system for the emissions reductions allowed by LNG-fueled vessels could be a valuable driver in supporting an LNG-fueled vessel market in the United States.

The San Pedro Bay Ports Clean Air Action Plan has proposed a clean fuel incentive program. Beginning in July 1, 2008 for a period of a year, the POLB and the POLA will collectively provide incentives to vessel operators who proactively meet the low sulfur fuel requirements that go into effect on June 30, 2009. For vessel operators on approach or departure within 40 nautical miles of the ports that burn low sulfur fuel and are also compliant with the vessel speed reduction program in place, the San Pedro Bay Ports will fund the cost differential between the typical marine diesel and the low sulfur fuel (San Pedro Bay Ports) for these qualifying vessel operators. The proposed incentive system does not allow for trading credits, as the market is not yet facing mandatory emissions regulations.

7 Future of the LNG-Fueled Market

7.1 Vessel Research & Development

The engine manufacturer Wärtsilä, in cooperation with Aker Yards (shipbuilder), DNV (classification society), and Marinetek, are some of the organizations working toward developing collections of specially designed LNG-fueled vessels. The developments of this consortium include an LNG Cruise Ferry, LNG Cruise Vessel, and LNG RoPax (Roll-on/Roll-off and Passenger) Ferry (Levander).



Figure 7-1: LNG-fueled concepts for cruise ferry, cruise, and RoPax. Three of the LNG-fueled vessel concepts developed by Wärtsilä include the LNG Cruise Ferry (pictured on the left), the LNG Cruise vessel (pictured on the right), and the LNG RoPax (pictured on the bottom center) (Hatley).



7.2 Further Study

An interesting pursuit would be to investigate the effectiveness of LNG cold-ironing at major ports in the United States as a way to drive the creation for an LNG-fueled vessel market in the United States. Once the LNG has been approved to be on port property (as it was in the case of the Port of Oakland) by the US Coast Guard and the appropriate port authorities, then it is likely that there would be little resistance to the delivery of LNG mobile storage containers to the port to refuel ferry and cruise vessels, harbor craft, or small container ships operating in a Short Sea Shipping network. The LNG cold-ironing demonstrations are likely to continue, so a case study on their implementation and their impact on the long-term availability of LNG at the port is an important future analysis.

Input from LNG distributors and those that design and operate LNG/CNG/LCNG refueling stations for vehicles here in the United States could potentially be valuable. Beginning discussions with these stakeholders would be useful in generating interest in this LNG-fueled vessel marine line of business for these companies. These stakeholders have a clear understanding of the requirements that need to be met at the local, state, and Federal levels for their current land-based LNG applications, so their expertise is highly valuable for the potential marine market.

8 Conclusions

Natural gas is a prevalent fossil fuel; given the current reserve to production ratio, it is likely to be in supply for over another 60 years. Natural gas is the favored fossil fuel for its clean properties among this group as it generates fewer emissions than its counterparts - coal and crude oil. The ability to liquefy the gas has created the economies of scale to make LNG a commodity that is traded globally. The United States is one of the countries that will become increasingly dependent on natural gas imports in the coming decades. The main use for natural gas in the United States is power generation for utilities, but CNG and LNG are also used by the transportation sector.

Concern has increased globally on the impact of burning carbon fuels, and has driven policy makers to create restrictions on industries that burn these fuels. Until recently, emissions restrictions were only being toughened for land-based industries. The impact of maritime-related emissions on total emissions in coastal areas is becoming better understood, and new emissions regulations are reflecting this increased knowledge. The new regulations are forcing some marine operators to modify or replace their existing technologies. In the case of marine vessel power systems, an option for reduced emissions is the LNG-fueled vessel.

LNG-fueled vessels can take on a few configurations. There are vessels that are only powered by gas turbines (that can be designed to burn natural gas) or gas engines (designed to burn natural gas), vessels that are hybrids and

powered by both gas turbines or gas engines and diesel engines (CODAG/CODLAG), and vessels that are powered by engines that can operate both on natural gas (bunkered as LNG) and on marine diesel fuel (DFDE). The applications of each configuration vary across the spectrum from small ferry vessels to large cruise ships and LNGCs.

The LNG-fueled vessel market is mainly supported by the demand for LNG-fueled LNGCs around the globe. However, the technology has applications to smaller vessels, traveling shorter distances, often at high speeds, with well-defined routes. The developing ferry, offshore supply vessel, and coast guard LNG-fueled applications in Europe, and the beginnings of a ferry market in Brazil, are examples of these growing markets. Major cruise lines are a potential market for LNG-fueled technology, as many have adopted combined gas turbine technology for their new-builds including Cunard Lines, Holland America, and Princess Cruises to name a few. These gas turbine systems can be modified from their diesel design to burn natural gas.

The benefits of burning natural gas as a marine fuel are clear: reduced emissions of NO_x and CO_2 , SO_2 is eliminated and particulate matter is reduced greatly; in some markets, burning natural gas allows for emissions credits that can be traded or sold; the price of marine diesel fuels is steadily increasing and LNG is often cheaper for the same energy content compared to the “cleaner” diesel fuels; in the case of combined gas systems, there is often more space for cargo made available on the vessel; in the case of dual fuel systems, bunkering decisions can be made by selecting the less expensive fuel in a given market;

and in the case of a multinational corporation or government entity, the benefits of progressing a green initiative with LNG has numerous benefits.

The capital cost for an LNG-fueled system is greater than that for a typical diesel propulsion system. The operating costs for the DFDE vary, depending on the fuel being used. In general, the operating costs of LNG-fueled vessels are lower than that of diesel engines running on MDO but higher than the operating costs for diesel engines running on HFO. The benefit of vessel power systems that run on natural gas is that the engine life is typically longer and the systems require less maintenance.

The development of LNG infrastructure in the United States is slow, as there is opposition to the building of structures that potentially affect the safety and security of populations. LNG is utilized by the land-based transportation industry as an alternative fuel for buses and trucks. LNG has also been used in cold-ironing to provide shore-side power to ships at berth in US ports where LNG terminals are not located. CNG as a transportation fuel has existed in the United States since the 1990s. However, using LNG as a marine fuel in the US has not been significantly exploited.

There is great potential for an LNG-fueled vessel market in the United States. With a growing ferry and cruise industry, a growing ocean trade, and increasing interest in a Short Sea Shipping Initiative, the applicable markets are demanding more marine fuels. The price for LNG in the United States has historically been lower than that of the “cleaner” marine diesel fuels for the same energy content, and is likely to remain cheaper in the future.

The safety and security concerns on LNG infrastructure need to be addressed by both private and public entities in order to further the acceptance of LNG as an alternative marine fuel in the United States. Investments from the Federal government, supplemented by investments from large multinational corporations looking to “green” their supply chain and venture capital firms, all tied to an incentive system to encourage private investment are likely ways to fund the development of an LNG-fueled vessel market in the United States.

Finally, useful information can be gained by continuing to follow the development of the LNG-fueled vessel industry in Europe as well as the rest of the world.

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