LNG MARINE FUEL APPLICATIONS

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[1] CEE is a noncontributory member of SIGTTO and participates in the regular PanAmerican Regional Forums in Houston and occasionally SIGTTO meetings in other locations.

BACKGROUND

The Bureau of Economic Geology's Center for Energy Economics has a rich history of research and publication on the topic of liquefied natural gas, LNG, extending over the last twenty years.[2] Continuing in this tradition, a research effort was begun in 2013 to explore economic value of LNG as a transportation fuel for on-road use. However, when oil prices collapsed in 2014 the robust spreads between petroleum fuels and natural gas (which has been cheap in historical terms since 2011) also diminished. These diminished spreads reduced economic motivation for U.S. trucking companies, already struggling financially, to invest in alternative fuel strategies. Not only cost of conversion but other factors as well, such as introduction of ultra-low sulfur diesel (ULSD) fuels, also contributed to the small amount of fuel switching that has occurred. Similar dynamics undermined many ideas for converting railroad locomotives to LNG. Light duty vehicle (LDV) conversions and promotion to natural gas have struggled for years given the complexity of conversion and refueling. Heavy duty vehicle (HDV) options held more promise because of fleet management and the smaller footprint of highway truck refueling as opposed to retail gasoline.

Three years on, it appears that the marine shipping industry, in spite of its own current financial difficulties, is becoming a source of developing demand. Natural gas, in the form of LNG, as a marine fuel is being driven in large part to new and stricter environmental regulations being implemented worldwide in ports and harbors. Port and harbor operations represent locations of emissions that create public nuisance and health impacts over metropolitan areas. They also represent point sources of emissions and fuel depot locations that can foster faster growth in market share. The continued low cost of natural gas and LNG for fuel procurement, a consequence of ample supply amid still soft demand (economic recession and seasonal variations), provides support for marine fuel strategies.

The purpose of this paper is to provide an overview of developments in LNG marine fuel applications and analysis of some of the drivers. Thus, this paper is a contribution to our continuing Global Gas & LNG research and public education effort. Transportation fuel supply and demand play out against a complex regulatory backdrop, thus our inclusion of this paper in a new CEE research series, *The Good, Bad, Ugly of Regulation*, which explores how rulemaking and oversight combined with market response can re-shape critical components of the energy system.

THE MARINE SHIPPING CONTEXT

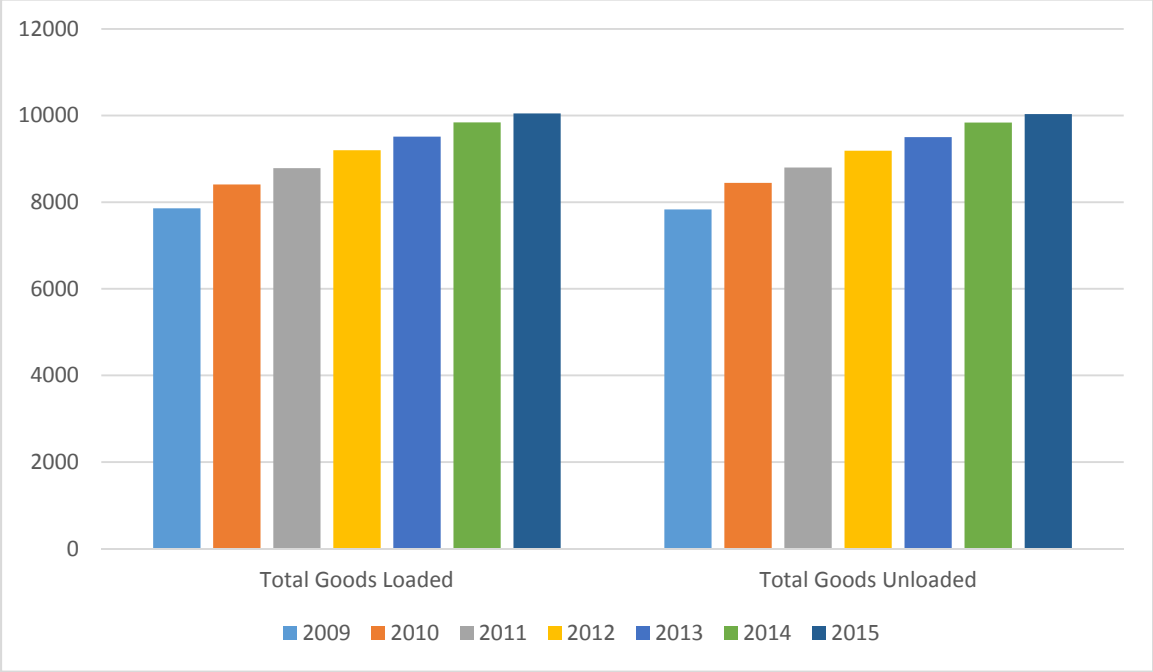
The marine shipping industry is global in scale and scope with approximately 80 percent of global trade by volume and 70 percent of trade by value being transported by sea and handled by ports worldwide. The percentages are even higher in the case of most developing countries (IMO World Maritime Day, 2016). Marine shipping is a vital link in the global economy; its financial health is driven by the level of economic activity and growth in world trade. Consequently, the marine shipping industry overall has been struggling with overcapacity amid a well-documented slump in global trade (WSJ 2016). These problems have been further exacerbated by low freight rates. This has resulted in shipping companies

[2] See CEE's Global Gas & LNG research page for background and links to our Introduction to LNG and LNG Safety and Security knowledge base papers which provide background, specifications, definitions and operating procedures for the U.S. and global LNG industries. http://www.beg.utexas.edu/energyecon/GlobalGas-LNG/

posting losses and ultimately in the filing of bankruptcy by South Korea's Hanjin Shipping Company, the world's seventh largest shipping line by capacity. According to ship brokers, Hanjin ships carried approximately 25, 000 containers a day across the Pacific Ocean and accounted for approximately 3.2 percent of the global container capacity (according to Alphaliner). In its third quarter results, Maersk also a dominant player in global marine transport, posted a loss in its shipping division and indicated that the company believes it will post a loss for the year due mainly to low freight rates (see www.maersk.com).

UNCTAD statistics indicated that since 2013, global GDP has shown moderate growth of 2.3 to 2.4 percent but total goods loaded and unloaded (see Figure 1) has continued to increase steadily. In 2015, it also reported moderate growth in world GDP, merchandise trade and seaborne shipments. It stated that there would be continuing downside risks to shipping such as a continued fragile recovery in Europe, diverging outlooks for net oil consumers and producers, geopolitical tensions, and a continued economic slowdown in China.

Figure 1. World Seaborne Trade in Metric Million Tons



Source: UNCTAD Stat (http://unctadstat.unctad.org/wds/TableViewer/downloadPrompt.aspx)

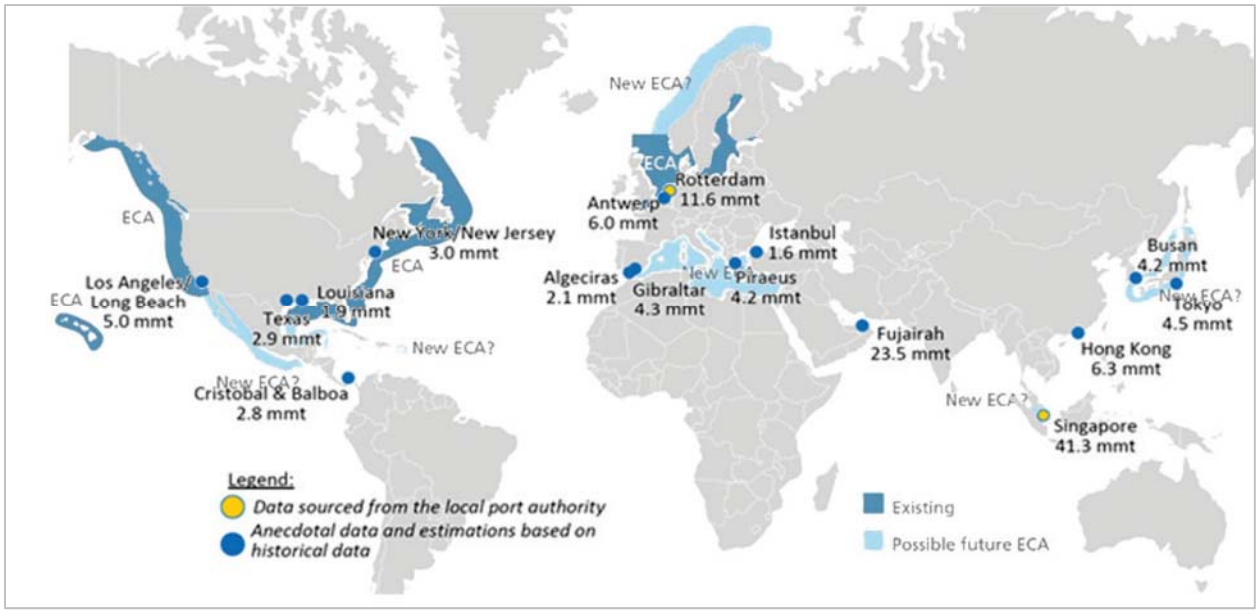
By contrast, the world fleet grew by 3.5 percent during 2014 which is the lowest annual rate in over a decade as compared to moderate growth in global seaborne shipments during the same year of 3.4 percent. The world fleet at the beginning of 2014 consisted of 89,464 vessels comprising a total of 1.75 billion dwt (dead weight tonnage). In addition, the average age of the world fleet increased only slightly in 2014 due to the delivery of fewer new build vessels. For the first time since the peak of the ship building cycle, newer tonnage did not compensate for the natural aging of the fleet (UNCTAD 2015, pg 34).

In spite of the anemic global economic recovery and world trade, the movement of goods by ocean vessels is still the most efficient and economical method of transportation and by no means is disappearing. Yet, an emerging major concern with shipping is that it is also a major contributor of air pollution caused by the type of fuels consumed. The main types of emissions from the combustion of current fuels are carbon dioxide CO_2; nitrogen oxides, NO_x; sulphur dioxides, SO_x; and PM or Particle Matters (IMO 2016, pg 65). Some ship fuels contain 10,000 times as much sulphur as on-road fuels and are responsible for approximately 14 percent of the sulphur dioxide pollution (SGMF 2014, page 5). It is not surprising then that the industry is facing new and tougher environmental concerns and must face the implementation of new regulations/limitations addressing these concerns.

Since the switch from coal to oil based liquid fuels more than a hundred years ago, marine vessels have been using heavy fuel oil (HFO) as their primary fuel under the generic term of "bunkers" which have a high sulphur content. Some low sulphur diesel is also used for getting engines moving before switching to the less expensive bunkers or for running certain pumps onboard but the work horse of fuel for marine use has been bunkers. Recently, LNG has begun to make some inroads into this usage as a fuel option for propulsion and onboard electricity generation as a means of addressing these environmental concerns. Although LNG as a fuel option is not new – carriers which transport LNG as a cargo have been using LNG as a fuel for over fifty years – the notion of non-LNG carriers using it as a fuel is relatively new. The first merchant ship which was not a LNG carrier to use LNG as a fuel was the Norwegian ferry, "GLUTRA" built in 2000. Since 2001, more than forty (40) vessels using LNG as a marine fuel have been built and more are on order (IMO 2016, pg 12). LNG is emerging as a preferred solution since it also leads to cleaner onboard environments, a particular advantage for passenger carrying vessels such as cruise ships and ferries. (LNG Fuel Summit 2016).

As regulatory bodies around the world begin to address environmental concerns in key locations like ports and harbors, LNG is becoming a viable option to marine fuel. This is especially true as more, and more stringent, sulphur limitations have gone into effect since 2015 when MARPOL adopted emission controlled areas (ECAs) and sulphur limitations became effective. In 2015, as part of MARPOL Annex VI, the sulphur content of any oil onboard a merchant vessel within a designated ECA is limited to 0.1 percent; outside of emission controlled areas the limit is 3.5 percent until 2020 (Marine InSight, July 20, 2016). Currently, there are four (4) designated ECA's in the world: the Baltic Sea Area, the North Sea Area, the North American ECA, and the U.S. Caribbean Sea ECA (IMO 2016, pg 12). The North American, ECA includes the 200 nautical mile territorial waters from the U.S. coast as well as Canadian and French territories and the waters of the coast of Puerto Rico and U.S. Virgin Islands. In July, 2015, Hong Kong was created an ECA for vessels berthing there. Other areas in the Mediterranean Sea, Asia and Mexico are considering becoming ECA's (Le Fevre 2016, pg 447-8).

Figure 2. Existing and Potential ECA's Worldwide



Source: Adamchak. Also see ExxonMobil (https://lubes.exxonmobil.com/MarineLubes-En/your-industry_hot-topics_emission-control-area-2015.aspx

Recent studies have shown that using LNG as a marine fuel significantly reduces SO_x emissions by nearly 100 percent as compared to conventional fuel oil which contains varying amounts of sulphur (IMO 2016, pg 12). Sulphur oxides result from the combustion of fuel containing sulphur which oxidizes and in the presence of a catalyst such as nitrogen dioxide, NO_2, and can form sulphuric acid, believed to be a contributor to acid rain. In addition, SO_x contributes to the formation of secondary inorganic aerosol gases, fine particles which are harmful to humans. LNG as a marine fuel also reduces by 25 to 30 percent and NOx gases by 85 to 90 percent (DNV GL 2015, pg 6).

Nor has all the regulatory attention been focused solely on the air pollution resulting from the use of marine fuels, with the growing use of engines using natural gas, the IMO has also turned its attention to the need to address the safety requirements and inspection guidelines for those ships using LNG as bunker fuels. The IMO in collaboration with shipping industry has developed the International Code of Safety for Ships using gases or other low flashpoint fuels (IGF Code) which goes into effect January 1, 2017; however, it will not apply to vessels using their own cargoes as fuel (SIGTTO, Spring 2016, Issue 35, pg 9).

REGULATORY ENVIRONMENT

A brief overview of recently adopted regulations and others soon to be implemented will provide a deeper understanding of one of the drivers towards using LNG as a transportation fuel.

MARPOL Annex VI

The IMO is a specialized agency of the United Nations and has responsibility for regulation of international shipping and in particular for the safety of life at sea (SOLAS) and the prevention of marine

pollution (IMO 2016, pg 11). MARPOL ("marine pollution") is the international convention for the prevention of pollution from ships and is the main international convention covering the prevention of operational or accidental pollution of the marine environment by ships. MARPOL Annex VI specifically addresses air pollution from ships and became effective in 2005. This regulation requires ships to meet increasingly more stringent emission limits for pollutants within ECAs (IMO 2016, pg 11). Current regulations cap the sulphur content of any oil onboard a ship within an emission controlled area to 0.1% and at 3.5% outside of an emission controlled area until 2020 (Marine InSight, July 20, 2016). The MARPOL regulation was implemented in the United States through the Act to Prevent Pollution from Ships, 33 U.S.C. 1901-1905 (APPS). Annex VI requirements comprise both engine-based and fuel-based standards and apply to U.S. flagged ships wherever located and to non-U.S. flagged ships operating in U.S. waters. On June 27, 2011, the Environmental Protection Agency (EPA) and the U.S. Coast Guard (USCG) signed a Memorandum of Understanding (MOU) to enforce Annex VI MARPOL. The MOU provides that the EPA and the USGC will "jointly and cooperatively enforce the provisions of Annex VI and APPS (EPA 2011).

On January 1, 2015, new lower sulphur emission levels of 0.1% went into effect within the designated emission control areas or ECAs while levels outside of an ECA are set at 3.5% until 2020 when new global limits go into effect. This new global limit was just adopted during the recent meeting of the IMO's Marine Environment Protection Committee (MEPC) in London in October, 2016. This represents a significant reduction from the current level. This action does not come as a surprise as the MEPC had been conducting a study to assess whether sufficient compliant fuel would be available to meet a 2020 deadline. However, regardless of the outcome of the study, the new reduced limits would still have gone into effect by 2025 (IMO October 31, 2016). Obviously, the MEPC felt that there would be no hardship to ships still relying on low sulphur fuels and the earlier implementation date was accepted. Until these new limitations are in effect, ship owners and operators can switch from traditional residual bunker fuel during ocean passages outside of the designated ECAs to low sulphur fuels when operating in ECA's. However, they will have to weigh longer term solutions to the problem (Adamchak 2015, pg 1-2).

Annex VI also addresses NO_x emissions and outlines certain limits in its Tier III which applies to ships constructed on or after Jan 1st, 2016 (www.dieselnet.com). Nitrogen oxide consists of nitric oxide (NO) and nitrogen dioxide (NO_2). When NO_x is combined with water it can form corrosive acids which may contribute to lung diseases such as asthma and heart disease. NO_x contributes to the formation of ozone and is thus a primary component of smog. Starting in 2011, MARPOL also required the reduction in NO_x emissions worldwide based on Tier II[3] and in 2016, Tier III requirements will go into effect for emission control areas. NO_x emissions vary depending upon engine size and speed and are very dependent on engine load and technology. None of the oil fuel options are able to meet the Tier II requirements unaided[4] by either the use of Catalytic Reduction Technology (SCR) or Exhaust Gas Recirculation (EGR) equipment (SGMF 2014, pg 5-7).

[3] MARPOL Annex VI sets limits on NO_x and SO_x emission limits from ship exhausts. IMO emission standards are referred to as Tier I, II and III. Tier III is the emission limit now in force for ships constructed on or after January 1, 2016 in North American or Caribbean ECAs. https://www.dieselnet.com/standards/inter/imo.php

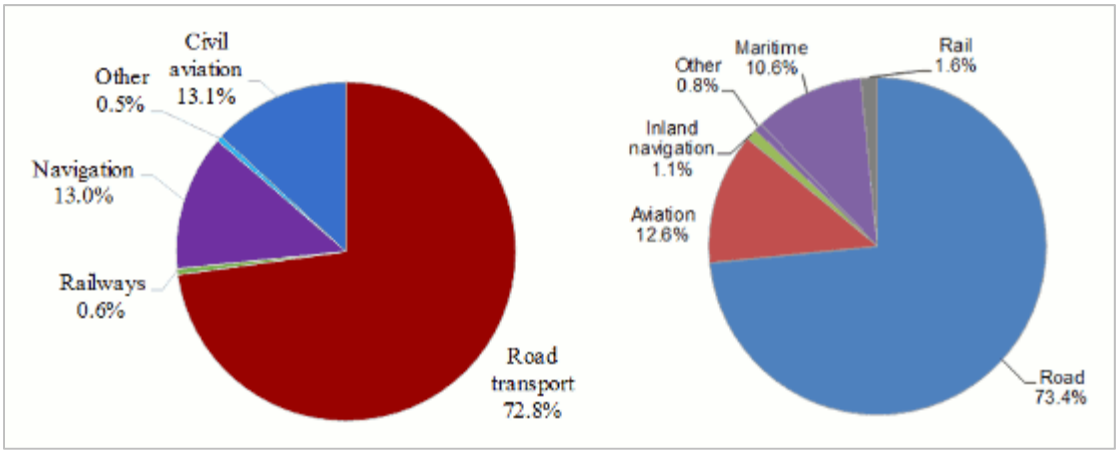
[4] Engines need to be further equipped with either Selective Catalytic Reduction technology (SCR) or Exhaust Gas Recirculation (EGR) in order to reduce NO_x emissions to within the Tier III requirements.

In addition to the new stricter global sulphur limits, MEPC also voted on new requirements for consumption data for each type of fuel used in addition to other required information for ships of 5,000 gross tonnage or greater. Ships of this size are responsible for approximately 85 percent of CO_2 emissions from international shipping. The data collected will be used to determine future decisions on other environmental measures in addition to those already in force. The data will be submitted to the ship's flag State at the end of each calendar year. Each flag State will then determine if the ship has complied with the requirement or not and if so, issue a "Statement of Compliance" for the individual ship. The flag State will then submit the data to the IMO Fuel Oil Consumption Database. Based upon this information, the IMO's Secretariat will summarize the collected data and produce an annual report to the MEPC. This new requirement goes into effect on March 1, 2018 (IMO October 31, 2016).

EU Emissions Reduction Deadline for 2020

The European Union (EU)'s 2020 Climate and Energy Package is a set of binding legislation to ensure the EU meets its climate and energy targets by 2020. It has three key targets: 20 percent reduction in greenhouse-gas emissions from 1990 levels; 20 percent share of EU energy consumption from renewable sources; and 20 percent improvement in energy efficiency.

Figure 3. Greenhouse Gas Emissions from transport by Mode (2014) and Share of Transport Energy Demand by Mode (2014)



Source: http://ec.europa.eu/clima/policies/transport/index_en.htm

IMO Gases or other Low-flashpoint Fuels (IGF Code)

As more ships began using LNG as a fuel, it was recognized that further regulations governing their use and safety were lacking. Therefore, in June 2015, the IMO adopted the IGF code, globally binding regulations for ships using LNG as fuel which go into effect in January, 2017. The new code will cover the safety of ships using gases or other low-flashpoint fuels but will not apply to LNG carriers. The IGF Code contains mandatory provisions for the arrangement, installation, control and monitoring of machinery, equipment and systems using low-flashpoint fuels, focusing initially on LNG (IMO 2015, pg 9).

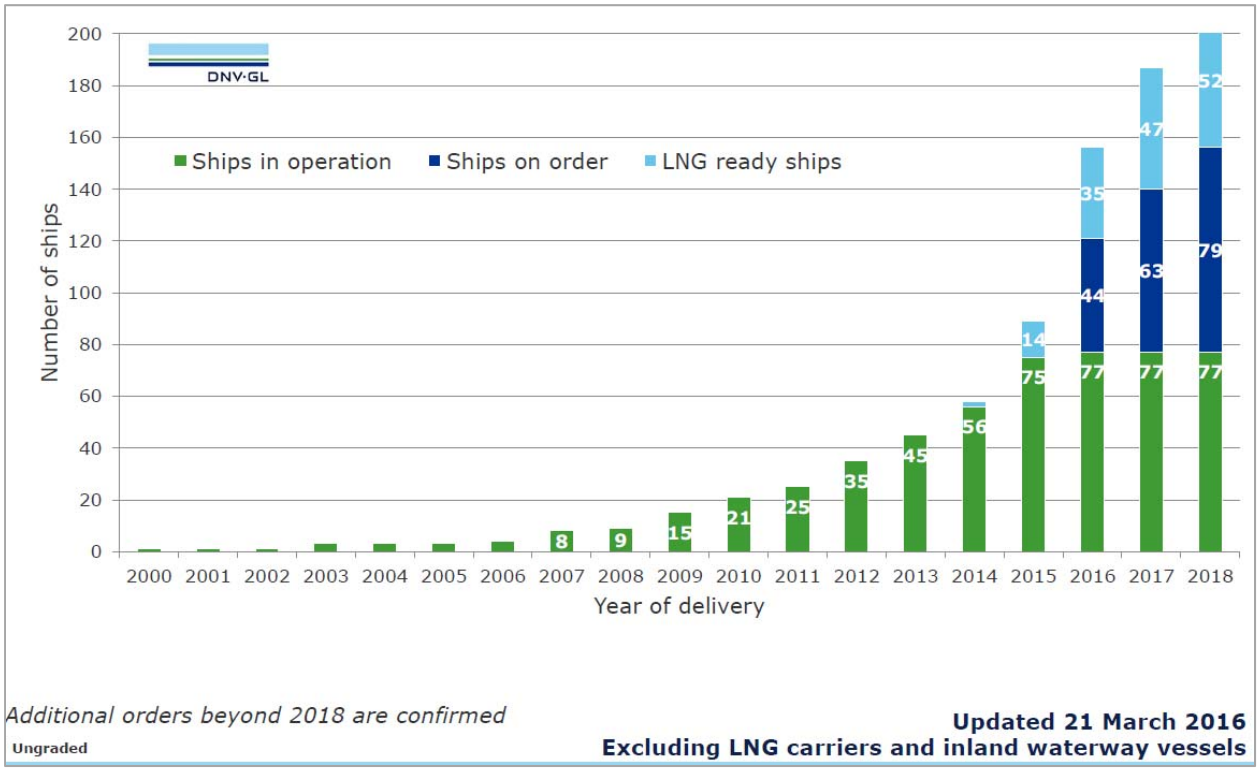
United States Regulations

According the U.S. Coast Guard, existing U.S. regulations do not address commercial vessel natural gas fuel systems design or installation and Coast Guard regulations only cover the means of boil-off gas on LNG carriers. However, the U.S. will be subject to the IGF Code beginning in January 2017. In meantime, the USCG has issued several policy letters including CG-OES Letter 01-15 Guidelines for LNG Fuel Transfer Operations and Training of Personnel on Vessels Using Natural Gas as Fuel; CG-OES Policy letter 02-15 Guidance Related to Vessels and Waterfront Facilities Conducting Liquefied Natural Gas (LNG) Marine Fuel Transfer (Bunkering) Operations; CG-ENG 02-15 Design Standards for U.S. Barges intending to carry Liquefied Natural Gas in Bulk; CG-ENG 01-12 Equivalency Determination-Design Criteria for Natural Gas Fuel System (Maritime Commons, 2016).

New Demand for LNG as a Marine Fuel

According to a March 2016, study by DNV-GL, there are 77 LNG fueled ships, excluding LNG carriers and inland waterway carriers, currently in operation with approximately 69 percent of them operating in Norway alone as this country was the pioneer in converting to LNG fueled vessels (DNV-GL 2016). There are another 85 confirmed orders for LNG fueled vessels through 2022 (with 79 due for delivery in 2018). This number does not include LNG-ready vessels, meaning those with the capacity to be converted to LNG fuel. By 2018, the total number of LNG fueled vessels will reach 162 vessels with another 52 of LNG-ready vessels for a total count of approximately 208.

Figure 4. LNG Ship Fuel Projects



Source: DNV GL

LNG tankers typically have used LNG as fuel from "boil off gas" (BOG) – natural gas that emerges from the cryogenic liquid state inside containment – along with dual fuel engines which burn a combination of diesel and LNG. Thus LNG carriers are not candidates for LNG bunkers in the future as part of this market's growth (IMO 2016, pg 26). An example is the *Creole Spirit* is the first M-type, electronically controlled, gas injection (MEGI-powered) LNG carrier vessel. It uses a two stroke engine technology which consumes only 100 tons of fuel daily as opposed to the dual fuel electric systems which consume 125-130 tons daily. The ship is on a long term charter to Cheniere Energy (Marine InSight, July 21 2016).

Notable examples of non-LNG carrier vessels currently operating or soon to operate are the following.

- The *Isla Bella* is the first LNG powered container ship and is owned by TOTE. It is also the largest LNG powered dry cargo ship and is Jones Act-qualified. Its sister ship, the *Perla del Caribe*, is expected to be launched in early 2016 (Marine InSight, July 21, 2016).
- Carnival Corporation, the world's largest leisure travel company, recently signed a framework agreement with Shell Western LNG B.V. for the supply of marine LNG fuel. Under this agreement, Shell will supply the company with LNG for its two new LNG-powered ships when they launch in 2019. Included in the agreement is the use of Shell's infrastructure in ports of call to refuel the ships. The ships will be equipped with dual-fuel engines. These ships will be the first in the cruise industry to use LNG to generate 100 percent of the ship's electric power while in port and at sea. In September of 2016, the company placed an order for 3 additional cruise ships which will be powered by LNG which brings the total of LNG fueled ships on order to a total of seven (7) with delivery dates expected in 2020 and 2022.[5]
- Interlake Steamship Company which owns eight self-unloading ore carriers operating on the Great Lakes in the U.S. has announced that it will convert seven vessels in its fleet to use LNG as the main propulsion fuel. The first vessel selected to undergo conversion is the M/S Mesabi Miner. (IMO 2016, pg 21).
- The US based company, TOTE Inc. has also recently announced that it will convert two of its existing ro-ro (roll-on/roll-off) vessels which operate between the Tacoma, Washington and Alaska to LNG as its fuel. In addition, the company has signed a contract for the construction of two 3100 TEU ships with an options for three more. All of these vessels will be Jones Act compliant (IMO 2016, pg 22).
- Matson, a U.S. company, has signed a contract with a U.S. shipyard for the construction of two 3600 TEU container ships to be equipped with dual-fuel engines and will also be Jones Act compliant with intended use between the US West Coast and Hawaii (IMO 2016, pg 22).
- Crowley Maritime has taken final decision to build two LNG fueled ConRo (combination container-roll-on/roll-off) ships with DNV class at a U.S. shipyard and will be Jones Act compliant. These vessels are intended for transit between the U.S. and Puerto Rico (IMO 2016, pg 23).
- Horizon Lines have announced plans to convert the power plants on two of its steam turbine cargo vessels and install duel fuel engines (IMO 2016, pg 23).
- Harvey Gulf Offshore which specializes in offshore supply and support vessels has made significant investments with 12 LNG fueled OSV's currently operating in the North Sea and have ten such vessels on order. The first of these vessels was delivered in early 2014 (IMO 2016, pg 23).

[5] See http://www.prnewswire.com/news-releases/carnival-corporation-signs-agreement-with-shell-to-fuel-worlds-first-lng-powered-cruise-ships-300337817.html.

- South Korea is the first Asian country to build an LNG fueled vessel which operates in the Incheon Harbor. Chinese oil company, CNOOC, has two LNG fueled tugs in operation and Japan may possibly order its first LNG fueled vessel to operate in Tokyo Bay (SGMF 2014, pg 12-13).

It is easy to anticipate that the U.S., Caribbean and Canadian regions would have great interest in LNG as a marine fuel as well as being likely sites for the build out of LNG bunkering facilities (thus providing test beds for refueling and related operations and regulatory oversight). The areas of greatest interest are the Gulf of Mexico, which is the busiest shipping region in North America; the Pacific Northwest, with its extensive network of ferries, container ports and bulk terminals; and the Great Lakes and Eastern Seaboard with their high level of international and domestic shipping activity (IMO 2016, pg 45).

It is not difficult to imagine that there will be growth in the demand for LNG as a result. Surprisingly though, there seems to be much variation among studies on the level of incremental demand that might develop. One study, conducted by Adamchak (2015), projects that demand for LNG as a marine fuel will reach 1 million tons by 2020 rising quickly to 8.5 million tons by 2025. However, their projections assume that any new build ships would engage in ECA-to-ECA routes and that the new stricter global sulphur emission limits would be delayed to 2025. The study incorporated a realistic market share for LNG, in competition with low sulphur fuels (Adamchak, 2015, pg 5). These assumptions would imply a more conservative outlook for future demand than other forecasts.

By comparison, WoodMac, CERA and Total have more robust outlooks for LNG marine fuel demand, ranging from 20 to 30 metric tons per annum by 2030 (SGMF 2014, pg 16). As mentioned, all analysis and forecasts will have to be tempered by the recent news on the new global sulphur restrictions and demand from marine shipping that could result. However measured, it appears that LNG will play a larger role in the marine fuel applications as new ships are built.

Current Fuel Options for Marine Vessels

In the short term, ship owners and operators can switch from traditional residual bunker fuel during ocean passages to low sulphur fuels when entering and operating in ECAs and thus, remain in compliance. However, in the longer term, the industry will have to make more permanent changes in order to be compliant, especially with the looming 2020 global sulphur limit of 0.5%. Some of the options to be considered are the following.

1. **Scrubbers or other technology can be deployed, allowing the continuation of oil based bunkers.** One alternative to the use of LNG for marine application is installing scrubbers to continue using liquid fuels. The question is whether scrubbers are economical for marine shipping. Scrubber installation requires retrofitting current engines and fuel residue must still be disposed of properly. Scrubbers function by washing out the sulphurous oxides by forcing hot exhaust gas through a curtain of water. The waste product must be disposed of either by dumping the excess sulphur into the ocean or by storing and disposing of it at onshore facilities (Adamchak 2015, pg 3). Finally, scrubbers are still an expensive option at an approximate cost of $5 million each and still may not be able to comply with stricter carbon dioxide emission limits if enacted in the future (Carr, 2016). It may take a substantial amount of time to recoup that capital expense cross a ship portfolio. Also, this capex does not address the operating expense of disposal of the cleaned material or any possible future regulations governing disposal. Nor does this capex estimate address the physical

space required for placement of scrubbers or their weight and the impact on performance and associated opex.

2. **Alternatively, ship owners can opt for using ECA-compliant fuels with a sulphur content below the ECA limit when operating in ECA zones and switch back to higher sulphur fuels when outside the ECA.** Low sulphur fuel oil is commonly described as a "distillate" as opposed to a "residual" fuel. The term "distillate" usually refers to light refined diesel fuel with a sulphur content of 0.5% or less and is commonly called MGO, marine gas oil, ISO DMA.[6] Marine diesel oil or MDO, ISO DMB, has some residual content but is considered a distillate as long as its sulphur component is below 0.5%. The term residual is used to refer to heavier fuel oils which are less refined and have a sulphur content of approximately 2.5%. Other names for residual fuels are heavy fuel oil (HFO), IFO 180 and IFO 380, corresponding to ISO RME25 and ISO RMG35 (IMO 2016, pg 38). Some refiners such as ExxonMobil, have developed specialized low sulphur fuels under unique brand names such as HDME 50 and AFME 200 to address these needs and are compliant with ECA requirements.[7] The following table summarizes the slate of fuel options, both high and low sulphur, currently available. As already mentioned, specific refiners will have their own brand names for these generic fuels.

Table 1. Definition of Diesel Fuels

IFO 380/ISO RMG35	Intermediate fuel with maximum viscosity of 380 Centistokes and less than 3.5% sulphur. Considered a HFO or Heavy Fuel Oil
IFO 180/ISO RME25	Intermediate fuel oil with a maximum viscosity of 180 Centistokes with less than 3.5% sulphur
LS 380	Low sulphur (less than 1.0%) intermediate fuel oil with a maximum viscosity of 380 Centistokes
LS 180	Low sulphur (less than 1.0%) with a maximum viscosity of 180 Centistokes
MGO/ISO DMA	Marine gas oil-light refined diesel fuel with 0.5% sulphur or less.
MDO/ISO DMB	Marine diesel oil- has some residual content but is considered as distillate as long as its sulphur content is at or below 0.5%
LSMGO	Low sulphur (less than 0.1%) marine gas oil
ULSMGO	Ultra-low sulphur marine gas oil-referred to as Ultra Low Sulphur Diesel (with sulphur content of .0015% max) in the U.S. and Auto Gas Oil (with sulphur content of .001% max) in the EU

Source: IMO pg 38-39

3. **The third option is to switch to LNG as an alternative fuel.** This option is considered most likely in the short to medium term due to availability of engine and system technology; environmental compliance; operational experience; and the availability of natural gas and LNG for many ship

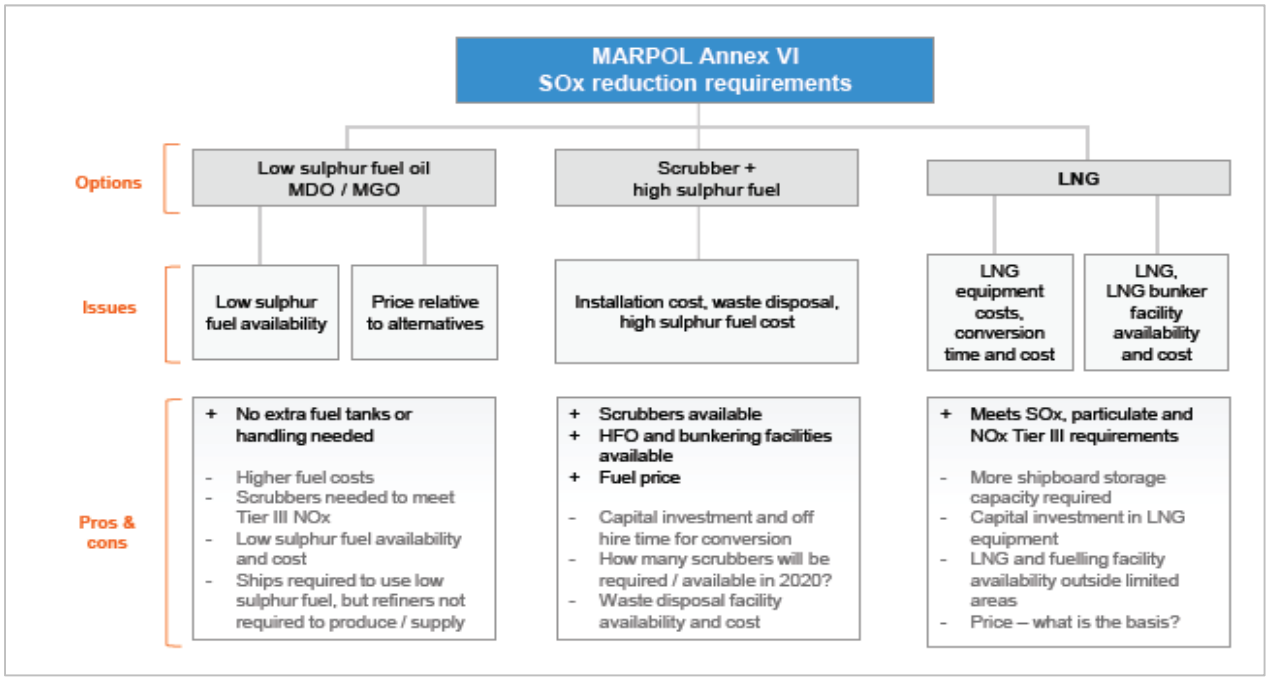
[6] See https://www.iso.org/obp/ui/#iso:std:iso:8217:ed-5:v1:en for details on marine fuels specifications (petroleum products fuels, ISO-F).
[7] See https://lubes.exxonmobil.com/MarineLubes-En/Files/exxonmobil-premium-afme-200-fact-sheet.pdf.

manifests. As noted previously, a major benefit of switching to LNG is that the emissions of SO_x and PM are negligible while NO_x emissions meet current IMO requirements and the maritime industry has experience with BOG as fuel for LNG carriers (IMO 2016, pg 39).

Fuel cost is a key consideration for fuel switching strategies. Managing bunker costs, the main variable operating expense, is crucial to competitiveness. Bunker fuel represents approximately 30 to 40 percent of a vessel's total operating cost (BCG 2015). Diesel fuel costs track the price of crude oil and with high crude prices comes high diesel costs. Consequently, factors impacting bunker costs and switching are crude oil and natural gas prices and the relative spread. Another consideration is the price of globally traded LNG. Current expectations are that global LNG will continue to be in oversupply for the medium term[8], keeping prices low and fostering fuel switching strategies. This is not to say that challenges to the use of LNG as a bunker fuel do not exist. Constraints include lack of abundant infrastructure; patchwork international regulation; confusing tax rules; and current pricing mechanisms (lack of transparent, traded LNG price indicators, such that sellers and buyers must rely on oil and natural gas proxies). Most of these impediments are slowly being addressed by the industry as LNG becomes more widely used.

The following decision flow summarizes the options faced by vessel owners in order to comply with sulphur reduction requirements.

Figure 5. Fuel Switching Decision Process



Source: Adamchak, 2015, Pg 3

[8] See CEE's view, *LNG Supply Outlook 2016 to 2030*, by Andy Flower, August 2016, http://www.beg.utexas.edu/energyecon/thinkcorner/CEE_Advisor_Research_Note-Andy_Flower_LNG_Supply_Outlook-Aug16.pdf.

Pros and Cons of Switching to LNG as a Marine Fuel

A number of considerations can be identified for deployment of LNG in marine fuel applications.

Uneven Application of Current IMO Regulations by Countries

One concern is the lack of standard enforcement of IMO requirements. For example, each country is allowed to implement IMO regulations under its own laws and can enforce them through its own procedures. Therefore, it is possible to have a patchwork of penalties and/or fines depending on the laws of each country (SGMF 2014, pg 9). This can be very complex and confusing for vessels operating in the various ECA's.

A related concern is lack of standardization of local regulations. For example, in Germany, each port can create its own rules for LNG bunkering which creates a tangle of protocols and may cause some vessels to divert to more "friendly" ports. The picture is complicated further by the fact that the market is immature, with a lack of uniformly accepted and applied definitions, and the regulatory environment has not fully emerged (Le Fevre 2016, pg 443).

Inconsistent Taxation

There also is a call for consistent taxation. Policies vary from country to country even though all of them support the use of LNG in transportation.

In the US, H.R. 3431, the Waterway LNG Parity Act, introduced in July 2015 proposes to amend the Internal Revenue Code to modify the excise tax rate for the Inland Waterways Trust Fund to equal twenty nine (29) cents per gallon or the energy equivalent of a gallon of diesel in the case of liquefied natural gas. This bill is still in committee and has not become law as of this writing. Diesel for off road use is not subject to Federal Excise taxes, which can be considerable and a detriment to LNG competitiveness.

Each country has different levels of and formulas for taxes applied to LNG and competing fuels, complicating decision making for ship design and fuel use.

Lack of Sufficient Infrastructure

The lack of sufficient refueling infrastructure is probably the most troublesome constraint to LNG use as a marine fuel. However, the situation is continually improving with investment in bunkering/supply facilities around the world. As new ships begin to operate, the "demand pull" will spur investment and building of these new facilities. In Europe, the ports of Antwerp, Amsterdam, Rotterdam, Stockholm, Zeebrugge, Bergen, Floro, Karmoy, Oslo, Stavanger, and Risavika can supply LNG fueled ships. Ports in Finland and Spain have also supplied LNG fueled ships as well (SGMF 2014, pg 15).

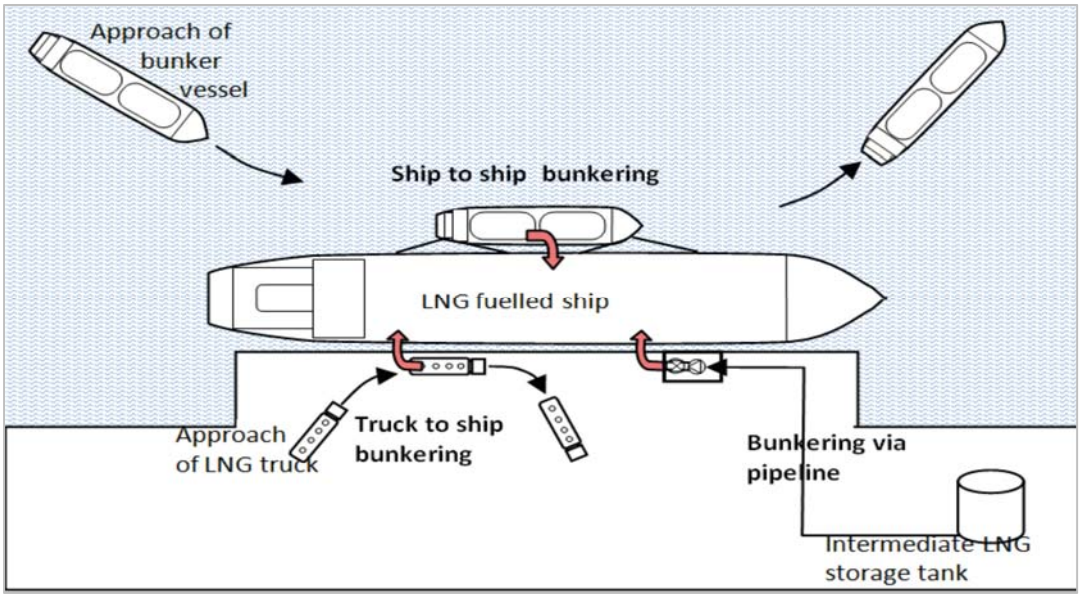
As well, there are several methods for ships to "bunker" or on-load LNG as fuel.

- Ship to ship transfer allows for large volumes of LNG to be loaded and can be done at sea or at dock. Development costs are high. Also, adequate room in port to accommodate vessels can be problematic. USCG indicates that ship to ship is not yet being pursued at U.S. ports. Ship to ship transfer for LNG carriers has been demonstrated and SIGTTO has published guidelines.[9]

[9] See http://www.sigtto.org/publications/publications-and-downloads.

- Truck to ship transfer is the most common refueling option in the U.S. at present. This option is much more flexible and can be accomplished at a lower cost, but quantities are smaller and loading occurs at slower rates.
- Shore to ship transfer is highly desirable for large volumes and established routes. USCG indicates that the turnaround for vessels is much faster. Shore to ship fuel loading requires large financial investments to build facilities. A number of U.S. locations are under development (see below). As a single source of LNG is used, shore to ship transfer also diminishes the risk of contamination.

Figure 6. Illustration of Three LNG Marine Fuel Bunkering Options



Source: IMO pg 48

Current European Union (EU) policy is to have at least one LNG bunkering port in each member state and about 10 percent of European coastal and inland ports included, or about 139 locations (SGMF 2014, pg 15). By 2025, EU member governments must have plans for LNG infrastructure locations. Furthermore, the EU has proposed timelines for the implementation of infrastructure for LNG marine fuel bunkering as part of its LNG strategy and is encouraging adoption of its proposed regulations by member states. Energy suppliers are responding. Engie already has confirmed that it plans to spend 100 million Euros over the next five years on small scale LNG supply projects to replace diesel (LNG Fuels Summit 2016).

Interestingly, European politics also play a role in the quest to develop LNG bunkering infrastructure. As Lithuania tries to move away from its reliance on natural gas supply from Russia's Gazprom, it is turning to imported LNG as a source of supply not just for its own needs but for the entire Baltic region. As part of its expansion plans, a joint venture (JV) between Litgas and Statoil was signed in 2015 to develop small scale LNG bunkering services (Pakalkaite 2016, pg. 31).

In the U.S., Harvey Marine is building a LNG bunkering facility at its vessel facility at Port Fourchon, Louisiana which will consist of two sites having 270,000 gallons of LNG storage capacity. Each facility will be able to transfer 500 gallons of LNG per minute. In addition, these facilities also support on-road

vehicles that use LNG.[10] According to company sources, Eagle LNG, LLC is building a ship to shore bunkering facility at the port of Jacksonville in Florida. According to company sources, the company will source and liquefy its own gas to supply exclusively Crowley owned vessels.

Shell is planning a small scale liquefaction plant in Geismar, Louisiana to supply LNG to vessels operating in the Gulf of Mexico and the Intra-Coastal Waterway (IMO 2016, pg 54).

Outside of the U.S., Korea has LNG bunkering services available at its Incheon port and is considering a second facility at Busan. Singapore, China and Japan are also considering LNG bunker facilities (SGMF 2014, pg 15).

The above examples are not exhaustive but are evidence that the buildout of necessary infrastructure to support LNG bunker operations has begun and will continue.

Cost of LNG

Without emissions control imperatives, LNG must compete in the marine transport fuel markets mainly on economics. Considering the costs to convert and transition from traditional fuels to LNG, this means having sufficient "head room" between traditional fuels and the LNG alternative to accommodate all of the costs associated with converting and switching from traditional bunkers to LNG. As this section indicates, "head room" can be ephemeral in the fuels markets.

According to Le Fevre (2016), for the ECA's of North America and Europe the appropriate price comparison (differential) is between the local natural gas price (such as Henry Hub in the U.S. or the National Balancing Point, NBP, in the UK), and gasoil. In market areas like North America and Western Europe where natural gas is traded and domestic production and/or regional pipeline imports are substantial and establish or influence pricing fundamentals, the economics of importing LNG for domestic gas supply must be achievable at the traded price. The tradeoff between LNG and bunker fuels is determined by comparing the price of gasoil (equivalent to No. 2 fuel oil in the U.S. and German heating oil in Europe) and the traded price of natural gas, all in energy equivalent terms. In Asia, where fuel oil is still prevalent and domestic natural gas production is minimal or nil, the average price of imported LNG (to Japan, for instance) minus the price of shipping oil (Singapore, for example) is the basis for determining pricing.

Fuel costs represent a major component of vessel operating costs, ranging from 30 to as much as 78 percent (depending upon information source). Thus, price differentials among competing marine fuels are of considerable importance. These will change extensively with shifting fuel supply fundamentals (underlying oil and natural gas commodity markets); cyclical economic conditions (and subsequent implications for marine transport activity and bunker fuel demand); seasonality; and as a result of other factors.

When oil prices are elevated, LNG can be more competitive from a pricing perspective if LNG supply itself is relatively abundant (and/or if underlying natural gas – methane – feedstocks are ample). Lower oil prices can inhibit attractiveness of LNG as a replacement fuel. Pricing for bunkers remains linked to crude oil with some hub pricing, some hybrid pricing and some short term fixed pricing. A rule of thumb

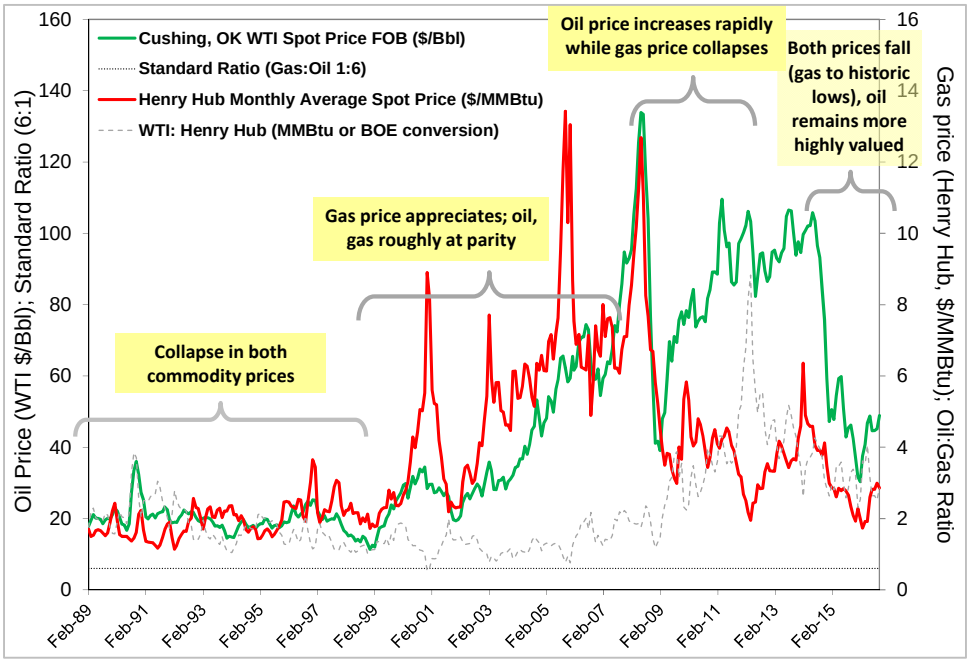
[10] See http://www.harveygulf.com/green.html.

from the German Shipping Association is that the price of LNG needs to be 20 percent less than marine gas oil in order to allow companies to recoup their cost of retrofitting current fleets and/or the cost of new build ships (LNG Fuels Summit, 2016).

Generally speaking, natural gas (methane) often trades at a discount to oil on a raw, barrels to Btu basis (in the U.S, the natural gas index price at Henry Hub and the light, sweet crude oil price, West Texas Intermediate or WTI at Cushing). However, as shown in Figure 7 below, during the history of traded oil and gas prices in the U.S. a number of different cycles in these price relationships have been experienced. Most prominent is the enormous depreciation of methane relative to the light, sweet crude oil marker, reaching a historical high of nearly twelve to one in 2012. The current discount is deeper than it was during the 1990s and early 2000s. The relationships between the U.S. traded commodities reflect several pronounced market disruptions.

- Following the mid-1980s oil price crash, drilling for oil and natural gas slumped during the 1990s. A large surplus in gas production deliverability relative to demand (the gas "bubble") kept the differential low through the 1990s. From late 2000 into 2005, a surge in gas prices, a result of the U.S. drilling deficit, and the global push on oil prices resulted in the differential between traded prices falling to near parity (close to the rough six to one engineering rule commonly used to convert gas to oil equivalent volumes).
- Natural gas supply surged primarily with unconventional resource investment in the U.S. (2002 through 2011) in response to natural gas price escalation ("shocks") as U.S. demand growth, much of it policy push for gas-fired power generation, pressured gas supply and deliverability. It also was during this period that a wave of LNG import capacity expansions and additions took place in North America, nearly quintupling receiving and regasification capacity (from roughly 4 BCFD to 19 BCFD of send out, including offshore, floating projects and facilities added in Canada and Mexico). U.S. imports of LNG peaked in 2007.
- Oil prices topped 1970s highs, in real terms, in a market characterized first by supply capacity constraints (2006-2008) and later by geopolitical events (2010-2014).

Figure 7. Natural Gas, Crude Oil Prices and Differential (WTI:Henry Hub, energy equivalent basis)



Source: CEE analysis using CME/NYMEX, U.S. EIA

As price differentials grew upwards of 9:1 (the 2011 peak in WTI:Henry Hub), the potential to sell methane in the traditional petroleum fuels markets appeared extremely attractive. Conditions seemed ripe, as they had during the late 1980s-early 1990s, to embark on gas conversion schemes and to push natural gas into vehicle markets.

Beginning in 2007-2008, a number of high profile efforts were launched for gas-to-liquids (GTL), which yields a middle distillate (via Fischer-Tropsch). Qatar's Pearl GTL facility is the best known example. A number of GTL proposals were introduced for the U.S. and Canada to take advantage of particularly cheap natural gas prices in North America.

In tandem, the international LNG industry plunged into even more ambitious plans to convert the wave of import receiving capacity additions to export and to build new export capacity, again lured by inexpensive methane feedstock in the Lower 48 states and Western Canada and soaring oil prices overall. As of this writing, U.S. liquefaction and shipping capability is undergoing a massive, orders-of-magnitude enlargement that would far exceed the 19 BCFD of import capacity. LNG export capacity could increase from an existing, roughly 0.25 BCFD in operation to about 3 BCFD with projects under construction and to a whopping 35 BCFD if all projects planned and proposed are executed (unlikely in our view).

Finally, numerous announcements, and investments, committed to LNG fuel strategies for fleet, regional and highway trucking were made. With relatively fewer refueling locations, roughly 5,000 to 55,000 for retail gasoline distribution, LNG conversion for on-highway trucking has long been thought to be the more penetrable natural gas vehicle market strategy. Indications were that LNG might be utilized for rail

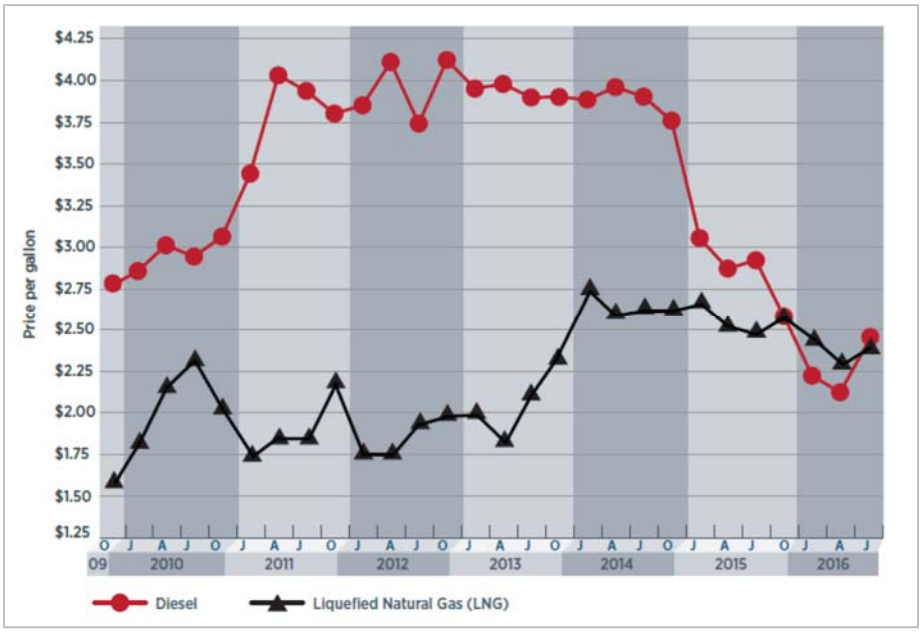
locomotives. And, for this paper, experiments in deploying LNG for marine transport fuels, mainly for ferries, began to surface.

Both raw materials – methane and crude oil – are, at present, in relative abundance, including methane in the form of LNG available to customers via global trade. As a consequence, spot prices and the oil to gas ratio in energy equivalent terms, as shown in previous Figure 7, have dropped to more realistic, long term, equilibrium levels. The decline in traded price differential has undermined most of the more ambitious gas conversion projects, especially those like GTL development that are contingent on lofty crude oil values to support project economics. Both the Pearl expansion and North American GTL projects have been shelved.[11] The lower oil to natural gas differential also is impacting on-land transportation fuel switching. When it comes to access to LNG fuel for marine use, the global surplus of LNG supply, widely expected to persist well into the next decade, may serve to sustain attractiveness of LNG for fuel switching. Current global liquefaction capacity of about 322 million tonnes per annum (MTPA) exceeds the 248 MT that were produced and delivered during 2016. In separate work, we estimate that global liquefaction capacity to support international LNG trade will increase by another 124 MTPA with projects under construction and could grow another 721 MTPA if announced projects are achieved.[12] This condition, along with persistently cheap gas feedstock for domestic liquefaction in the U.S. and Canada, may help to support competitiveness of LNG for marine transport use.

The cost of LNG as a delivered fuel includes liquefaction (the conversion process cost comparable to refining cost for petroleum fuels). Liquefaction is estimated to be 23 percent of LNG cost (roughly 30 percent of LNG cost if taxes are excluded).[13] The U.S. Department of Energy-Alternative Fuels Data Center surveys market conditions in the U.S. to establish competitiveness across various fuels for land vehicles. Domestic LNG price[14], expressed as diesel gallon equivalents (DGE), is compared with low sulfur diesel in Figure 8. Although bunkers are not included in the DOE-AFDC data, petroleum products follow crude oil price trends very closely and prices between low sulfur diesel and heating oil are typically very close (Figure 9 below).

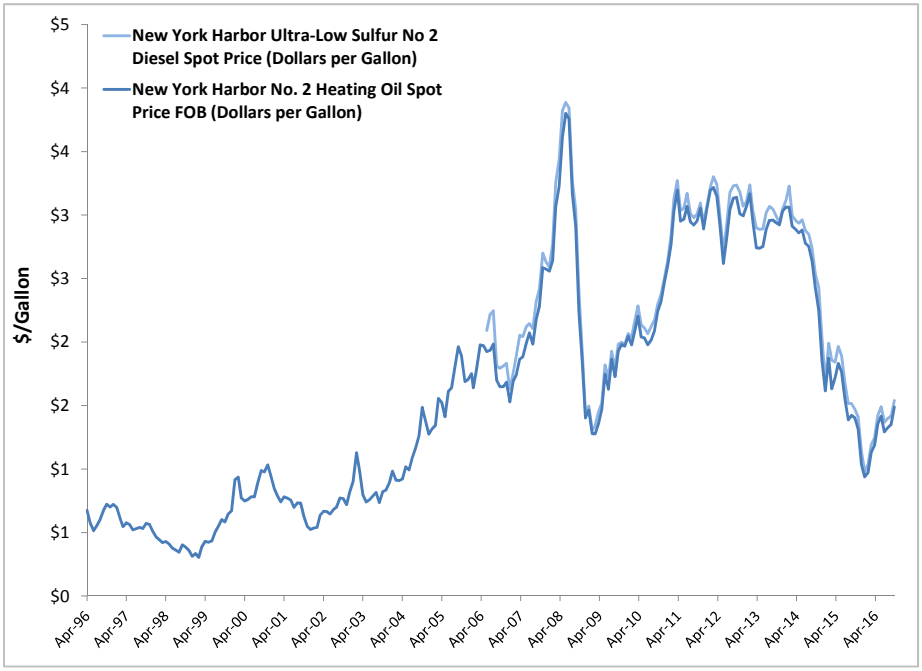
[11] Based on industry reports.
[12] Andy Flower, 2016, LNG Supply Outlook 2016 to 2030, commissioned by CEE. See http://www.beg.utexas.edu/energyecon/GlobalGas-LNG/.
[13] Based on ACT Research, *Natural Gas Quarterly*. http://www.actresearch.net/
[14] The U.S. has several onshore liquefaction sites operated by utilities and pipelines historically for peak shaving, seasonal gas supply. Some of these facilities, along with new onshore, small scale plants can provide LNG for the transportation market. Import/export terminals can serve the domestic fuels market if their LNG can be priced competitively. For the most part, however, liquefaction built at coastal terminals that serve the international LNG trade is considerably more expensive, designed for large volume shipping.

Figure 8. Low Sulfur Diesel and LNG as DGE Price Comparison



Source: DOE-AFDC, http://www.afdc.energy.gov/[15]

Figure 9. Low Sulfur Diesel and Heating Oil Price Trends



Source: EIA, CME/NYMEX.

[15] Also see the DOE-AFDC fuels comparison chart for useful specifications across various fuel options, including diesel and natural gas. http://www.afdc.energy.gov/fuels/fuel_comparison_chart.pdf. The fuels comparison does not include marine bunkers.

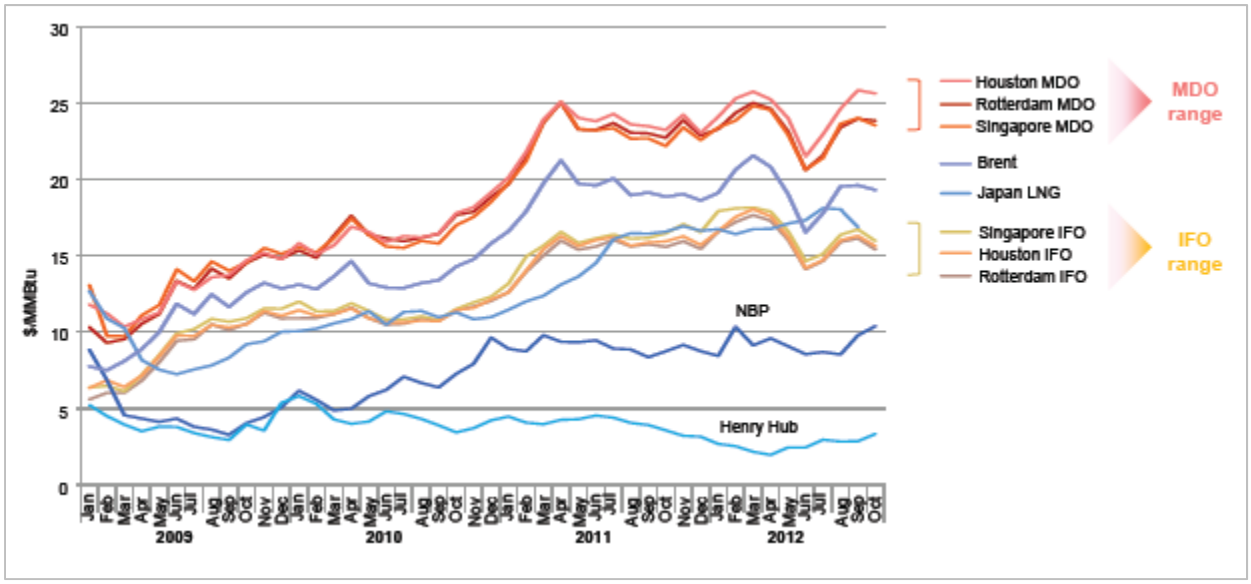
In his study of imported LNG as a marine fuel alternative Adamchak (2015), using data into 2012 (see Figure 10 below table) suggested that there can be a clear price advantage to the use of LNG. A snapshot example is provided in Table 2. With stronger crude oil prices, natural gas had been the cheaper fuel in Europe and the U.S. (Le Fevre 2016, pg 450). Lower crude oil prices, making petroleum fuels less expensive, along with the diminished oil to gas spread means greater pressure exerted on the economics of fuel switching programs.

Table 2. Price Comparisons for Marine Fuels after Conversion (US$/MMBtu)
As of June 2014

Fuel Type	Europe (Rotterdam)	U.S. (Houston)	Asia (Tokyo)
HFO	14-15	14-15	16-17
MDO	20-21	23-24	21-22
LNG	7-8	4-5	15-16

Source: SGMF pg 43

Figure 10. Price Comparisons for Marine Fuels



Source: Adamchak, 2015 pg 3

With regard to acquisition of LNG for marine fuel, it appears that various pricing options are beginning to emerge. These can based on some type of hub pricing as already mentioned plus a premium, or the price formulas can continue the traditional oil linkage with a comparison to fuel oil or marine gas oil. Advantages and disadvantages exist to each of these pricing mechanisms depending upon factors such as seasonality (Le Fevre 2016, pg 451). Natural gas generally is more in demand during winter in the Northern Hemisphere, with defined price peaks associated with winter heating use. As demand for natural gas for power generation increases, summer peaks have emerged. Volatility due to unrelated weather events can also cause natural gas prices to temporarily spike. Petroleum fuels can be exposed to seasonal and other sources of variability as well (for instance, seasonal changes in demand for transportation

fuels and refinery turnarounds). Price risk management by customers will inevitably revolve around both broader fundamentals as well as offsetting seasonal patterns.

Overall, with the current LNG market being oversupplied, LNG prices have continued to be under pressure falling within the $4-8 per MMBtu range in Table 2. As noted previously, our work, along with that of other industry analysts, indicates that the LNG market will continue to be oversupplied well beyond 2020 and possibly through 2030. This suggests that LNG prices will be competitive with other low sulphur fuel options but a host of market dynamics will affect future price trajectories.

Adequate Supply of Natural Gas

The preceding discussion on LNG costs and underlying commodity prices reflects two important conditions – an abundance of natural gas resource in North America and an abundance of global LNG supply. Natural gas in the North American ECA is widely available although sites for the storage of LNG are less so. Most of the sites in the U.S. are owned by public utilities or public companies vested in LNG export strategies with LNG storage contractually committed to offtakers. Likewise, LNG storage in other ECA's would have to be developed to support marine fuels disposition. This can be facilitated through smaller, satellite LNG storage akin to utility and pipeline use. However, LNG distribution and storage to support marine fuels markets must be incorporated into the economic equation.

SUMMARY

LNG as a fuel for marine application is being demonstrated via a number of applications and seems primed for growth. A most likely growth pathway in the short term is for vessels that operate mainly within ECA areas or short-distance shipping and transport use, such as ferries, tugs, offshore vessels and coastwise or regionally bound vessels. More growth will no doubt occur as the deadline for implementing the new global sulphur limits of 0.5% approach. LNG can be appealing from a cost standpoint especially if oil prices rise into the future. Betting on commodity price directions and spreads is a difficult undertaking, at best.

More attractive is LNG as a relatively low cost option with substantial environment benefits and ample supply. Compared to diesel fuel, LNG will reduce NO_x emissions by about 90 percent with negligible SO_x and PM emissions. CO_2 emissions with LNG combustion are approximately 20 percent lower than petroleum fuels, although the IMO anticipates that further studies on the GHG emissions will be needed (IMO 2016, pg 65). A new push in Europe to reduce diesel use in dense urban corridors in order to address public health hazards from PM may add an accelerating effect to IMO rules. Many ports and harbors, especially those that serve public transportation needs, are proximal to urban air sheds that tend to have challenges with air quality management. Given all of these drivers, as long as LNG can compete with its low sulphur counterparts on price, it is estimated that LNG could penetrate the bunker market by 20-27 percent by the year 2025 (BCG 2015).

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