LNG Opportunities for Marine and Rail

in the Great Lakes, Gulf of Mexico, and Inland Waterways

Prepared for

anga
America's
Natural Gas
Alliance

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With multiple offices in California and New York, GNA is North America's leading full-service professional consulting firm specializing in market development of alternative fuel technologies for the on-road and rapidly developing off-road high horsepower sector where natural gas is increasingly being used in locomotive, commercial marine, mine haul, and oil and gas exploration and production applications. GNA provides comprehensive market research and reporting, strategic planning, financial modeling and expert technical assistance to its clients. For more than 20 years, GNA has been working on large over-the-road truck projects with fleets such as Waste Management, UPS, Frito Lay, Ryder, City of Los Angeles, and many others, and has helped to spearhead the development of several natural gas corridor projects including the ICTC and Texas Triangle projects. In the last few years, GNA has become increasingly engaged in multiple off-road high horsepower projects working to transition to natural gas, including work with the Class I railroads, several large commercial marine projects, oil and gas drilling and pressure pumping applications, and large mine haul trucks. In addition to its consulting services, GNA produces two of the nation's leading conferences on these topics—Alternative Clean Transportation (ACT) Expo, North America's largest alternative fuels and clean vehicle technologies show, and the Natural Gas for High Horsepower (HHP) Summit. Please see www.gladstein.org for more information.

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The Great Lakes Maritime Research Institute (GLMRI) was established in 2004 to pursue research efforts in marine transportation, logistics, economics, engineering, environmental planning, and port management. GLMRI represents a consortium of the University of Wisconsin-Superior Transportation and Logistics Research Center and the University of Minnesota Duluth Swenson College of Science and Engineering and Labovitz School of Business and Economics.

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List of Acronyms and Terms

Acronym	Definition
AAR	American Association of Railroads
ABS	American Bureau of Shipping
AIS	Automatic Identification System
ANGA	America's Natural Gas Alliance
BCF	Billion cubic feet
BTU	British thermal unit
CMAQ	Congestion Mitigation and Air Quality Program
CNG	Compressed natural gas
COTP	Captain of the Port
DF	Dual fuel
DGE	Diesel gallon equivalent
DNV GL	Det Norske Veritas
DOE	United States Department of Energy
DOT	United States Department of Transportation
DPF	Diesel particulate filter
DWT	Deadweight tonnage
E&P	Exploration and Production
ECA	Emission control area
EIA	United States Energy Information Administration
EMD	Electro Motive Diesel (a Caterpillar company)
EPA	United States Environmental Protection Agency
ERTAC	Eastern Regional Technical Advisory Committee
FERC	Federal Energy Regulatory Commission
FRA	Federal Railroad Administration
GDP	Gross domestic product
GE	General Electric
GLMRI	Great Lakes Maritime Research Institute
GNA	Gladstein, Neandross & Associates
HHP	High horsepower
Hp	Horsepower
IHB	Indiana Harbor Belt Railroad Company
IMO	International Maritime Organization
kW	Kilowatt
LNG	Liquefied natural gas
LOOP	Louisiana Offshore Oil Port
MARAD	US Department of Transportation's Maritime Administration
MIT	Massachusetts Institute of Technology
MMBTU	Million British thermal units
MMSI	Maritime Mobile Service Identity
MRGO	Mississippi River Gulf Outlet

MT HFOe	Metric tons of heavy fuel oil equivalent
NG	Natural gas
NOX	Oxides of nitrogen
NPV	Net present value
PM	Particulate matter
SO_x	Sulfur oxide
SCR	Selective catalytic reduction
SIMOPS	Simultaneous operations
STQ	Société des traversiers du Québec
TCF	Trillion cubic feet
TEN-T	Trans-European Transport Network Programme
TEU	Twenty-foot equivalent unit
TOTE	Totem Ocean Trailer Express
USACE	United States Army Corps of Engineers
USCG	United States Coast Guard

Vessel Types (Marine)	**Vessel Type Definition**
Articulated Tug-Barge (AT/B)	Vessels that can be "connected" to a bunker barge by a notch at the rear of the barge. For higher volume applications, ATB's may have a vessel-like design more suited to open ocean sailing over longer distances, as well as in more typical in-port barge operations.
Cargo (General)	Vessels that transport wide variety of cargo, and some Cargo (General) vessels may be capable of carrying passengers.
Cargo (Ro-Ro)	Vessels that transport Roll-On / Roll-Off (Ro-Ro) equipment, such as heavy-duty trucks or construction equipment
Carrier (Dry Bulk)	Vessels that transport bulk dry goods such as grain, cement, coal, and steel. Those operating on the Great Lakes are known as "Lakers" and run from 500' to 1,000' in length. Lakers also have self-unloading capabilities for cargoes of iron ore, coal, limestone, cement, salt, sand, and gravel.
Containership	Vessels that transport containerized goods.

Vessel Types (Marine)	Vessel Type Definition
Offshore Support Vessel (OSV)	Vessels used in the exploration and production of oilfields and covers a wide variety of vessel types.
Passenger (Cruise)	Vessels that transport passengers and used for pleasure voyages, typically to a series of destinations and return to a home port.
Passenger (Other)	Vessels that transport passengers for either transportation or pleasure voyages. Vessels include some ferries, harbor cruises, or charters.
Passenger (Ro-Ro)	Vessels that transport passengers and Ro-Ro cargo. These are typically larger car or truck ferries.
Pushboat	Flat-bottomed vessels that push or pull other vessels and unpowered barges. Pushboats operating north of St. Louis, MO ("above the locks") on the Mississippi River or its tributaries are typically smaller than conventional pushboats because they have to navigate thinner, shallower locks.
Tanker	Vessels that transport bulk liquid products including crude oil, refined chemical products, liquefied gases, and a number of other liquids.
Tugboat	Vessels that push or pull other vessels and unpowered barges. Tugboats typically help large vessels maneuver in port or operate in open water to push or two barges. Tugboats operating north of St. Louis, MO ("above the locks") on the Mississippi River or its tributaries are typically smaller than conventional tugboats because they have to navigate thinner, shallower locks.
Vehicle Carrier	Vessels that transport vehicles, typically light duty vehicles such as passenger cars and trucks

Locomotive Types (Rail)	**Locomotive Type Definition**
Line-Haul Locomotive	Locomotives that travel long distances (e.g. between cities)
Short-line locomotive	Locomotives that fall into two categories: local railroads that do not travel at least 350 miles and/or earn at least $40 million in annual revenue or locomotives that transfer cars between railroads or a group of facilities.
Switcher locomotive	Locomotives that operate primarily in a single railyards, splitting and joining rail cars. These are not intended to move trains over long distances but rather for assembling trains that are ready for a line-haul locomotive to transport.

Railroad Companies	
BNSF	Burlington Northern Santa Fe
CN	Canadian National Railway
CP	Canadian Pacific Railway
CSX	CSX Transportation
KCS	Kansas City Southern
NS	Norfolk Southern
UP	Union Pacific

Executive Summary

Overview

The availability and abundance of clean, low cost, North American shale gas is prompting a comprehensive reevaluation of transportation fuel operations across the nation. In the on-highway marketplace, companies like UPS, Frito Lay, Ryder, Waste Management and many others are making large-scale investments in natural gas vehicles across their nationwide fleet. Off-highway high horsepower industries are rapidly catching up, with marine vessel operations and locomotives offering two of the highest potential near-term growth opportunities.

High horsepower natural gas users can significantly reduce fuel costs, improve environmental performance, increase the use of domestically produced fuels, and comply with air quality regulations. This report examines the intersections between marine and rail operations to identify liquefied natural gas (LNG) growth opportunities in three geographic regions: the Great Lakes, inland waterways along the Mississippi River and its major tributaries, and the Gulf of Mexico. This study finds that the total potential demand across all three regions could reach 1 billion gallons annually by 2029, which equates to approximately seven times current LNG fuel use for transportation in the United States (U.S.). This large-scale transition to natural gas would allow users to collectively realize $575 million in annual fuel cost savings.[1]

Although LNG offers attractive cost and environmental benefits for end users, challenges with the availability of emerging technologies, regulatory uncertainty, end user familiarity, and fuel supply and distribution questions have contributed to slow initial adoption in the North American marketplace. Any large-scale operational shift to a new fuel will present a range of interconnected challenges, and so this report aims to identify opportunities for fueling collaboration and strategies to overcome any local implementation barriers related to policy, technical or other market factors. This effort will thereby help reduce market entry barriers for infrastructure developers and end users to facilitate more extensive LNG adoption.

Total potential LNG demand across all three regions could reach one billion gallons annually by 2029, which… would allow users to collectively realize $575 million in annual fuel cost savings

In the U.S, companies such as Crowley Maritime, Harvey Gulf International Marine, Totem Oceans Trailer Express (TOTE), and others are investing in LNG projects. However, the domestic LNG-powered commercial marine fleet is still a fraction of the emerging international LNG vessel growth. Currently, there are 46 LNG-fueled commercial marine vessels (non-LNG carriers) worldwide with another 41 under construction. The vast majority of the current LNG fleet operates in the Baltic region of Europe and demonstrates the technological feasibility of LNG-powered ships for operators worldwide. According to Lloyd's Register and IHS CERA, the long-term growth rate for marine LNG adoption by 2030

[1] Conservatively assumes that end users save $1.00 per gallon of diesel fuel displaced with LNG.

ranges from 11 percent to 22 percent of the global vessel fleet. Experts project that worldwide LNG demand from vessel operators will grow from approximately 56.6 million gallons(4.3 billion cubic feet (BCF))in 2012 to between 2.5 billion gallons (192.5 BCF) and 4.4 billion gallons (336.9 BCF) in 2020[2], to over 41 billion gallons (3.1 trillion cubic feet (TCF)) in 2030.[34] This level of demand represents roughly 2.6 percent of worldwide natural gas consumption in 2012.[5] In fact, one forecasting firm projects there may be as many as 10,000 LNG vessels operating worldwide by 2020.[6]

The North American rail industry is dominated by the seven Class I railroads: Burlington Northern Santa Fe (BNSF), Canadian National (CN) and Canadian Pacific (CP), CSX Transportation (CSX), Kansas City Southern (KCS), Norfolk Southern (NS) and Union Pacific (UP).[7] North American railroads used approximately 4.1 billion gallons of diesel in 2013, spending approximately $11.6 billion on fuel.[8] Given the immense fuel volumes used, railroad companies dedicate significant resources to efficiency and fuel cost reduction strategies. If the railroads converted even one third of their operations to dual fuel natural gas operations, they would be able to save approximately $2.6 million each day.[9] Given these numbers, it's no surprise that the majority of the large railroads are actively working with leading technology providers to take advantage of the cost-saving potential of natural gas. The two largest locomotive manufacturers – Electro Motive Diesel (EMD, a Caterpillar company) and General Electric (GE) – are developing natural gas products that could help shift the nation's rail system to natural gas, much as the railroads shifted from steam propulsion to diesel in the mid-1900s.

Report Origin and Objective

This report was commissioned by America's Natural Gas Alliance (ANGA) to examine the LNG growth potential in three regions with high concentrations of high horsepower operations. ANGA represents North America's leading independent natural gas exploration and production companies, and works to promote increased demand for this clean, domestic, low-cost fuel across the transportation marketplace. Using natural gas in the transportation sector helps diversify America's fuel mix and enhance the nation's energy and economic security. The goal of this study is to identify the locations, vessels, and rail operations with the best near-term project success factors, and the actions that might be taken to facilitate their conversions to LNG.

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[2] Jonathan Abrams, DNV, Tallinn, Oct. 31, 2012.

[3] "The Next Bunker Fuel", Olivier Abadie , Michael Stoppard , David Ledesma , and Wolfgang Moehler Cambridge Energy Research Associates (CERA), September 7, 2011.

[4] 1 billion gallons of LNG is approximately equivalent to 76 BCF of natural gas.

[5] US EIA, International Energy Statistics, 2014.

[6] MEC Intelligence, "LNG Propulsion: 2012 and Beyond", October 2011.

[7] "Class I" is a U.S. designation for line-haul freight railroads with operating revenue of $433.2 million or more (as of 2011). Two Canadian railroads, CN and Canadian Pacific, have enough revenue that they would be U.S. Class I railroads if they were U.S. companies. Both companies also own railroad systems in the United States that, by themselves, qualify to be Class I railroads. For the shorthand purposes of this report, CN and Canadian Pacific are referred to and analyzed as "Class I railroads"

[8] Surface Transportation Board, Schedule 750 filings from Class I railroads for 2013.

[9] Conservatively assumes that end users save $1.00 per gallon of diesel fuel displaced with LNG. Based on a 70 percent diesel displacement rate for locomotives.

Summary of Key Findings

There are a number of near-term opportunities for LNG project development within the three study regions. Offshore service vessels, cargo and container ships, and Great Lakes bulk carriers (commonly referred to as "lakers") offer near-term marine prospects in the 2018 timeframe, with pushboats and tugs following in the 2020s. Commercial freight line-haul locomotive adoption will likely begin to accelerate in the 2018 to 2019 timeframe.

The rollout and timelines of actual adoptions will be dependent upon clear and defined regulatory guidance for the rail and marine sectors, end user specifics (such as fuel substitution rates, useful life, capital reserves, and technological feasibility of operational routes), broad market factors (fuel availability, technology availability, fuel cost spread), and specific geographies. In order to assess potential LNG growth over a fifteen year timeframe, Gladstein, Neandross & Associates (GNA) analyzed regional inventories and spoke with local industry stakeholders, end users, fuel providers, and technology manufacturers to project an upper bound estimate of realistic fuel use by 2029, based on end user types and regional market factors.

All of the applications considered in this report can offer positive net present values (NPV) over the life of the equipment. Based on fuel cost savings, simple payback for LNG in key applications is approximately 3.4 years for lakers, 7 years for long haul freight locomotives, 7.8 years for short sea shipping, and up to 15 years for offshore service vessels[10]. These timeframes all provide favorable economic payback periods for high horsepower equipment that generally has a minimum asset life of 20 years and can extend up to 40.

Within fifteen years, GNA projects that 363 U.S.-flagged vessels could generate 380 million gallons of LNG demand annually, or 1.04 million gallons of LNG each day. Much of the growth is projected to be from chemical / product tankers, containerships, offshore support vessels, and pushboats. The Gulf of Mexico is projected to be the key growth region, as it will be home to nearly 75 percent of the study areas' projected LNG-fueled vessels. Due to European investments in LNG infrastructure and environmental market drivers, the Gulf of Mexico could also be an LNG bunkering destination for approximately 35 ocean going vessels which operate in an international trade. These vessels could generate another 343 million gallons (29 BCF) of annual LNG demand by 2029.

The Gulf of Mexico is projected to be… home to nearly 75 percent of the study areas' projected LNG-fueled vessels

[10] Due to lack of cost data on the conversion of tugboats and pushboats to LNG, simply payback was not calculated for this application. Based on $1.00 per DGE price spread between diesel/fuel oil and LNG. Higher price spreads accelerate payback periods.

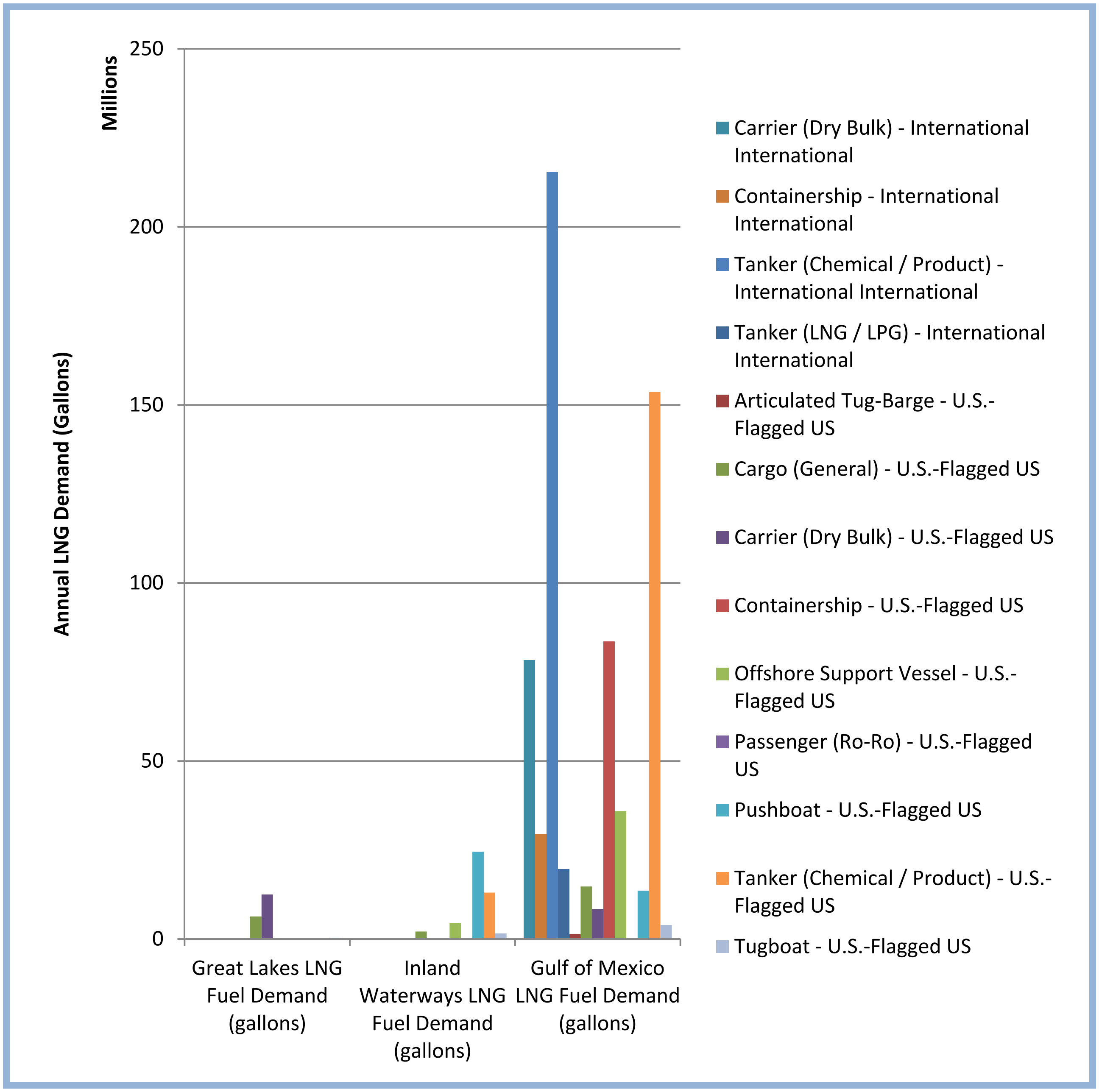

Figure 1: Potential annual demand for LNG by 2029 from domestic and international vessels operating in the U.S.

Rail use could add another 273 million gallons (20.7 BCF) of annual LNG demand within the states comprising the study region, which alone could nearly double current demand for LNG in transportation in the U.S.[11] Although operations at many large classification yards could support liquefaction investments without marine or other intermodal user support, this study looked for opportunities where rail and marine fuel use might support shared, cost-effective LNG liquefaction that could promote more rapid market transitions within a region. Rail deliveries of LNG from classification yards to marine locations could provide initial LNG project development support throughout the study region, pending development of appropriate regulations. However, some specific opportunities for co-location emerged in Duluth, Minnesota and along the inland waterways.

Significant new sources of LNG fuel supply will need to be developed throughout the study regions to support this anticipated demand growth, since current liquefaction is not capable of supporting such increases. An estimated $1.5 billion to $2.5 billion in capital investments will be required to build out infrastructure capable of producing, storing and dispensing the estimated 2.7 million gallons per day of LNG projected within this report by 2029, though some of this may be supplied by existing infrastructure.[12]

Rail use could add another 273 million gallons of annual LNG demand… which could nearly double current demand for LNG in transportation in the U.S

LNG adoption will not be consistent throughout each of the Great Lakes, inland waterways and Gulf Coast regions. Instead, project development will begin in key locations within each region where end user equipment populations and operations support near-term project feasibility and infrastructure investment. GNA's analysis identified the most likely opportunities for LNG commercial marine vessel deployments within the study regions based upon operations, industry knowledge and fuel use. The total fuel use of these marine vessels was layered over rail switcher fuel use[13] in order to then identify regions where the greatest amount of marine and rail based fuel demand intersect. The resulting green regions on the map in Figure 2 helped identify intermodal activity hubs for high-potential LNG marine and rail users.

[11] Daily LNG sales for transportation in the US assumed to be 400,000 gallons per day based on confidential conversations with LNG producers.

[12] Assumes liquefaction infrastructure costs of $250-$500 per LNG gallon and storage tank capacities of five times daily output. Tank costs based on $10/gallon of capacity. Additional costs reflect permitting, installation, and contingency; totaling 40% of overall costs.

[13] Although switcher locomotives do not represent a near- or medium-term LNG opportunity, switcher fuel use is a key indicator of freight activity in rail yards. Given that there is no publicly available information about Class I line-haul rail yard fueling locations, switcher fuel use identifies yards with significant freight sorting activity and thus helps to identify potential areas of overlap with marine-based fuel demand and thus the best potential opportunities for future aggregate LNG fuel demand.

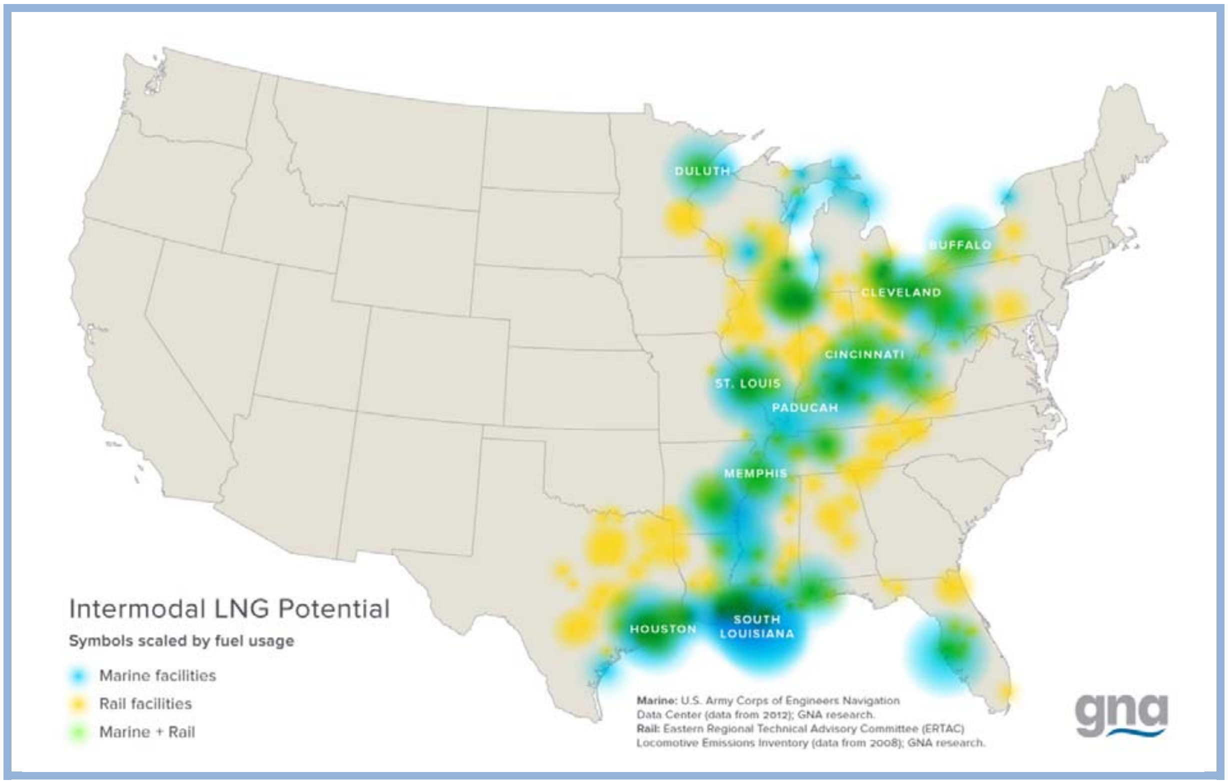

Figure 2: Marine and Switcher Activity Heat Map

For this study, GNA used existing public data sets, spoke with end users and industry stakeholders, and further researched operational challenges, available LNG infrastructure, and other local factors to identify the best location-based targets for LNG growth opportunities. The results indicated opportunities where a single large end user or multiple medium-sized end users could provide enough baseload fuel demand to support the development of a new LNG liquefaction production facility. As a goal of this report was to identify the regions with the greatest opportunity to develop such new LNG production infrastructure, the focus was therefore on those applications that could help to achieve the goal in the most efficient manner.

While on-road LNG truck deployments have grown in recent years, particularly in fleet operations such as UPS, the fuel demand created by the off-road high horsepower sector is much greater than is typically seen in the on-road truck market. For example, an average on-road truck may consume between 10,000 to 25,000 gallons of LNG per year, depending on its duty-cycle and specific operations; which is equivalent to approximately 40 to 100 gallons of LNG fuel use per day (assuming 260 days/year operation). On the other hand, a single LNG-powered locomotive may consume close to 300,000 gallons of LNG per year, or more than 1,100 gallons of LNG fuel use per day (based upon the same 260 days/year of operations). Further, small commercial marine vessels using LNG as a propulsion fuel can generate daily fuel demands in the tens of thousands of gallons per day.

Given the tremendous LNG fuel demand that can be created in the off-road high horsepower sector, the conversion of a smaller number of units in these applications can effectively justify the investment in the development of a new LNG production plant. Whereas it may require between 1,000 and 3,000 on-road

LNG trucks to fully subscribe the output from an 80,000 gallon per day LNG production plant, such a volume can be consumed by less than 100 LNG powered locomotives, or a few dozen (or less) commercial marine vessels. Accordingly, it is these large off-road applications that will drive near-term demand and investment in LNG production plants. While LNG on-road trucking will likely also grow within the target study region of this report, these on-road LNG trucks also can easily be served by the production infrastructure required to support the off-road high horsepower market.

This report therefore assumes that LNG production opportunities and demand growth will be driven primarily by the off-road markets rather than the on-road truck market, and that any resulting infrastructure development will also be able to accommodate regional growth in the on-highway sector, as well as other sectors with small per-unit LNG fuel consumption requirements. Subsequently, the summaries below highlight the major opportunities for marine and rail natural gas use within each study region, with supporting information and background described in the chapters that follow.

Great Lakes Opportunities

The Great Lakes is a major center for marine and rail commerce, encompassing 15 large international marine ports and 50 regional marine ports across the U.S. and Canadian shorelines. Chicago is home to the world's largest rail junction, and regional rail supports major commodity shipments of mined and manufactured goods. However, rail fueling typically takes place outside of Chicago due to regional congestion. The marine industry is dominated by lakers with highly individualized trade routes, so liquefaction planning and coordination is not as straightforward as other regions. The following marine fueling and rail operations hubs offer key LNG targets in the Great Lakes:

- Duluth-Superior, MN: Lakers, line-haul rail along fixed routes, mining connectivity, proposed LNG fueling
- South Lake Michigan: existing marine fueling center, proposed LNG fueling
- Detroit, MI: existing marine fueling center
- Williamsville and Buffalo, NY: some lakers and rail, proposed LNG fueling across the border in Canada
- Cleveland, OH: significant line-haul rail fuel use state-wide, some laker use

Gulf of Mexico Opportunities

The oil and gas economy in the Gulf Coast supports a robust population of marine vessels supporting offshore oil and natural gas production rigs, international energy and chemical tankers, and international trade. Texas also sells more Class I rail fuel than any other state in the nation, with large rail fueling facilities in the Dallas region and with rail line connections to the Houston Ship Channel region. LNG will be available for domestic marine fuel use once the Cheniere export facility comes online in Louisiana, through agreements with LNG America, precluding the need to build baseload for new liquefaction investments, at least for initial projects. Several other export facilities and LNG production facilities are also proposed for the region. The following marine and switcher rail hubs offer key LNG targets in the Gulf Coast:

- Port Fourchon and Galliano, LA: Offshore service vessels
- Ports of Houston and Galveston, TX: offshore service vessels, pushboats, tugboats, international vessels, U.S.-flag vessels with home ports outside the Gulf (container, cargo, carriers, and tankers above 10,000 DWT), connectivity to Class I rail fuel hubs
- Ports of Baton Rouge, New Orleans, Plaquemines, and South Louisiana: pushboats, tugboats, international vessels, U.S.-flag vessels with home ports outside the Gulf (container, cargo, carriers, and tankers above 10,000 DWT), connectivity to inland waterways fuel corridors, proposed LNG fueling in Port of Baton Rouge with rail line connectivity

Inland Waterway Opportunities

The inland waterways encompass the Mississippi River and its major tributaries, and serve as a major interstate trade route, particularly for states on the Gulf Coast, Midwest, and Ohio Valley. The Mississippi River System is home to thousands of pushboats, tugs, and other vessels that help transport, deliver, or export cargo, liquid, and bulk materials. These riverway freight routes also connect and directly compete with rail freight transport routes, particularly in locations like Memphis, TN and St. Louis, MO. Municipal utility peak shavers with LNG trailer loading facilities could support pilot project development in Memphis, TN and Paducah, KY. The proposed Tenaska Bayou LNG facility could supply LNG in and around the Port of Baton Rouge, or LNG America could supply LNG via barge from Sabine Pass, LA to support lower Mississippi LNG fueling. Long term, liquefaction capacity may need to be developed to serve the pushboat market that is currently refueling in Memphis, St. Louis, and Paducah. Because of the pushboat operational routes throughout the rivers, LNG capacity may need to be developed at multiple sites to support initial project growth. The following marine and rail hubs offer key LNG targets along the inland waterways:

- Corridor between New Orleans and Baton Rouge, LA: pushboats, tugboats, create baseload with offshore support vessels and bulk cargo vessels.
- Memphis, TN: pushboats, tugboats, rail operations
- Saint Louis, MO: pushboats, tugboats, rail operations
- Paducah, KY: pushboats, tugboats

Although this report emphasizes the overlap opportunities for LNG project development, it should be noted that some marine operators (such as TOTE) might be able to provide enough fuel in their own operations to support baseload liquefaction development that could jump start project development for an entire region. Similarly, a single line-haul rail operator generally uses enough fuel at its major classification yards to justify liquefaction development. Class I fueling takes place at large rail yards with maintenance and transfer facilities serving locomotives that traverse multiple states and broad regions. A single LNG plant in or near these yards could support significant numbers of locomotives, although the rail companies would still need to work through routing and logistics questions to support operations. There is no publicly available information identifying these specific fueling locations, but EIA identifies rail fuel sales at the state level. Several states in the study region, including Texas, Minnesota, and Ohio support large volumes of Class I rail use.

Study Conclusions and Recommendations

Prospective fuel cost savings are driving current investment in LNG vessels, vessel conversions, and rail demonstration projects. Although fuel cost savings and emissions benefits are certainly spurring initial project interest, operators seek reliable fueling and clear regulatory guidance to propel large-scale adoption. These high horsepower projects are technologically feasible, but true project development and commercial growth will require coordinated effort on the part of end users, fuel suppliers, technology providers, and regulatory agencies to turn these burgeoning opportunities into sustainable, growing LNG markets.

The marine LNG marketplace offers some clear emerging opportunities in the Gulf Coast, given its international connections and the near-term supply from LNG export facilities. While the Great Lakes and inland waterways also offer demand growth potential, these markets will likely require more multi-user coordination and multiple fueling sites to support the regions. In general, marine cargo routes are highly individualized and may change based on freight contracts or chartering arrangements with varying terms (usually only a few years). This variability creates fueling challenges when LNG infrastructure isn't fully developed in all ports where a vessel may sail, or when a new charter agreement is executed in a route where there is no fuel availability. Many marine users are also taking a "wait and see" approach, hoping for other owners to make the initial investment risk so they can assess the results, despite the clear cost saving potential.

The marine LNG marketplace offers some clear emerging opportunities in the Gulf Coast, particularly given its international connections and the near-term supply from LNG export facilities. While the Great Lakes and inland waterways also offer demand growth potential, these markets will likely require more multi-user coordination and investment in multiple fueling sites

There are a few high-volume fuel vessels operating on set routes that can baseload an entire region, such as TOTE's Jacksonville and Tacoma projects. However, most marine infrastructure projects will need to aggregate multiple users to succeed. Working with line-haul railroads could provide new opportunities for baseload development. Aggregation and cross-sector fueling arrangements provide a pathway for LNG growth, but project development will have to overcome reliance on "the way things are done," to coordinate new fueling protocols and partnerships.

Given the single-user fuel demand and cost drivers, railroads can offer an important baseload development opportunity for all users across the three study regions. It should be noted that fueling for Class I locomotives does not always take place in cargo centers or port regions, where there would be overlap with marine and switcher fuel use. Instead, Class I fueling often occurs at large rail classification yards with maintenance and transfer facilities serving locomotives across multiple states. LNG produced at these large rail yards could be transported economically via rail car to support fueling for marine and other markets, pending development of the appropriate federal standards. Given that early marine projects from TOTE and Harvey Gulf are relying on LNG deliveries via tanker truck to support their initial operations, rail deliveries of LNG could provide a more cost-effective transport system than smaller truck loads. Once marine markets are more fully developed they could then justify the development of a more local marine-focused LNG plant.

Although this study forecasts 2018 for initial commercial growth in the rail and marine sectors, this development is not a given and requires demand aggregation and continued coordinating efforts. This study identifies some of the most optimal locations and end users for LNG, but these end users and industry stakeholders will ultimately shape the resulting marketplace. In order to support growth plans, the study authors put forth several core recommendations that will help build the market and support a more effective infrastructure development and user deployment plan:

- Focus on regions with existing or near-term LNG infrastructure to support initial pilot and demonstration projects, such as the Gulf Coast and inland waterways.
- Focus on ships and rail operations with simpler operations, i.e. those that operate fixed routes or in captive regions, such as offshore supply vessels and unit trains.
- Build local LNG markets in regions that can also support international vessel fleet fueling.
- Develop cross sector fueling partnerships, building on line-haul rail and key marine centers.
- Support the ongoing development of federal standards for natural gas tender cars to allow the use of natural gas in the locomotive sector.
- Continue work with the United States Coast Guard to accelerate the finalization and adoption of a national set of guidelines and best practices for LNG bunkering.
- Educate appropriate permitting, port, other agency officials, and key decision makers about relevant codes, standards, regulations and permitting requirements related to LNG liquefaction and fueling in specific ports and regions.
- Work with local Coast Guard, port officials, and industry stakeholders to support “SIMOPS”, or simultaneous fueling and cargo operations with LNG.
- Convene stakeholder groups to determine how and where to facilitate project development that can support regional high horsepower markets
- Convene stakeholder groups to identify opportunities and challenges associated with LNG fueling of International vessels, helping make the United States an international hub of highly cost-competitive domestic gas marine fueling.

These recommendations will help to overcome some of the initial barriers related to LNG project development efforts, thereby easing the way for near-term growth opportunities in the LNG transportation market. The Unites States has a unique opportunity to become the world’s leading bunkering hub for LNG. The country has access to the least expensive natural gas in the world and policymakers should be working to aggressively promote growth opportunities for clean, low-cost natural gas markets for both domestic and international high horsepower markets. LNG demand growth will support economic growth in the marine and rail sectors, reduce emissions in local communities, and create capital investment and job opportunities throughout the upstream and downstream energy sectors.

Background and Introduction

Natural Gas Supply

The momentum behind natural gas project development in high horsepower industries is being driven by fundamental shifts in long-term supply of low cost natural gas. Rapid technology advancements in unconventional drilling have unlocked vast resources of natural gas that were previously too expensive to extract. Since the beginning of 2005, natural gas production in the United States has increased 30 percent, and Energy Information Administration's (EIA) most recent 2014 figures[14] show a 56 percent projected increase in total natural gas production from 2012 to 2040. This increased production will supply enough domestic natural gas to power our nation for generations, with the EIA, MIT, and the Potential Gas Committee all projecting ample long-term domestic supplies of natural gas. The most recent projections show a range of technically recoverable gas using today's technology from 2,203 to 3,545 trillion cubic feet.

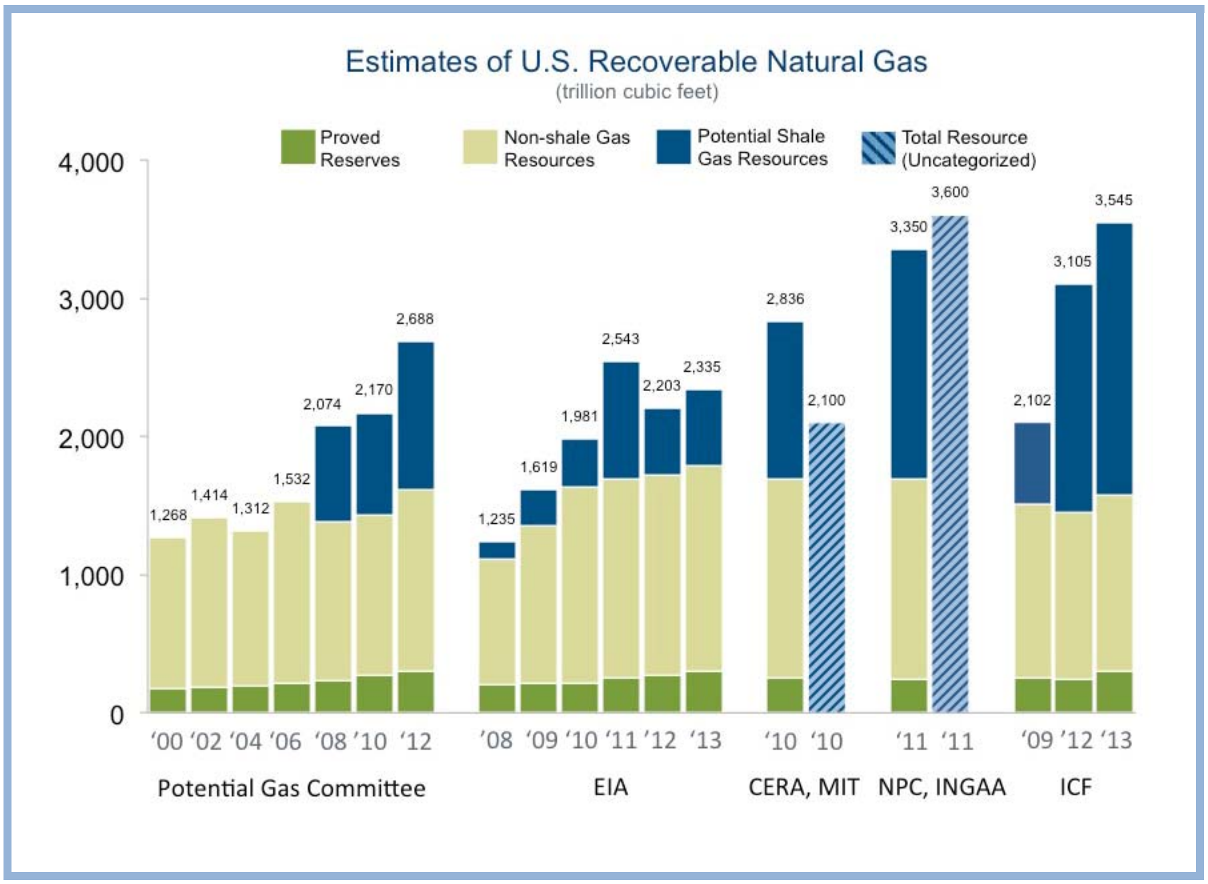

Figure 3: Estimates of U.S. Recoverable Natural Gas

[14] EIA, "Annual Energy Outlook 2014." May, 2014.

This increased, stable, long-term supply of low-cost natural gas has led to a fundamental change in the energy marketplace, as energy consumers such as utility, industrial, and transportation users are increasingly turning towards natural gas powered technologies. As indicated in Figure 4 below, the U.S has enough natural gas to remain affordable despite this increase in demand, helping companies project stable long-term cost saving benefits when investing in a switch to natural gas. Using today's technology, ICF International estimates more than 1,500 TCF of dry gas is recoverable at $5 per MMBTU or less in the United States and Canada.[15] These price projections are comparable to analysis from EIA, Wood Mackenzie, and CERA (Figure 5).

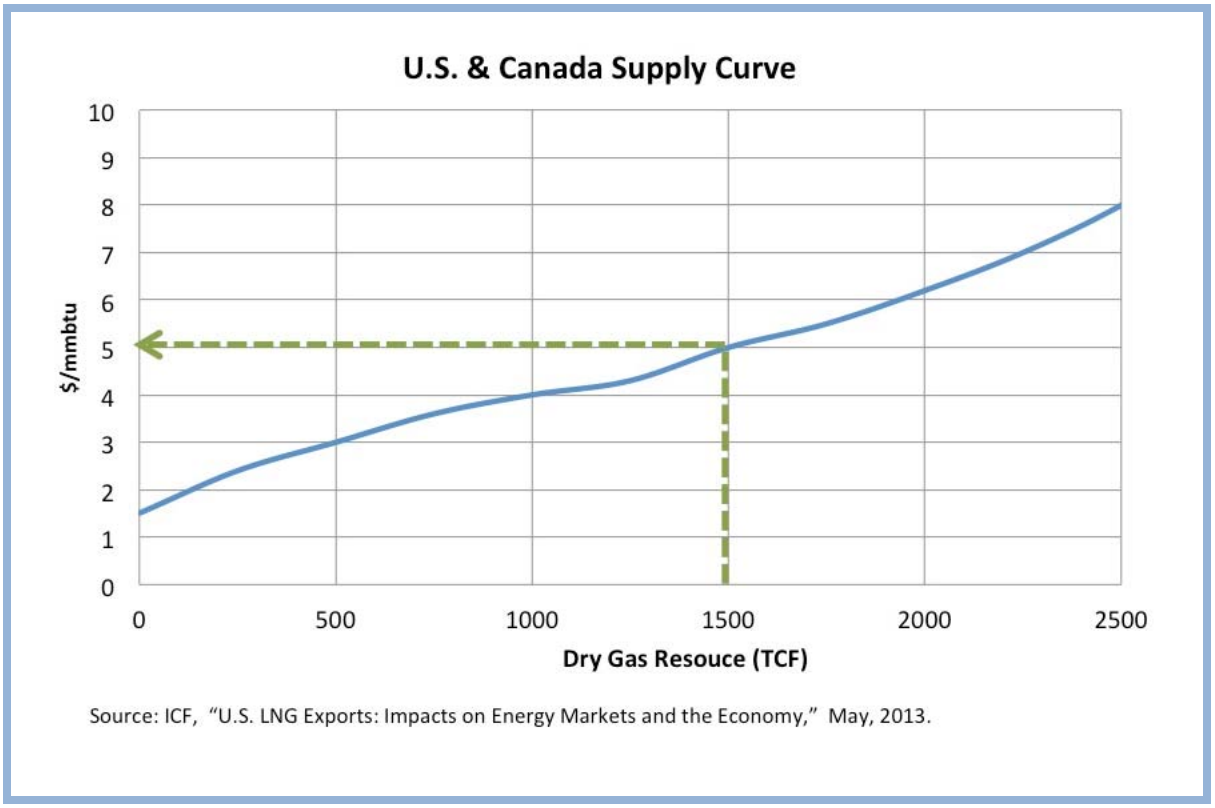

Figure 4: Dry Gas Supply Curves for the U.S. and Canada

[15] ICF International, "U.S. LNG Exports: Impacts on Energy Markets and the Economy." May, 2013. pg. 44-45.

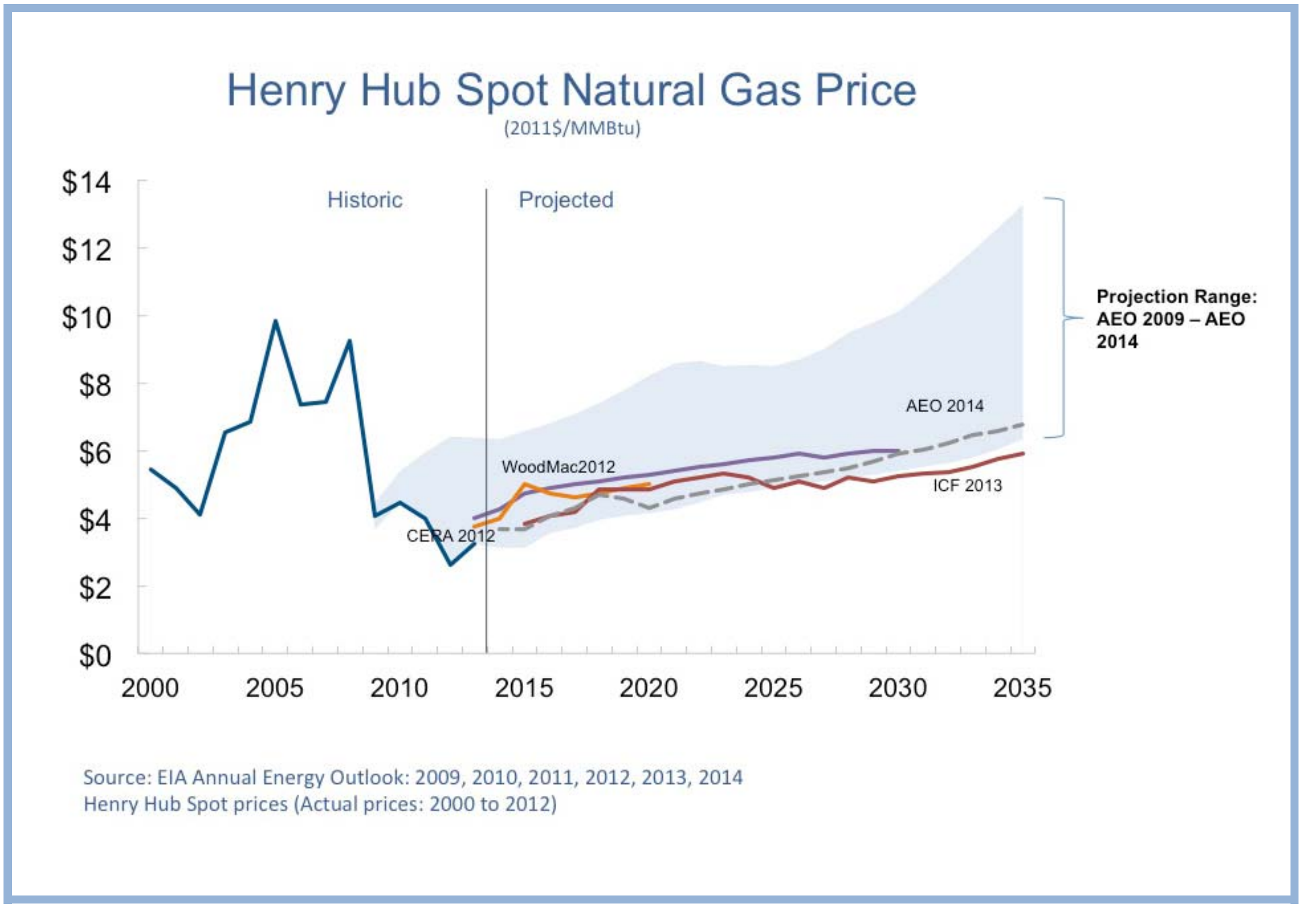

Figure 5: Henry Hub Natural Gas Price (2011$/MMBTU)

Marine Sector

Overview

Currently, there are 8,980 vessels registered under the U.S. flag (Figure 6). These vessels vary greatly in size, power, and speed based on function and operating location. The largest sector of vessels is comprised of pushboats and tugboats. The greatest density of pushboats and tugboats travel along the Mississippi River and Gulf Intracoastal Waterway and are responsible for the transport of unpowered barges carrying commodities between domestic ports. Still others assist in docking operations in ports along the Atlantic, Gulf, and Pacific Coasts. The next largest sector comprises a mix of self-powered cargo and passenger vessels. This sector is dominated by offshore supply vessels in the Gulf of Mexico (1,085 vessels), which deliver cargo and personnel to drilling platforms.

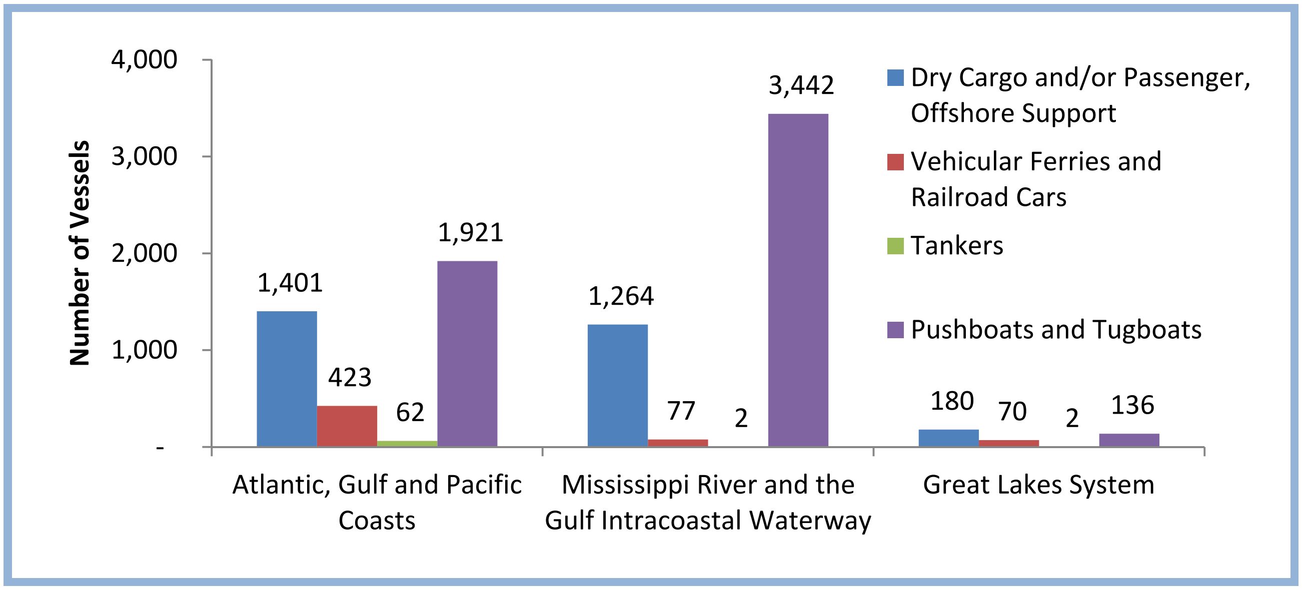

Figure 6: Summary of U.S.-flagged vessels by type and region[16]

It is important to note that, although a vessel is registered with U.S. authorities, it does not mean that a registered vessel is in active operation. Many registered vessels are in reserve duty, in dry dock for repairs, or laid up ("mothballed"). Nonetheless, it is important to understand the make-up of the dominant vessel classes, so that we can better determine which may be better candidates for conversion to LNG.

Furthermore, while the number of U.S.-flagged vessels bodes well for the LNG market, not all will be suited to LNG operations, based on low fuel use or other operational factors. In order to identify the best possible project development opportunities, this analysis focuses primarily on offshore support vessels, pushboats, and tugboats. These vessels use the largest amounts of fuel and are also "captive" fleets, meaning that their operations are entirely within the North American Emission Control Areas (ECA). Furthermore, the analysis also identifies other key vessel types such as dry bulk carriers in the Great Lakes (commonly referred to as "lakers"), and the freight fleet in the Gulf of Mexico, consisting of containerships, bulk carriers, and tankers.

Table 1 describes the major vessel types comprising the national inventory and identifies the high opportunity vessels included in this report analysis. The analysis excludes vessel types with limited potential for switching to LNG operations. Generally, these low opportunity vessels have: low fuel use operations; limited operations in the target regions (they might be foreign flagged vessels with significant operations outside the region); limited available data on actual fuel use; or, they have publicly stated they are uninterested in LNG. For instance, of the 358 vessels categorized by the U.S. Army Corps of Engineers as "Passenger (Cruise)" vessels, only 55 are registered within the Great Lakes and Gulf of

[16] "National Summaries, Volume 1 (2012)." Waterborne Transportation Lines of the United States, US Army Corps of Engineers Navigation Data Center, 2012. http://www.navigationdatacenter.us/veslchar/pdf/wtlusvl1_12.pdf, accessed July 29, 2014.

Mexico (none registered on inland waterways). Furthermore, these vessels typically operate as sightseeing vessels or dinner cruises and thus generate low levels of fuel demand and the larger cruise operators are currently pursuing scrubber compliance strategies for ECA.

Finally, it is important to note that this analysis largely covers U.S.-flagged vessels and thus does not factor in the demand generated by international vessels calling on ports throughout the Great Lakes and inland waterways, though some information is available for projections in the Gulf of Mexico. These international vessels in the Gulf of Mexico are typically much larger than U.S.-flagged vessels and use high quantities of fuel in their operation. However, although they may contribute to potential future LNG demand, ocean going vessel operations are variable and ships bunker in locations worldwide, only stopping in the U.S. once every several weeks. This makes local demand from any single LNG vessel difficult to predict and challenging to use in initial project development goals.

Table 1: Description of vessel types

Vessel Type	Description
Articulated Tug-Barge	Vessels that can be "connected" to a bunker barge by a notch at the rear of the barge. For higher volume applications, ATB's may have a vessel-like design more suited to open ocean sailing over longer distances, as well as in more typical in-port barge operations.
Cargo (General)	Vessels that transport wide variety of cargo, and some Cargo (General) vessels may be capable of carrying passengers.
Cargo (Ro-Ro)	Vessels that transport Roll-On / Roll-Off (Ro-Ro) equipment, such as heavy-duty trucks or construction equipment
Carrier (Dry Bulk)	Vessels that transport bulk dry goods such as grain, cement, coal, and steel. Those operating on the Great Lakes are known as "Lakers" and run from 500' to 1,000' in length. Lakers also have self-unloading capabilities for cargoes of iron ore, coal, limestone, cement, salt, sand, and gravel.
Containership	Vessels that transport containerized goods.
Offshore Support Vessel	Vessels used in the exploration and production of oilfields and covers a wide variety of vessel types.
Passenger (Cruise)	Vessels that transport passengers and used for pleasure voyages, typically to a series of destinations and return to a home port.
Passenger (Other)	Vessels that transport passengers for either transportation or pleasure voyages. Vessels include some ferries, harbor cruises, or charters.
Passenger (Ro-Ro)	Vessels that transport passengers and Ro-Ro cargo. These are typically larger car or truck ferries.
Pushboat	Flat-bottomed vessels that push or pull other vessels and unpowered barges. Pushboats operating north of St. Louis, MO ("above the locks") on the Mississippi River or its tributaries are typically smaller than conventional pushboats because they have to navigate thinner, shallower locks.
Tanker	Vessels that transport bulk liquid products including crude oil, refined chemical products, liquefied gases, and a number of other liquids.
Tugboat	Vessels that push or pull other vessels and unpowered barges. Tugboats typically help large vessels maneuver in port or operate in open water to push or two barges. Tugboats operating north of St. Louis, MO ("above the locks") on the Mississippi River or its tributaries are typically smaller than conventional tugboats because they have to navigate thinner, shallower locks.
Vehicle Carrier	Vessels that transport vehicles, typically light duty vehicles such as passenger cars and trucks

LNG for North American Marine Vessels

Marine operators are increasingly turning to LNG to power their vessels. As marine fuel prices increase and international emission regulations are phased in, LNG offers ship owners a clean and economical fuel to meet their new environmental and operational requirements. The primary regulatory factor driving adoption of LNG in the marine sector is the International Maritime Organization's (IMO) imposition of Emission Control Areas (ECAs), which are coastal regions where marine vessels must reduce emissions of sulfur oxides.[17] For North America, beginning on August 1, 2012, any vessel entering within 200 miles of the coast must reduce its sulfur dioxide emissions to no more than that equivalent to the use of propulsion fuel with no more that 0.5 percent sulfur.[18] Beginning on January 1, 2015, the sulfur limit falls to 1,000 ppm, or 0.1 percent sulfur content. In addition, on January 1, 2016, all new vessels must achieve an 80 percent reduction in their NOx emissions below Tier 1 levels. The three primary ECA compliance options are currently: a) use lower-sulfur distillate fuels (which are highly refined products similar to diesel fuel or heating oil), 2) install exhaust emissions after-treatment systems, or 3) switch to LNG.

Vessels that choose to continue using conventional bunker fuels must use costly cleanup technologies when traveling in ECA zones. Selecting this cleanup technology compliance approach requires: the capital investment of a scrubber retrofit for SOx (an approximate $2.5 million investment), the addition of selective catalytic reduction (SCR) technology to remove NOx (an approximate $1 million expenditure), and adds annual operations and maintenance costs which that are projected to be hundreds of thousands of dollars per year. These clean up technologies also introduce challenges related to disposing of the hazardous waste they collect from the ship's exhaust. Another compliance option is to fuel ships with low-sulfur distillate fuel, which will permanently double annual fueling costs. Given the narrow profit margins and intense competition in the shipping industry, adding permanently higher operating costs via scrubbers or low-sulfur distillate is not an attractive option, particularly when LNG holds the promise of lower costs in addition to dramatic emission reductions. LNG is a clean, fuel-based ECA compliance strategy that requires no additional clean up technologies (there is effectively no sulfur in natural gas) and costs approximately half as much as conventional residual bunker fuels, on an energy content basis.

LNG is a clean, fuel-based ECA compliance strategy that requires no additional clean up technologies and costs approximately half as much as conventional residual bunker fuels, on an energy content basis

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[17] "Sulphur oxides (SOx) – Regulation 14." International Maritime Organization. http://www.imo.org/OurWork/Environment/PollutionPrevention/AirPollution/Pages/Sulphur-oxides-(SOx)-percentE2 percent80 percent93-Regulation-14.aspx, accessed July 29, 2014.

[18] "Designation of North American Emission Control Area to Reduce Emissions from Ships." U.S. Environmental Protection Agency, March 2010. http://www.epa.gov/otaq/regs/nonroad/marine/ci/420f10015.pdf, accessed July 29, 2014.

Figure 7: Harvey Energy, Harvey Gulf's LNG-fueled platform supply vessel[19]

LNG vessels can cut expenses and reduce emissions for long-term operations, despite the required incremental investment required for natural gas engine and fuel system conversions, and North American operators are starting to take note. For instance, Washington State Ferries, which is currently considering the conversion of six of their Issaquah-class ferries to LNG, projects that the total costs of switching these vessels will be $75.2 million, including design, shipyard, construction engineering, and owner furnished equipment. Over the 30-year life of the retrofitted vessels, however, Washington State Ferries projects that the vessels will produce $256 million in total benefits, including $149 million in reduced fuel costs.[20] Noting these economics, several other car and passenger ferries are actively pursuing LNG project opportunities, including BC Ferries, the Staten Island Ferry, Quebec Ferry and the car ferry that crosses Lake Michigan. Some have, in fact, already placed purchase orders for LNG powered vessels.

The first North American LNG-fueled vessel, the Harvey Energy, is currently undergoing final sea trials and will be formally launched in the fourth quarter 2014 by Harvey Gulf International Marine, an oilfield services company based in New Orleans, Louisiana. This vessel is the first of six LNG-powered platform supply vessels that the company has ordered, with delivery expected from 2014 through 2016. Several other North American commercial vessel owners have confirmed orders (Table 2) for LNG conversions or newbuilds, including BC Ferris (Canada), Crowley Maritime (U.S.), Sea LNG America (U.S.), Star Lines

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[19] "Harvey Energy". Harvey Gulf International Marine. http://harveygulf.com/assets/pdf/harvey_gulf_spec_sheets/Harvey_percent20Energy_percent20Rev-1.pdf, accessed July 29, 2014.

[20] Endicott Fay, "Washington State Ferries LNG Retrofit", High Horsepower Applications for Natural Gas Summit, Houston, Texas, September 27, 2012.

(U.S.), Société des traversiers du Québec (Canada), and Totem Ocean Trailer Express (U.S.). An additional 9 companies have proposed LNG conversions and newbuilds or are building LNG-ready vessels. These companies are American Petroleum Tankers, BC Ferries, Conrad Shipyard, Crowley Maritime, Horizon Lines, Interlake Steamship, Matson, Minyan Marine, SEACOR, Staten Island Ferry, U.S. Army Corps of Engineers, and Washington State Ferries.

Table 2: Confirmed orders for North American LNG-fueled newbuilds and conversions

Area of Operations	Operator	Number of Vessels	Conversion or Newbuild	Fuel	Expected Delivery Dates
Atlantic (Florida to Puerto Rico)	Crowley Maritime (U.S.)	2 container / Ro-Ro vessels	Newbuild	Dual Fuel	2017
Gulf of Mexico	Harvey Gulf (U.S.)	6 offshore support vessels	Newbuild	Dual Fuel	2014 - 2016
Gulf of Mexico	LNG America (U.S.)	1 bunker barge	Newbuild	TBD	2015
Pacific Northwest	TOTE (U.S.)	2 Ro-Ro cargo vessels	Conversion	Dual Fuel	2015-2016
Atlantic (Florida to Puerto Rico)	Sea Star Line (U.S.)	2 container ships	Newbuild	Dual Fuel	2015 - 2016
Pacific Northwest	BC Ferries (Canada)	3 ferries	Newbuild	Dual Fuel	2016 - 2017
St. Lawrence River	Société des traversiers du Québec (Canada)	3 ferries	Newbuild	Dual Fuel	2014 - 2015

Each of the vessels listed above will use dual-fuel engines are capable of 95-99 percent diesel substitution rates (the rate at which diesel is replaced with natural gas in the engine). While dual-fuel engines allow for increased operational flexibility and a sense of comfort in that they can fall back to 100% fuel oil operation, in the long term operator have indicated that they will seek to maximize the amount of diesel substitution to achieve maximum LNG use and associated cost savings. For the purposes of this report, GNA estimated the LNG fuel substitution rates of these vessels to be 95 percent. For emerging vessel markets such as articulated tug-barges, pushboats, tugboats, and small passenger vessels, GNA estimated a more conservative substitution rate of 55 percent, based on experiences with Caterpillar's dynamic gas blending technology in other high horsepower market segments like the exploration and production engine markets. Actual marine end user substitution rates may higher than these conservative estimates.

LNG End User Highlight: Totem Ocean Trailer Express and Sea Star Line

Artist's rendition of TOTE vessel with LNG conversion

With the implementation of the North American Emission Control Area, Totem Ocean Trailer Express, Inc. (TOTE) saw the writing on the wall: many in the current fleet of vessels wouldn't comply with the increasingly stringent regulations. Furthermore, the company was handling two unique yet related concerns, both of which would feed into TOTE's decisions to move towards LNG as a marine fuel.
Sea Star Line, which is 90 percent owned by TOTE, operates a shipping line between Jacksonville, Florida and San Juan, Puerto Rico. The company was faced with an aging fleet, as its two vessels were nearly 40 years old and thus pushing the maximum operating age for Jones Act vessels in open water. Moreover, these vessels spend nearly half of their operations in waters covered by the North American ECA, greatly impacting fuel and technology choices. The trade route also required additional tonnage as trade increased between Florida and Puerto Rico.

TOTE was addressing concerns of its own on the company's shipping lane between Anchorage, Alaska and Tacoma, Washington. Totem recognized that its customers were concerned about environmental impacts of shipping operations in Alaska. This route also operated completely within the North American ECA. Thus, the technical issues faced by Sea Star Line and the environmental concerns about shipping operations in Alaska presented TOTE with an opportunity: LNG as a marine fuel.
In the course of analyzing its options for ECA compliance, TOTE realized almost immediately that fuel was the driving force behind all of the company's challenges. Low sulfur diesel fuel is expensive, difficult to acquire in the quantities TOTE uses, and subject to availability concerns. Moreover, the vessels currently operating would need to be retrofitted with expensive exhaust scrubber technologies in order to comply with the ECA requirements. TOTE thereby realized that LNG would solve many of the challenges it currently faced, whether they be environmental, technical, operational, and/or economic.

Sea Star Line's Puerto Rico trade will use two new 3,100 TEU LNG powered containerships that will use MAN ME-GI duel fuel engines.1 Running on a fixed schedule, the vessels sail weekly from Jacksonville and will receive fuel from a yet-to-be-built liquefaction plant at Davis Point in the Port of Jacksonville. This facility will provide LNG bunkering services via tug and barge to Sea Star Line as well as other LNG vessel operators in the area. WesPac and Pivotal will provide the fuel and construct the liquefaction facility.

TOTE's Alaska route will benefit from the complete engine replacements of its two existing Orca class vessels (M.V. Midnight Sun and M.V. North Star).1 Wartsila will provide the dual fuel main engines, generators and integrated LNG storage and fuel gas handling systems. Puget Sound Energy, in partnership with the Port of Tacoma, will construct a liquefaction facility directly adjacent to TOTE's terminal. That facility is expected to become operational by 2018 and will be able to directly fuel Totem's vessels via cryogenic pipeline and fueling arm.

These vessel operations and regional challenges related to LNG adoption vary widely. Operators like Sea Star Lines, TOTE, and Crowley operate large cargo ships between two fixed points. Given these known, consistent, high-fuel use routes, the operators could use enough LNG fuel to justify development of new liquefaction for their own ships alone. In contrast, offshore supply vessels like those ordered by Harvey Gulf are chartered by offshore production companies that largely operate the vessels and pay for their own fuel. In addition to creating challenges related to the payback benefits associated with LNG fuel, these vessels don't use enough fuel on their own to justify new fueling infrastructure. The vessel markets and geographies are incredibly varied, and each region and vessel operator faces their own unique cost-benefit analysis related to LNG.

Many marine operators have expressed interest in exploring the use of LNG in their operations. In addition to the active projects now underway, many others have undergone engineering and feasibility analyses. However, there is still significant uncertainty in the marketplace involving many aspects of the LNG use in marine applications, including questions about fueling operations, LNG supply, regulations governing bunkering and onboard storage, and long-term cost savings. Ongoing concerns about these and other issues have prevented several companies from going "all-in" with LNG.

One set of significant issues are related to the regulation of vessels fueling and operating on LNG. For the most part, the industry is waiting for the U.S. Coast Guard (USCG) to develop definitive guidance on LNG bunkering. Preliminary guidance that was issued in early 2014 provided some information on the USCG's thinking; however, the guidance still provides tremendous latitude to each Captain of the Port (COTP) to apply their discretion to LNG fueling operations in their jurisdiction. While most would agree that the USCG has been tremendously helpful in working with end-users and industry stakeholders to review individual project proposals in order to ultimately approve the project and LNG bunkering operations, the industry would prefer a clearly defined "checklist approach." The opportunity for individual discretionary decision-making at the local level provides continued uncertainty among end-users contemplating a move to LNG as the potential operational and thus cost impacts of such discretionary decision-making are unknown until a project is more fully developed. As is the case in any industry, those making major investment decisions desire as much certainty as possible around the investment in order to then gauge the anticipated payback period and risk associated with that payback scenario.

Related to the issue of COTP discretion is the issue of simultaneous operations ("SIMOPS"). SIMOPS refers to the simultaneous fueling and loading/unloading of the vessel. For most cargo operations, which rely on very and precise turnaround of the vessel when in port, it is imperative that they are able to load and unload cargo at the same time as they are fueling the vessel. If these activities cannot occur simultaneously, it can increase the costs of operations. Such a result is an additional challenge for most ship owners considering LNG. As of this writing, it is not clear where the USCG will rule on this crucial issue on a federal level. Currently, each COTP can establish rules within their local jurisdiction.

In addition, uncertainty about international regulations is leading to some ship owners to hesitate regarding their plans to convert to LNG. Whereas the ECA requirements go in to full effect in the North American and Northern European ECAs on January 1, 2015, there are other IMO air quality regulations with which the industry is concerned. The most relevant is the current requirement that all marine fuel contain no more than 0.5 percent sulfur worldwide by 2020. This regulation has led many ship owners to take a serious look at LNG. There is a push, however, by some countries to delay the implementation of this requirement to 2025. The possibility of a delay has led several companies looking at LNG to slow or pause their efforts. Given their lack of familiarity with LNG as a marine fuel and the infancy of the industry, they are distrustful that the current price spread will continue. They fear that if they commit to LNG now, and the IMO delays the implementation of the 0.5 percent requirement, their competitors who have not switched to LNG may have an economic advantage. Again, uncertainty about the implementation of regulations is giving some operators pause.

These regulatory issues impact questions about the ultimate delivered cost savings related to LNG. Without a clear sense of the requirements for LNG operations or the market drivers surrounding ECA adoption, it is hard for some marine operators to project what the "all-in" LNG project costs will be or how they compare to other fuels or ECA compliance choices. Without a clear sense of whether SIMOPS will be permitted, operators can't project efficiency losses associated with the fueling logistics for LNG.

LNG for European Marine Vessels

Although the local market for marine LNG is beginning to emerge, the U.S. has lagged behind other countries in the development of LNG projects in the marine sector, particularly countries in Northern Europe. LNG-fueled vessels have operated in Europe since 2001. The first vessels were ferries and offshore service vessels in Northern Europe within a relative limited geographical area, with projects expanding since then to include tugs, barges, bulk and cargo vessels and even national coast guard patrol vessels. An important driver is the Baltic and North Sea Emission Control Area (ECA) which sets strict limits on the sulfur and particulate emissions from international shipping, similar to the North American ECA.

European vessels owners and operators are using LNG in various sectors. The Norwegian cargo ship Høydal, powered by Rolls-Royce Bergen engines, became the first sea-going vessel (non-tanker) to use LNG as its sole fuel for propulsion.[21] The oil and gas industry is making use of natural gas vessels, especially with offshore and platform supply vessels. In late 2013, Norway's Bukser & Berging took delivery of the world's first dedicated-LNG escort tug – the Borgøy will operate for Norway's Statoil ASA and Gassco.[22] The Finnish ferry, Viking Grace, uses LNG as it transits between Turku and Stockholm. On March 20, 2013, Shell Shipping & Maritime launched in the Netherlands the world's first powered barge fueled exclusively by LNG. The tank barge, Greenstream (Figure 8), is used to deliver petroleum products to customers along Europe's inland waterways, namely the Rhine and its tributaries in the Netherlands, Belgium, Germany, and Switzerland.

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[21] "MS Høydal – World's First LNG Powered Ship," Marine Insight, November 29, 2012 (http://www.marineinsight.com/marine/marine-news/headline/ms-hoydal-worlds-first-lng-powered-ship/)

[22] Piellish, R. "LNGEurope Bunkers the Bokn in Rome." HHPInsight, May 21, 2014. http://hhpinsight.com/marine/2014/05/lngeurope-bunkers-the-bokn-in-rome/, accessed July 29, 2014.

Figure 8: Shell's Greenstream, an LNG-fueled Barge Operating in Europe

In 2006, the Trans-European Transport Network (TEN-T) Programme announced the initiation of the LNG Masterplan for Rhine-Main-Danube. The purpose of the Masterplan is to create a platform for governmental and industrial authorities to cooperate in the creation of a harmonized European regulatory framework for LNG as fuel and cargo in inland navigation. In addition, the LNG Masterplan is targeting inland navigation as an initial market for LNG as transport fuel. It hopes to enable the cost-effective transportation and distribution of LNG from seaports to end customers in major industrial areas along the inland waterways. This would facilitate a wide-scale development of LNG as fuel and as energy source. Critical to the success of the LNG Masterplan is that the inland ports on the Rhine-Main-Danube Rivers become key distribution centers for LNG. Inland terminals will then function as satellites to inland Europe and will enable LNG to reach the public transportation and heavy-duty transport sectors, as well as the energy industry. This satellite fueling center approach provides an intriguing model for U.S. LNG fueling plans.

The last few years have seen a high interest in the development of LNG bunkering facilities and infrastructure in several of the major European ports that also fuel the international fleet. The vessels in these LNG bunkering ports have trade routes that visit the US and the Gulf of Mexico, creating opportunities for cross-Atlantic LNG fueling. In Europe, the development of the LNG bunkering infrastructure is often a partnership between the industry, local and national government. The government often provides incentives and financial support, financed by taxes or fees.

The most important developments in LNG bunkering infrastructure are taking place at the Ports of Rotterdam (Netherlands), Hamburg (Germany), Antwerp (Belgium), and Zeebrugge (Belgium). In July 2013, the Port of Rotterdam, one of the busiest in the world, initiated LNG bunkering for inland barges and will expand to ship-to-ship bunkering for ocean going vessels by 2015. LNG bunkering at the Port of Hamburg is expected to start in 2014 with the supply of LNG to a passenger ferry. The Port of Antwerp will expand on its current truck-to-ship bunkering by deploying ship-to-ship bunkering and terminal-to-ship bunkering by 2016. Finally, in September 2013, an international cooperation was established among the ports of Zeebrugge, Antwerp and Singapore for coordination on the development of LNG bunkering infrastructure.

Another important development regarding LNG bunkering in Europe is the assessment of LNG bunkering risk, and the establishment of procedures and guidelines related to the bunkering process and safety management systems. Specifically, SIMOPS for LNG bunkering and cargo operations have been accepted in some ports, and this development is likely to continue in Europe, thereby enabling the further adoption of LNG as a ship fuel. Although European ports have different governance structures than many U.S. ports and thus may not serve as an appropriate apples-to-apples comparison in terms of a model for North America to follow, this continent-wide infrastructure planning and coordinated development of bunkering guidelines have helped create a more cohesive market that supports LNG growth.

The LNG marine market in Europe thus provides the U.S. with a model for growth, via their coordinated infrastructure planning and LNG guidelines, and with an immediate fuel sales growth opportunity for LNG ships originating in Europe. Given the higher costs for LNG in Europe, companies that operate trans-oceanic routes from Europe have been examining scrubbers and distillate fuel for ECA compliance when they are within the 200-mile ECA zones. However, the availability of low-cost U.S. LNG could change their investment decisions. These vessels require such high quantities of fuel that they could use LNG bunkering facilities at each end of their route, in Europe and the U.S, enabling them to access low-cost North American fuel when in a U.S. port. Thus, the development of LNG bunkering capabilities in key U.S. ports is a high-growth potential investment.

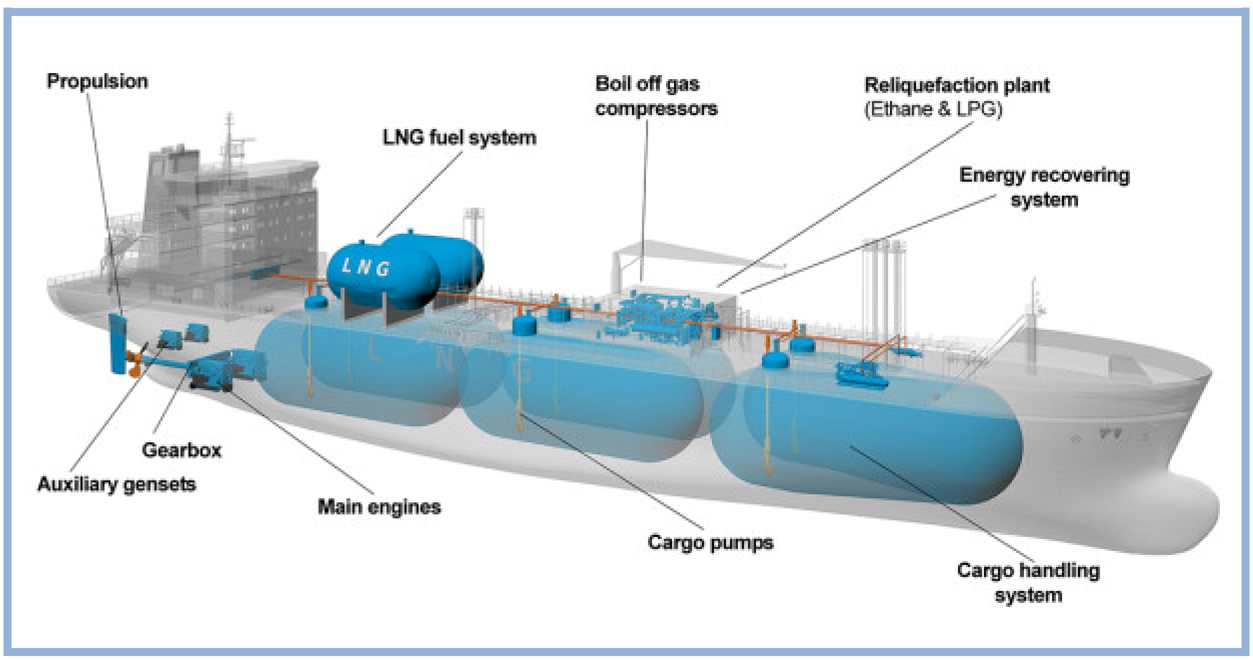

Figure 9: Artist's rendering of dual-fuel Evergas carrier

Denmark's Evergas is an example of an international LNG vessel that is planning to call in Houston and fuel locally to take advantage of low-cost U.S. ethane (as a product) and low-cost U.S natural gas (as its fuel source), highlighting some of the international natural gas project development opportunities presented by the Gulf Coast's energy and petrochemical economies. Evergas owns and operates a fleet of highly advanced semi-refrigerated LNG-multigas carriers, liquid ethylene carriers and pressurized carriers. The company is currently building six LNG fuelled multi-gas carriers in China. The vessels are contracted to carry liquefied ethane from the U.S. to Europe. Evergas will call in Philadelphia in 2015 and Houston in 2016, depending on LNG fueling access. The company has been explicit that low-cost U.S. LNG and the long-term project economics were a major factor in its decision to build LNG-powered ships. The company has also confirmed that it will not bunker LNG in Europe, instead, it will have sufficient on-board LNG fuel storage to make the round trip and thus ensure it is able to refuel with the more cost-effective U.S.-sourced LNG.

This Everagas project should send a strong signal to U.S. policy makers, port authorities and other public officials about the tremendous potential for the United States to be the world's leading marine bunkering hub for low cost natural gas. The potential domestic benefits of such a scenario – billions of dollars of investment in LNG plant construction, significant job creation, new markets for U.S. energy sources, reduced air pollution, etc. – are simply tremendous.

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Rail Sector

Overview

The seven Class I railroads in North America consume approximately 4 billion gallons of fuel annually, transporting a wide range of goods from bulk commodities, like coal, to intermodal goods including shipping containers and automobiles. As shown in Figure 10, the rail network has several critical intersections and rail links that can carry up to several hundred trains per day. Many of these key intersections are major intermodal hubs, including Chicago, Memphis, and Houston that connect port and rail shipments of containerized goods.

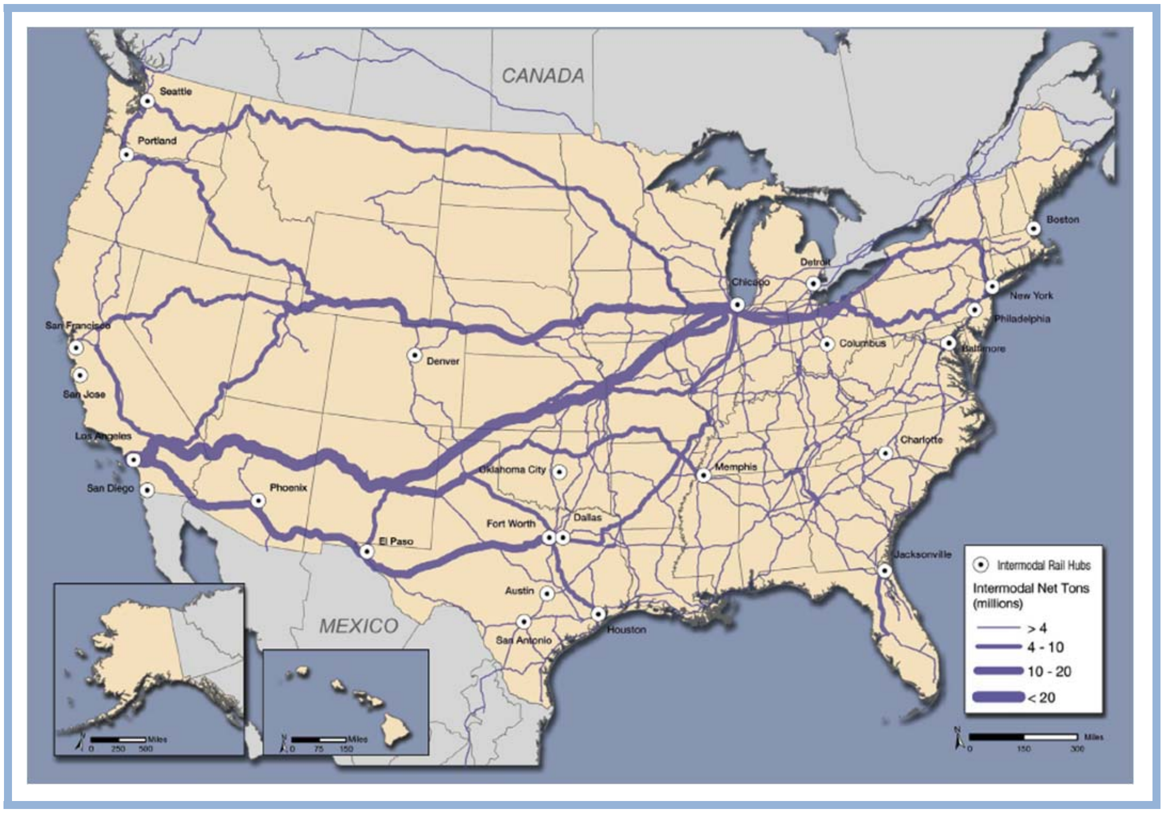

Figure 10: Tonnage of Trailer-on-Flatcar and Container-on-Flatcar Rail Intermodal Moves (2011)[23]

As summarized in Table 3, 92 percent of rail fuel use is associated with line-haul locomotives. The remaining 8 percent of fuel use is associated with switcher locomotives, which are largely used within single rail yards or between two nearby rail yards. The line-haul locomotives travel long distances, operating at the national level. It is not uncommon for a line-haul locomotive to circumnavigate the U.S. over the course of a year, operating on track owned by multiple Class I railroads, without a single set route or regular fueling locations for each locomotive. Railroads have distributed their fueling facilities to support their national fleets and support this operational variability.

[23] "Freight Flows by Highway, Railroad, and Waterway: 2010." United States Department of Transportation. http://www.ops.fhwa.dot.gov/freight/freight_analysis/nat_freight_stats/images/hi_res_jpg/tonhwyrrww2010.jpg.

Table 3: Fuel Use for Class I Rail Operations

Railroad	2013 Line-haul Fuel Use (gal)[24]	2013 Yard Fuel Use (gal)[25]	Total 2013 Fuel Use (gal)	Total Cost ($)
BNSF	1,328,531,642	50,109,515	1,378,641,157	$4,318,571,000
CSXT	438,496,974	43,367,833	481,864,807	$1,546,648,000
GTW (CN)	104,086,716	8,457,859	112,544,575	$363,434,000
KCS	62,608,055	3,335,436	65,943,491	$203,091,000
NS	446,869,376	29,435,062	476,304,438	$1,473,183,000
CPRS	71,511,004	3,474,856	74,985,860	$245,341,000
UP	963,559,993	128,537,666	1,102,446,131[26]	$3,446,691,000
All Class I RRs	**3,756,143,388**	**312,039,994**	**4,068,183,382**	**$11,596,959,000**

While the railroads do not disclose their fueling facility locations or the amount of fuel distributed at each location, it is possible to estimate the total fuel dispensed at a state level, based on U.S. EIA data. Figure 11 depicts the railroad fuel use by state and highlights the importance of Texas as a major railroad fuel consumer and likely the location of major locomotive refueling operations. Within the Great Lakes region, Ohio also stands out as a significant region for locomotive fuel use. However, the states along the Mississippi river do not stand out as significant consumers of diesel fuel, despite the major intermodal hubs in St Louis, Memphis and Chicago. The railroads have indicated that they avoid major fueling in freight hubs because fueling operations in the midst of network congestion could create additional delays within the system and costs on multiple fronts. This highlights the distinction between freight activity and fuel demand. Freight activity does not always coincide with fuel demand on a regional basis, particularly for line-haul locomotives where fueling facilities in one state supply locomotives that visit multiple states.

[24] Railroad’s Schedule 750, Line 1
[25] Railroad’s Schedule 750, Line 3
[26] Includes 10,348,472 gallons of diesel fuel for passenger rail.

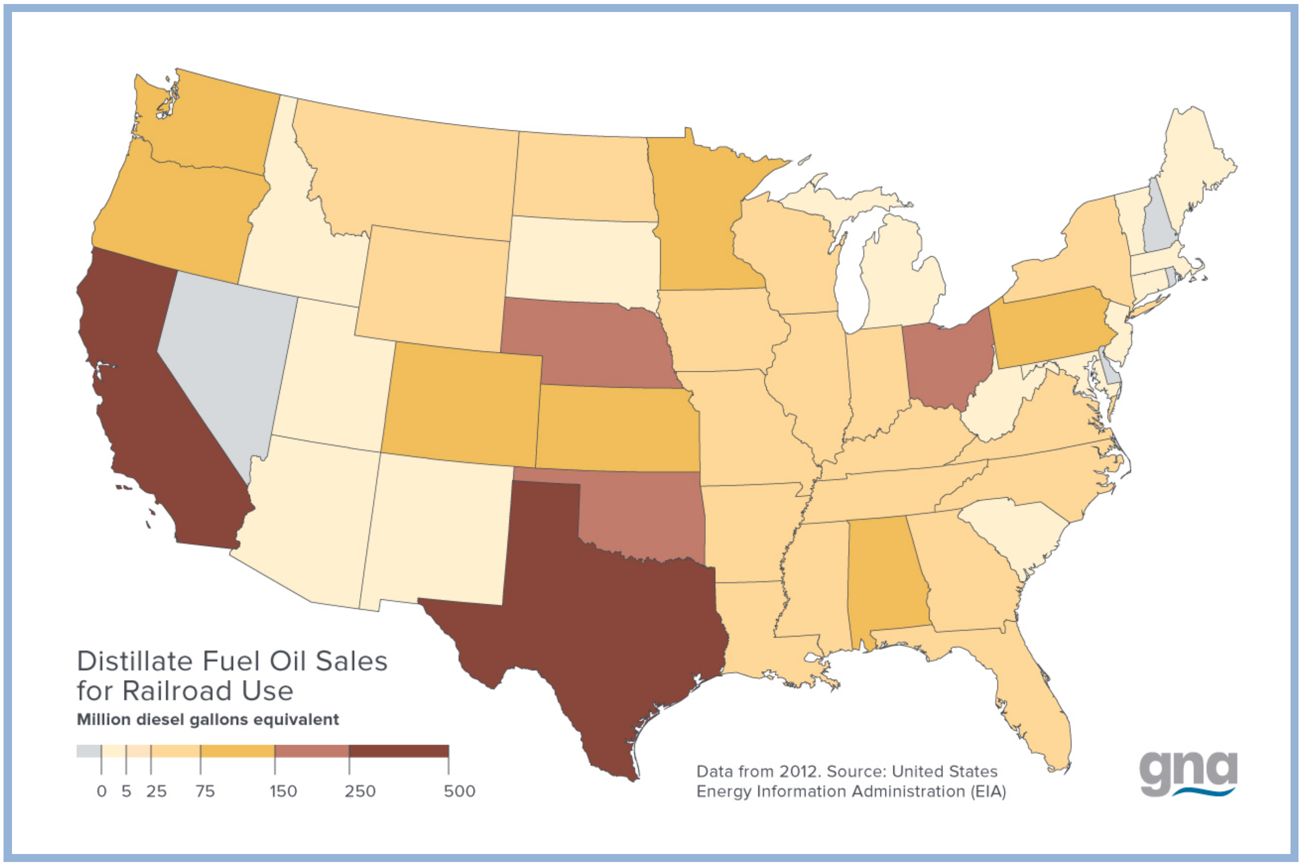

Figure 11: Distillate (diesel) fuel sales by State for Railroad End Use (2012)[27]

Switcher locomotives consume the remaining 8 percent of diesel fuel used in rail. Switchers are smaller than line-haul locomotives and are used to break down and build trains to transfer freight across rail or networks or intermodal connections by shuttling groups of rail cars within a rail or between two nearby rail yards or between a port and a rail yard operation. As with line-haul fuel demand, railroads do not disclose the amount of fuel used at individual rail yards in a comprehensive list. To estimate switcher fuel use, this report draws upon data from a study prepared by the Eastern Regional Technical Advisory Committee (ERTAC). In this 2012 study, ERTAC estimated carbon dioxide emissions from switcher locomotives at rail yards based on activity data from the Federal Railroad Administration (FRA).[28] Emissions inventory data from this study have been converted to estimates of diesel fuel use. Although the aggregate fuel use is far lower for switcher locomotives versus line-haul rail, the geographic specificity of switcher locomotives and their fueling operations can help identify additional LNG project opportunities to aggregate demand within a region.

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[27] "National Rail Freight Infrastructure Capacity and Investment Study" Cambridge Systematics, prepared for the American Association of Railroads, 2007

[28] Bergin M., Harrell M., Janssen M., "Locomotive Emission Inventories for the United States from ERTAC Rail", 2012. http://www.georgiaair.org/airpermit/downloads/planningsupport/regdev/locomotives/inventory_ertacrail_2012.pdf

LNG for North American Railroads

North American railroads spent approximately $11.6 billion on 4.1 billion gallons of diesel in 2013.[29] Simultaneously, railroads are facing increased costs for equipment and low sulfur diesel fuel to meet new EPA emission standards[30]. Given the potential to reduce fuel costs by up to 30 to 60 percent, this high fuel use market sector is aggressively investigating the feasibility of displacing diesel consumption with natural gas in their locomotives.

Figure 12: Canadian National (CN) locomotive

The use of alternative fuel and natural gas in locomotives is not a new idea. In 1936, the Plymouth Locomotive Company developed a gaseous fuel (propane) locomotive for the for the Joplin-Pittsburg Railroad in Missouri that remained in service with the Kansas City Public Service Company until approximately 1980. Other propane projects followed in the 1950s and 1960s.[31] In 1983, BNSF initiated a series of CNG and LNG test projects. Starting in 1992, BNSF operated a line-haul LNG locomotive in revenue service for three years and both BNSF and UP demonstrated LNG switcher locomotives in multi-year pilot demonstration projects in the 1990s.[32] These projects were technologically successful, but were discontinued largely because the cost spread between diesel and natural gas was not large enough at the time to justify continued investment by the railroads or locomotive manufacturers. Current natural gas pricing significantly changes the economics that were the basis of BN's decision in the 1990s.

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[29] Surface Transportation Board, Schedule 750 filings from Class I railroads for 2013.

[30] Code of Federal Regulations, Title 40: Protection of Environment, Chapter I-Environmental Protection Agency, Subchapter U-Air Pollution Control: Part 1033-Control of Emissions from Locomotives, Part 1065-Engine Testing Procedures, and Part 1068-General Compliance Provisions for Highway, Stationary, and Nonroad Programs

[31] Page 17 The American Association of Railroads, BNSF Railway, California Environmental Associates, and Union Pacific Railroad Company. (2007). *An Evaluation of Natural Gas-fueled Locomotives*. San Francisco, CA.

[32] Page 25-31, The American Association of Railroads, BNSF Railway, California Environmental Associates, and Union Pacific Railroad Company. (2007). *An Evaluation of Natural Gas-fueled Locomotives*. San Francisco, CA.

Today, the two largest locomotive manufacturers, GE and Electro-Motive Diesel (EMD, a Caterpillar company), are working with the Class I railroads and several short-line railroads to develop commercial railroad products for the current marketplace. BNSF, UP, CN, CSX and Norfolk Southern are all in varying stages of project development and fuel assessments weighing natural gas options, with some prototype units currently in pilot operation. Several short-line railroads are also examining natural gas options, including the Florida East Coast Railway, Oklahoma Department of Transportation and Indiana Harbor Belt.

Both line-haul and short-line railroads have indicated significant eagerness and willingness to test natural gas in their operations in order to demonstrate the technology in a variety of applications as they move to more aggressive commercial deployments. However, at the time of this report, Federal Railroad Administration (FRA) regulations do not allow for the use of natural gas tender cars and thus locomotives in commercial operations. The pilot programs now underway have received a "concurrence letter" from FRA – which is essentially a special authorization granted outside of the current regulation – in order to use natural gas in a defined demonstration program. To facilitate wide scale commercial adoption of natural gas as a locomotive fuel, it will be required to develop natural gas tender car standards and amend current FRA regulations to allow for such use.

The American Association of Railroads (AAR) has convened a technical advisory group and is working with FRA on LNG tender car design standards. According to the FRA, the development of these standards will take 12 to 24 months. Following the development of these standards, computer modeling and physical testing of natural gas tender cars will be required in order that the FRA can then amend its current regulations to allow natural gas to be used commercial applications (via tender cars) as a locomotive fuel. FRA projects that this process will require 4 to 5 years of effort, thus setting the stage for an acceleration of the natural gas rail industry in the 2018 to 2019 timeframe.

LNG Infrastructure Overview

Overview

The current state of LNG demand in the North American transportation market is supplied by two primary types of LNG facilities: merchant LNG facilities (plants designed to produce LNG for commercial sale) and utility peak shave storage facilities (plants designed to provide pipeline supply of natural gas to regulated natural gas utilities during periods of peak demand, particularly during the winter). Merchant plants are the dominant source of LNG for the U.S. transportation market, since peak shavers often have limited excess capacity or state utility regulatory constraints inhibiting large-scale fuel sales into the non-utility marketplace. Due to the growing demand for LNG through North America, there are a number of merchant facilities that are projected to be constructed or expanded in the near future by such LNG fuel suppliers as Clean Energy, Applied LNG, Stabilis Energy, Noble Energy, and Pivotal. Some utilities like Atlanta Gas and Light are working with their public utility commissions to develop transportation fuel supply from peak shavers, but this approach isn't always feasible due to capacity constraints or regulatory limitations. Other peak shavers are able to supply limited truckloads of LNG, which are enough to support pilot projects and proof-of-concept projects that can help secure long-term commitments for project development, but cannot likely offer enough long-term supply to support marine or rail market growth.

Another near-term option for LNG fueling will come from the proposed LNG export facilities. Although there are dozens of proposed export facilities throughout the United States, three of the six facilities that have FERC approvals (which are the most likely to be constructed) are located in the study region.

Table 4: Proposed LNG export facilities in study region with FERC approvals

Proposed LNG Export Facility	Location	Status
Cheniere Energy	Sabine Pass, LA	FERC approval, Under Construction, Operational Q4 2015/Q1 2016
Sempra	Hackberry, LA	FERC approval, Planned
Freeport LNG	Quintana, TX	FERC approval, Planned

These facilities offer a unique opportunity to build marine market growth by using existing, large-scale, waterfront liquefaction at the export facility site, instead of needing to invest in transportation-specific liquefaction infrastructure. Given the immense storage and production capacities at these sites (Cheniere's location has 15 Bcf storage capacity and will have initial daily processing capacity of 1 Bcf/day and ultimate capacity of 4 Bcf/day at full build out), they will likely provide the lowest cost LNG that could potentially be produced. Further, the cost to provide the infrastructure for domestic markets, such as commercial marine vessels, will be very small compared to the total project cost, as well as the cost of a new LNG plant developed to serve the domestic market. The ability to fill bunker barges at these locations with very low cost LNG and to transport these barges throughout the region, either for direct bunkering into ships or for distribution of the LNG into satellite fuel storage locations, can reduce the overall barriers related to fuel access and can ultimately make smaller vessel deployment projects more cost-effective.

The location of LNG plants is critical to transportation project economics. Generally speaking, if LNG plants are located more than 250 miles from an end user, the costs associated with transporting LNG can begin to meaningfully impact the payback analysis due to the cost of round-trip transportation by a truck beyond this range. The economic calculus could change for bunker barge transport of fuel from a waterfront liquefaction facility or rail transport of LNG, since the efficiency of high volume rail or water-borne transportation will improve long-distance economics for users located further from a liquefaction facility. The map below identifies all current and planned merchant, peak shave, and export facilities that operate within the states targeted by this market analysis, to help identify the potential supply and current market gaps.

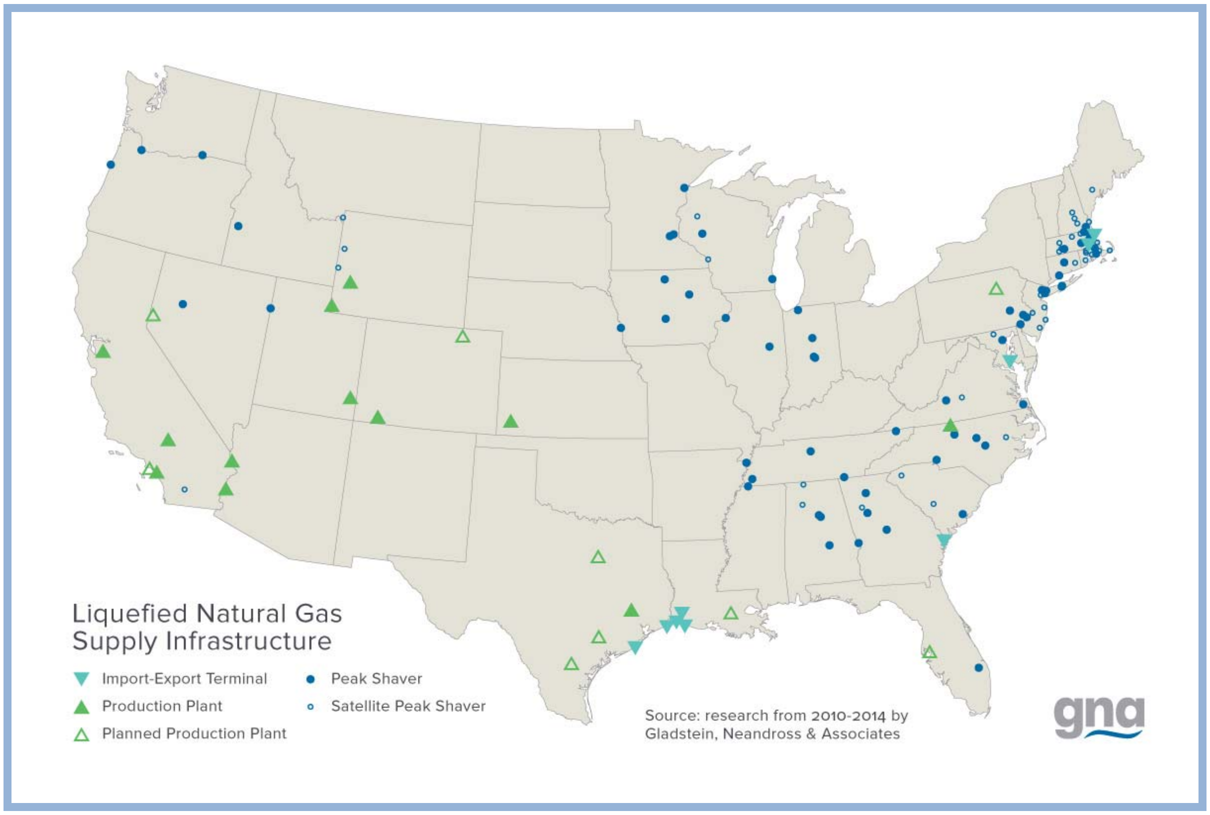

Figure 13: Liquefied Natural Gas Supply

In order to generate the economics required for project investment and ultimately cost-effective LNG fuel to the end-user, many liquefaction sources for the transportation fuel market are generally developed to supply at least 80,000 gallons per day or more. In some unique situations, customers like TOTE can generate enough baseload fuel demand themselves to justify investment in a new LNG plant; however, these cases are rare. Most often, a project developer will look to aggregate several sources of potential demand in order to subscribe approximately 30 to 50 percent of the total target production capacity before making the investment decision to build the plant. Given the relatively large volumes of fuel associated with freight locomotive and commercial marine operations, these sectors represent a very viable opportunity for LNG plant developers to effectively aggregate the potential LNG fuel demand required to build a new production plant.

Fueling Operations

Large commercial marine vessels generally receive fuel from bunker barges that pull alongside the vessel. In some cases, marine vessels may receive fuel via a pipeline at the berth, however, this is generally not the case. Bunkering of large commercial marine vessels is provided by fuel service companies while the vessel is at berth or when anchored awaiting a berth. For pushboat operations, on the inland waterways, fueling of the vessel can take place while in transit, a process often referred to as "mid streaming."

LNG fueling can be similarly managed, with on-dock or bunker-barge flexibility; however, mid-streaming of LNG is far from being an approved practice at this time (even though there is much less of a spill risk than with petroleum fuels). Developing distribution in existing bunkering hubs, plus developing bunker barge service models will help marine operators with a more seamless fuel transition. However, because LNG cannot be transported over long distances via pipeline, fueling operators need an economical way to transport LNG to the bunkering facilities or barge loading facilities. In general, the most cost-effective facilities will have waterfront liquefaction; however, waterfront land can be expensive and permitting can present challenges. LNG can also be transported to the waterfront via truck or rail. Truck distribution is currently supporting the Harvey Gulf model, and is effective for short-term fuel supply. However, truck traffic volumes can create challenges at full operations for multiple vessels. For bunker facilities with rail access, there may be economical opportunities to transport LNG via rail cars.

Line-haul rail fueling does not typically take place in the regions where the railroads conduct intermodal freight transfers. Instead, railroads set up large classification yards in lower cost regions such as Nebraska and Ohio and in areas outside of more congested junction points. These yards support vast regional fueling, crew change, maintenance, and freight transfer operations. The largest classification rail yard in the world is Union Pacific's Bailey Yard, in North Platte, Nebraska. The fueling center at this yard processes over 8,500 locomotives[33] and dispenses over 14 million gallons of fuel each month.[34] Although Nebraska isn't part of the study region, it is likely that many of the long haul railcars destined for the western Great Lakes ports fuel at Bailey.

The disconnect between freight traffic and fueling locations highlights the challenges in trying to identify marine and rail intersectionality for LNG. Although Chicago represents a large freight center with marine drop-off and rail distribution activity, it doesn't correlate with significant fueling for either sector. Locomotive fueling takes place outside of the Chicago rail network congestion and marine fueling takes place in Northwest Indiana, throughout the underutilized steel mill region, via truck or barge. However, the fact that fueling doesn't currently overlap doesn't mean that it can't overlap in the future, particularly if users in both sectors want to take advantage of low cost LNG. Operations and fuel distribution may need to shift, which requires logistics and coordination, but the cost savings may help overcome the inertia of "the way things are done." There is value in examining options for shared liquefaction, particularly given the potential for cost-effective rail deliveries of LNG to waterfront locations or from more remote locations to central rail yards. Although rail users have indicated they would want direct access to LNG fuel onsite, cost-sharing initial regional facilities may help support ramp up across multiple sectors.

[33] "Bailey Yard". Union Pacific. http://www.up.com/aboutup/facilities/bailey_yard/.
[34] "Bailey Yard". Golden Spike Tower. http://www.goldenspiketower.net/bailey_yard.php.

Great Lakes Region

Overview

The Great Lakes St. Lawrence Basin is a bi-national region (United States and Canada) comprising eight states (Minnesota, Wisconsin, Michigan, Illinois, Indiana, Ohio, Pennsylvania, New York), two provinces (Ontario and Quebec) and many large urban population centers. This region generates 30 percent of U.S. and Canadian gross domestic product (GDP) through its extensive manufacturing capacity and significant consumer marketplace. A complex multi-modal transportation sector using marine, rail and truck shipments manages manufacturing, consumer product, and commodity transport needs throughout the Great Lakes region.

Marine shipping is one of the key transportation modes in the region, providing commodity and goods movement services for national and international markets. There are 15 large international marine ports and 50 regional marine ports in the Great Lakes. The lakes are also linked to other domestic marine transportation routes via the Inland Waterways, including the Mississippi River and its major tributaries, the Ohio and Illinois Rivers. The region is linked to international markets through the Great Lakes St. Lawrence Seaway System and its 19 locks. The largest vessels on the Great Lakes are the "lakers," which are bulk carriers that serve as the primary mode of bulk transport on the lakes. Rail transportation also plays a major role, with the largest rail junction in the world located in Chicago, IL and all seven North American Class I railways operating in the region. There is a total of 30,778 miles of track, including 68 intermodal terminals, several short lines, and rail border crossings. An extensive highway system and multiple border crossings also facilitate significant on-road freight movement. The major commodities moved within and exported from the region include iron ore, limestone, coal, automotive, machinery, and other manufactured goods.[35]

[35] Roy, M. and Booth, M. "Understanding and Promoting Multimodal Freight Transportation System Performance within 3 Mega-Regions: Lessons from the Great Lakes-Saint Lawrence Basin." CPCS Transcom Limited, July 31, 2011. http://docs.trb.org/prp/12-2811.pdf, accessed August 7, 2014.

Fuel Use

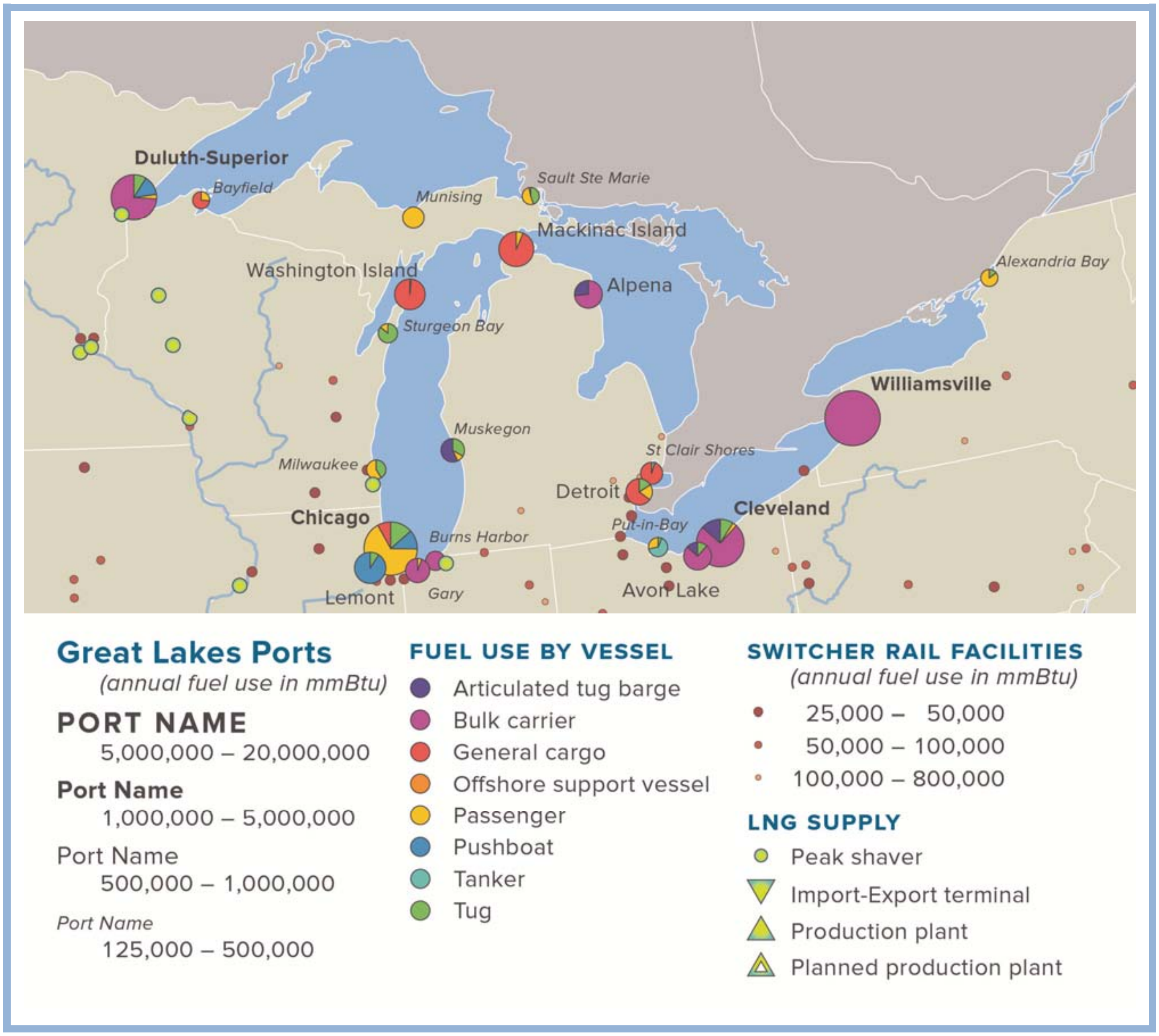

Figure 14: Great Lakes Marine and Switcher Fuel Use with LNG Supply Points

Marine

There are 415 registered, U.S.-flagged vessels on the Great Lakes with a collective 835,000 horsepower.[36] The Great Lakes System is home to the smallest portion of the U.S. vessel fleet, accounting for just 4.6 percent of the registered fleet and 3.8 percent of horsepower. In addition, 102 of these vessels (nearly a quarter of the registered fleet) were built before 1950. However, the operational profile and fuel use demands of certain vessel types creates meaningful opportunities for natural gas as a marine fuel.

[36] For a complete description of the data sources and analysis methodology, please see Appendix 1

Great Lakes vessels have exceptional longevity, thanks to their freshwater operations, with hulls lasting up to 100 years. Given these timelines, the entire Great Lakes fleet averages approximately one new laker purchased every 10 years, throughout the entire region. This leaves minimal opportunity for LNG growth via new purchases. To identify the best LNG conversion opportunities, this analysis excluded the 102 pre-1950 ships on the Great Lakes, since these vessels have dwindling remaining useful life and also present considerable technical challenges due to available space and extensive upgrades that would be required if the vessels were converted to LNG. This exclusion also covers the 13 U.S.-flagged steamships identified by the EPA's Great Lakes Steamship Repower Incentive Program.[37] Under the program, these vessels were granted exemption from the North American ECA's fuel sulfur requirements, which went into place in August 2012. As these vessels present considerable cost barriers and space limitations for storage, their removal from the analysis is warranted. After accounting for these technical feasibility and exclusion issues, 37 ships were identified as high-opportunity LNG vessels. Further analysis using these constraints revealed that these 37 high-LNG potential U.S.-flagged lakers consume 36 percent of the marine fuel use in the Great Lakes region (Figure 15). Additionally, cargo vessels account for another 16 percent of fuel use, though only 16 of these vessels are registered in the Great Lakes.

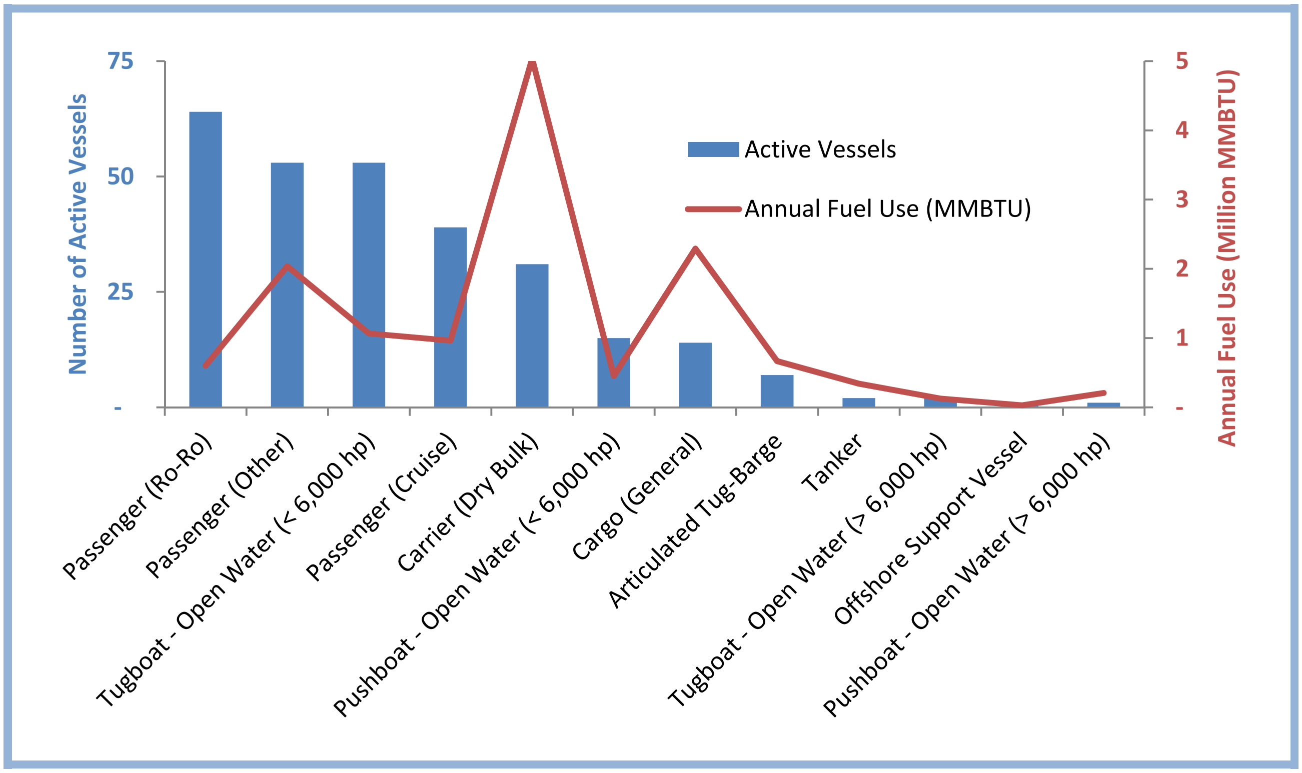

Figure 15: U.S.-flagged vessels active in the Great Lakes System and their annual fuel use[38][39]

[37] "Great Lakes Steamship Repower Incentive Program." United States Environmental Protection Agency, January 2012. http://www.epa.gov/oms/regs/nonroad/marine/ci/420f12003.pdf, accessed July 29, 2014.
[38] "National Summaries, Volume 1 (2012)." Waterborne Transportation Lines of the United States, US Army Corps of Engineers Navigation Data Center, 2012. http://www.navigationdatacenter.us/veslchar/pdf/wtlusvl1_12.pdf. accessed July 29, 2014.

The 37 U.S.-flagged lakers identified in this analysis offer the most potential for LNG opportunity, accounting for an estimated annual demand of 64 million gallons of LNG, which is equivalent to 175,000 gallons per day. This potential stems from a combination of high installed engine power and fuel use, along with the upcoming emissions requirements under the North American ECA. Switching to LNG operations presents a significant cost savings potential for Great Lakes vessels. Based on fuel cost savings, simple payback for an LNG conversion is approximately 3.4 years for lakers, assuming a $1.00 per DGE price spread between diesel/fuel oil and LNG, with ongoing fuel cost operational savings after maintenance expense associated with scrubber compliance technologies.

Table 5: Annual fuel use and LNG demand for select Great Lakes vessels

Vessel Type	Number of U.S. Flagged Vessels	Annual Fuel Use *(MMBTU)*	Annual LNG Demand *(Gallons)*
Carrier (Dry Bulk)	37	5,034,226	64,005,819
Cargo (General)	14	2,292,758	29,150,425
Passenger Vessels (Ferries)	54	2,036,344	14,989,148

The highest priority LNG project opportunities will come from converting U.S.-flagged lakers and other large cargo vessels built after 1950, which can anticipate at least another 20 years of useful life for investment payback and will have fewer technical challenges than pre-1950 vessels. While the high opportunity lakers operate throughout the region, they are registered in four key locations: New York, Ohio, Minnesota, and Indiana (Table 6).

Table 6: Registered locations of Lakers in the Great Lakes[40]

Location	Number of Registered Lakers	Vessel Owner / Operator
Williamsville, New York	15	American Steamship, Co. – 15 vessels
Cleveland and Avon Lake, Ohio	10	Interlake Steamship Co. – 7 vessels Grand River Navigation – 2 vessels Black Creek Shipping Company, Inc. – 1 vessel
Duluth, Minnesota	8	Key Lakes, Inc. – 12 vessels
Burns Waterway Harbor and Gary, Indiana	4	Indiana Harbor Steamship, Co – 2 vessels Interlake Steamship Co. – 1 vessel American Steamship Co. – 1 vessel

[39] The marine sector uses multiple types of fuels, spanning the different distillate, intermediate, and residual mixtures, each of which has different densities and weights. As such, it can be difficult to adequately quantify fuel use and demand when measuring in volumes. Thus, in order to present a consolidated and fuel-neutral view, this report's analysis of the marine sector displays fuel use and demand figures by their energy content (shown in MMBTU), rather than the volume of a specific fuel. This was then used to identify energy demand clusters and to project LNG demand scenarios.

[40] "National Summaries, Volume 1 (2012)." Waterborne Transportation Lines of the United States, US Army Corps of Engineers Navigation Data Center, 2012. http://www.navigationdatacenter.us/veslchar/pdf/wtlusvl1_12.pdf. accessed July 29, 2014.

Additionally, passenger vessels, especially ferries, present a good opportunity for second-tier demand in the Great Lakes Region (approximately 15 percent of annual fuel demand) that might be suitable for medium-term project development activities. LNG-fueled ferries have seen great success across Europe, with nearly 30 in operation or under construction.

It is also important to note that any Canadian-flagged vessels were excluded from this analysis given the study area parameters. As is the case with this analysis, there are several opportunities for LNG conversion projects with Canadian-flagged vessels and it is recommended that these opportunities be further evaluated in order to determine the potential impact on and use of U.S.-based LNG production and bunkering infrastructure.

Currently, there are no Great Lakes vessel operators implementing LNG projects on either the U.S. or Canadian side. Interlake and Shell agreed earlier this year that, while LNG is a viable and attractive option for both companies, recent market dynamics did not support continuing a joint-development program at the time. The Great Lakes fleet has indicated its preliminary interest in LNG opportunities, though concerns about fueling access have halted any serious project development. In Canada, the ferry vessel operator Société des traversiers du Québec (STQ) is expected to take delivery of the first of three LNG-diesel dual fuel ships in late 2014. However, the location of these vessels, well up the St. Lawrence Seaway north of Montreal, will provide minimal opportunity for shared infrastructure support with the Great Lakes fleet. Several Canadian laker fleets have also indicated interest in LNG operations, though they are still assessing infrastructure and cost issues.

Table 7: Status of LNG-fueled vessels in the Great Lakes

Status	Vessel Name	Operator	Expected Delivery Date	Builder Name	Function
Awaiting Delivery	F.A. Gauthier	Société des traversiers du Québec (STQ)	2014	Fincantieri (Italy)	Ferry
Under Construction	STQ Tadoussac Newbuild #2	Société des traversiers du Québec (STQ)	2015	Chantier Davie Canada	Ferry
Under Construction	STQ Tadoussac Newbuild #3	Société des traversiers du Québec (STQ)	2015	Chantier Davie Canada	Ferry
Proposed Conversion	Mesabi Miner	Interlake Steamship Company	TBD	TBD	Laker

While many lakers have undertaken engineering studies or consultant cost studies, there are many unknown costs related to LNG fueling locations, operations, and fuel storage modifications due to the highly individualized routes and shipping vessels used by the Great Lakes operators. Laker owners have also expressed some trepidation related to LNG investments, following the pause of the Shell Sarnia project. Interested operators have begun requesting dual fuel systems in their project analyses to provide for more fuel security. However, a dual fuel approach can add twice the amount of fueling storage onboard, which has negative consequences for cargo and profit.

Rail

In general, Class I rail offers important opportunities for LNG project development nationwide due to their high fuel use, concentration amongst a small number of companies, and centralized fueling practices. There is no publicly available data on site-specific Class I rail fueling activities, making the identification of LNG opportunities challenging for non-rail stakeholders. However, it is reasonable to assume that the majority of line-haul locomotive fueling occurs at rail yards with the greatest freight throughput and switcher locomotive activity. Therefore, this analysis relies on US EIA state-wide rail fuel sales information and existing estimates of switcher fuel use for most rail yards in the US [41] to identify regions of interest for rail LNG opportunities.

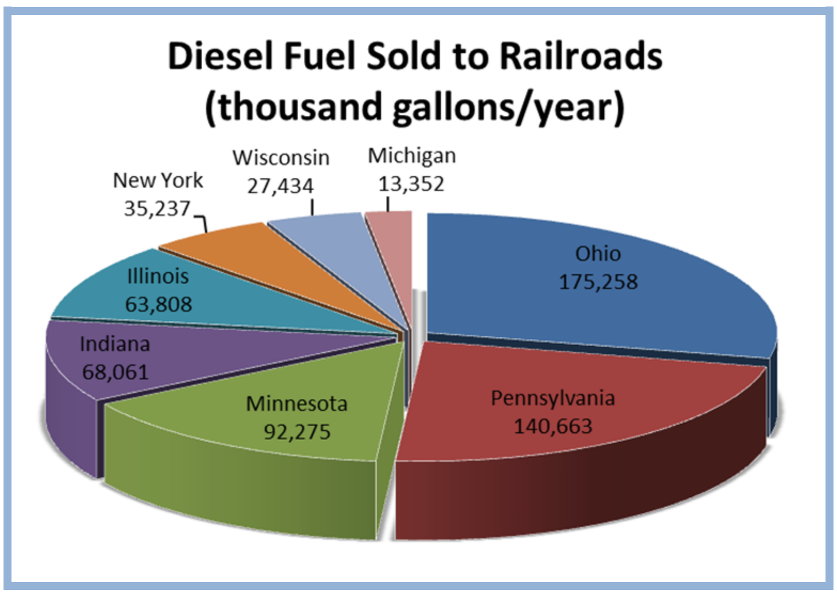

Figure 16: Diesel fuel sales by state to railroads - Great Lakes Region[42]

In the eight states that touch the Great Lakes, a total of 616 million gallons of diesel fuel were sold to railroads. Pennsylvania and Ohio host the greatest fuel demand, representing slightly more than half of the total rail fuel use (Figure 16), with Minnesota then accounting for about 15 percent of the total rail fuel in the region.

Of the EIA fuel sales, GNA estimates that total switcher locomotive fuel demand in these states accounts for only 65 million gallons of fuel sales. Due to economic and logistical challenges of natural gas in

[41] Bergin M., Harrell M., Janssen M., "Locomotive Emission Inventories for the United States from ERTAC Rail", 2012. http://www.georgiaair.org/airpermit/downloads/planningsupport/regdev/locomotives/inventory_ertacrail_2012.pdf
[42] US EIA, "Sales of Distillate Fuel Oil for Railroad Use", 2013

switcher locomotive applications, the Class I railroads have chosen to focus on line-haul locomotives for near-term LNG opportunities. Based on this, switchers are not considered a near- or medium-term LNG project development opportunity and their fuel use was removed from the analysis. The remaining 551 million gallons of line-haul diesel demand in the eight Great Lakes states represent an LNG demand opportunity totaling 668 million LNG gallons per year[43].

Some short-line railroads have begun examining CNG options instead of LNG, particularly in regions with strong pipeline systems. The Indiana Harbor Belt Railroad Company (IHB) in the Chicago region – which is the largest switch carrier in the U.S. – is actively transitioning to CNG. In 2013, IHB announced plans to convert 70 percent of its locomotives from diesel to natural gas. Backed by a $35 million Congestion Mitigation and Air Quality (CMAQ) grant from the Department of Transportation, the IHB's five-year, $60 million project includes the conversion of 31 switcher locomotives to CNG, as well as the construction of a new CNG fueling station at IHB's Hammond, IN rail yard.[44] The railroad expects to reduce particulate matter (PM) emissions by 97 percent compared to its current operations, while also reducing annual diesel consumption by 1 million gallons.[45] As of March 2014, IHB had identified a list of 11 potential vendors, who will participate in the Request for Proposals process and bid on the contract to remanufacture the locomotives.[46] IHB expects to take delivery of the first converted CNG locomotive by mid-2015, with the remaining 30 arriving over the next four years.

Although Class I switcher operations might not be a near-term opportunity for LNG, their activity is assumed to be indicative of line-haul locomotive activity and fueling opportunities. To identify key rail yards and regions for line-haul fueling opportunities, GNA estimated the total switcher fuel use at rail yards within ten miles of significant ports on the Great Lakes. Not surprisingly, Chicago area rail yards (including rail yards in Gary, IN) top the list with an estimated 26 percent of total switcher fuel use in the Great Lakes region. Note that this total does not include rail yards that may be in the greater Chicago region but are not near the Great Lakes ports. The Buffalo, NY region utilizes an estimated 25 percent of the switcher fuel in the Great Lakes region each year. In Ohio, Toledo and Marblehead switchers represent 15 percent of the regional switcher fuel demand. The major operator in the region is CSX, which uses about half the switcher fuel throughout the Great Lakes region.

[43] Assuming a 70 percent substitution rate for dual-fuel natural gas engines.
[44] Piellisch, R. "31 Chicago-Area Locomotives on CNG." HHP Insight, October 28, 2013. http://hhpinsight.com/rail/2013/10/31-locomotives-on-cng/, accessed August 5, 2014.
[45] Stagl, J. "Indiana Harbor Belt Railroad adopts compressed natural gas as a locomotive fuel alternative." Progressive Railroading, February 2014. http://www.progressiverailroading.com/mechanical/article/Indiana-Harbor-Belt-Railroad-adopts-compressed-natural-gas-as-a-locomotive-fuel-alternative--39401, accessed August 5, 2014.
[46] Nicoletti, M. "Indiana Harbor Belt Railroad Announces Qualified Potential Vendors eligible to bid on future Request for Proposals of 31 Locomotives to Natural Gas." Indiana Harbor Belt Railroad Company, March 31, 2014. http://www.ihbrr.com/IHB%20Qualification%20Announcement.pdf, accessed August 5, 2014.

Table 8: Top 5 Great Lakes rail yards (regional) and estimated switcher fuel use

Port City	Number of Rail Yards	Fraction of Great Lakes Regional Switcher Fuel Use	Fraction of State Switcher Fuel Use
Chicago, IL Area	16	26%	15%
Buffalo, NY Area	13	25%	62%
Toledo, OH Area	9	15%	17%
Cleveland, OH	10	10%	12%
Detroit, MI	11	7%	26%

At full conversion, line-haul rail operations in the study region could represent 107 million gallons of current annual diesel demand, or 130 million gallons of potential LNG demand.[47] Given the concentration of rail operations in the region, all of the Class I railroads may be able to identify LNG opportunities in the region. Given CSX's switcher activities throughout the Great Lakes, and particularly in Ohio and New York, where there is also a concentration of line-haul use, CSX may represent an LNG project development target for the Great Lakes region.

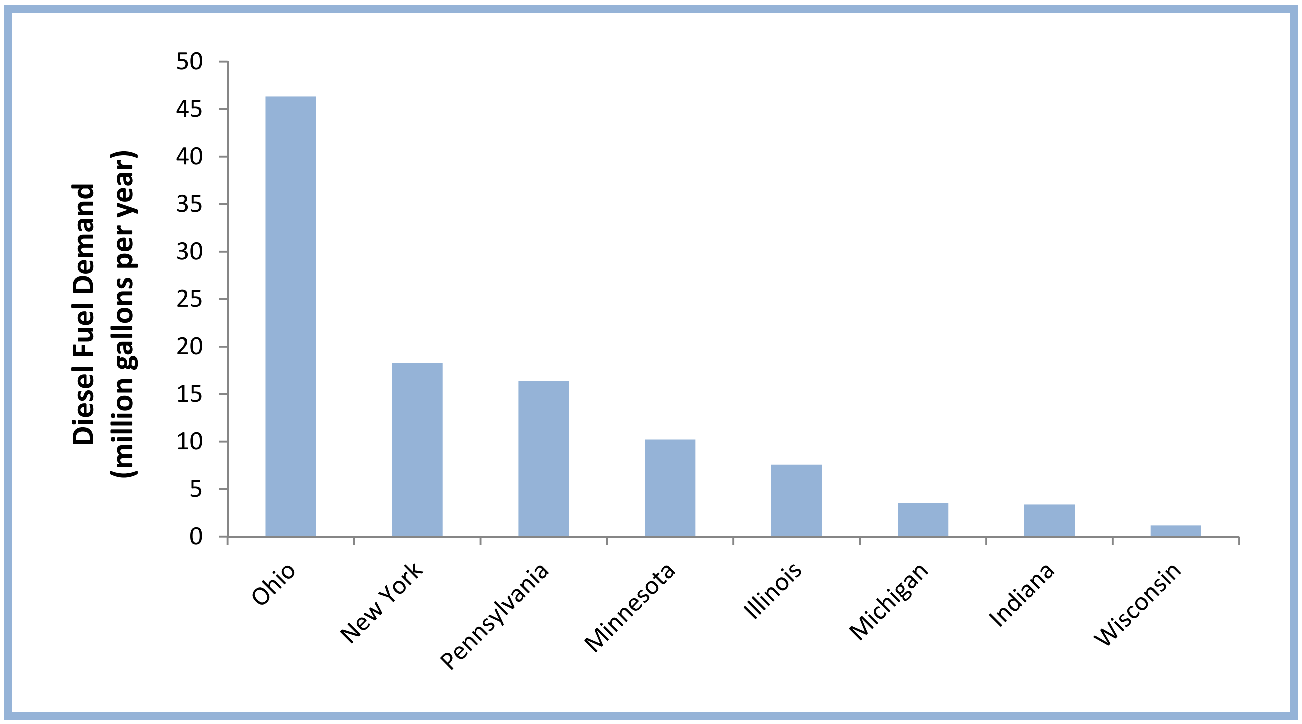

Figure 17: High opportunity railroad fuel use in the Great Lakes Region

[47] Assuming a 70 percent substitution rate for dual-fuel natural gas engines

Fueling and Infrastructure

Fueling Operations

Current U.S. Great Lakes marine fueling operations take place at one of three bunkering locations in U.S. Great Lakes ports (Duluth, MN; Calcite, MI; and Detroit, MI), via barge at unloading locations along South Lake Michigan, or at smaller loading docks such as Two Harbors, MN. Table 9 includes a listing of all the public marine fuel terminals in the international Great Lakes.[48]

Table 9: Top 5 Great Lakes public bunkering docks

City, State	Type of Dock	ype(s) of Cargo Handled
Calcite, MI	Bunkering, Unloading	#2 Fuel Oil
Detroit, MI	Bunkering, Unloading	#2 Fuel Oil, #6 Fuel Oil, Asphalt
Duluth, MN	Bunkering, Loading, Unloading	Bunker "C", Diesel oil, IFO blends, misc
Montreal, Quebec	Bunkering, Loading, Unloading	Bunker "C", Crude oil, Diesel fuel, Furnace oil, Gasoline, Jet Fuel, Stove oil
Port Alfred, Quebec	Bunkering, Unloading, Grain Unloading	Bunker "C", Blended fuels, Diesel oil, Galley fuel, Gasoline, Gas Oil, Intermediate bunkers, Lube oil distillate, Marine diesel
Sarnia, Ontario	Bunkering, Loading, Unloading	Bunker "C", Diesel oil, Fuel oil, Galley fuel, Gasoline, Fuel oil, Intermediate bunkers, Lube oil distillate, Marine diesel, Solvents, Stove oil
Sept-Iles, Quebec	Bunkering, Unloading	Gasoline, Diesel fuel, Jet fuel, Turbo fuel, Varsol
St. Romuald, Quebec	Bunkering, Loading, Unloading	Blended fuels, Bunker "C", Crude oil, Furnace oil, Gasoline, Marine diesel, Stove oil
Windsor, Ontario	Bunkering, Unloading	Asphalt, Blended fuels, Bunker "C", Marine diesel

The location of any vessels' fueling locations is driven by the range of the vessels' fuel tanks and their specific trade routes on the Great Lakes. One challenge in identifying clear locations for cost-effective Great Lakes LNG infrastructure is to develop liquefaction in as few locations as possible but which can cater to as many trade routes as possible. Although this report was able to gather data on vessel registrations, these home port locations are not necessarily where fueling takes place. Routes are highly individualized, even within a fleet. However, in speaking with vessel operators, there are three primary fueling locations that could likely support much of the Great Lakes vessel traffic:

[48] "Greenwood's Guide to Great Lakes Shipping." Harbor House Publishing, 2013, with additional insight from discussions with fleet managers

- Detroit/St. Clair, MI: Fueling currently occurs via bunkering or barges. There are three refineries on the Canadian side and one on the U.S. side of the border. SIMOPS fueling takes place during cargo operations.
- South Lake Michigan: Decentralized fueling currently occurs throughout the steel mill region Northwest Indiana, in places like Burns Harbor. SIMOPS fueling takes place during cargo operations via truck or barge.
- Duluth, MN: SIMOPS fueling currently occurs via bunkering at the refinery docks, which are owned by Calumet Fuels.

Another consideration for LNG fueling operations is that LNG has a lower BTU content per gallon than marine fuels, which means that LNG vessels will either need to add extra fuel storage or add additional fueling stops along their routes or at their loading or unloading ports. Vessels owners will not want to replace revenue generating cargo space with additional fuel tankage or add operational down time unless the fuel cost savings provide enough economic incentive. Interlake addressed this issue by designing ship modifications that would install four LNG tanks vertically on the stern of the vessel versus inside the hull. Each tank would be capable of storing 52,800 LNG gallons, which would enable the vessel to have enough fuel without either losing cargo space or adding additional fueling downtime. However, not all ships can be converted in this way, either due to their configuration, cargo, or fuel storage needs.

Vessel operators are also highly attuned to fueling efficiencies when considering any operational changes. Fueling takes time, and time means that vessels aren't on the water and generating income. Therefore, to maximize efficiency, lakers tend to engage in SIMOPS fueling at the ports where they load or unload goods. Lakers can fuel with diesel in as quickly as four hours, and operations are measured in time increments as short as 15 minute efficiency intervals, so fueling downtime factors into overall cargo economics.

Great Lakes vessels and routes are highly individualized, and both of these factors can have significant impacts on LNG project economics. While many vessel owners have undertaken LNG engineering studies and basic cost-benefit analyses, it is difficult to project real figures without knowing where LNG fueling infrastructure will be located and what SIMOPS fueling might look like. These factors will be critical in assessing fuel storage needs, fueling operations, and overall project economics.

Most of the Class I railroads specifically avoid fueling in Chicago due to congestion. Instead, the Class I railroads fuel in adjacent regions and states, depending on where their rail yards are located. The high volumes of rail fuel sold in Ohio and Pennsylvania, followed by Minnesota, suggest that these states host significant fueling facilities for Class I line-haul locomotives.

Existing and Planned LNG Infrastructure

At this time, the only existing large scale liquefaction plants in the Great Lakes region are utility peak shaving plants. In 2013, Shell Oil announced that they would build a liquefaction plant in Sarnia, Ontario.[49] However, Shell paused the ongoing development in 2014 to allow the review of its LNG for Transport opportunities in North America.[50] This pullback from Shell has created LNG supply concerns among operators throughout the region, leading to demands for more costly dual fuel ship designs that may be untenable with cargo size and engineering needs.

Other private industry players have been evaluating existing port and conventional bunkering for LNG in Sarnia (Ontario) or across the border in Detroit (Michigan) and Duluth (Minnesota). In August 2014, BLU LNG announced that it had two LNG bunkering permits under review for Duluth and South Lake Michigan with the USCG and hoped for approval in the fourth quarter of 2014.[51] The company has expanded its focus from on-road LNG to create a new marine group with four marine engineers on staff. The company is developing full service LNG packages that include engine upfits, fuel liquefaction, fuel transfer, fuel storage and vessel fueling. In Ontario, near the Williamsville/Buffalo port and rail center, Northeast Midstream LLC recently received environmental compliance approval from the Ministry of the Environment in May 2014 for a new LNG plant.

Companies have also been analyzing LNG opportunities at sites without significant existing marine fueling operations such as Calcite and De Tour, MI which are currently used for winter dry docking and minimal service functions. These locations are situated at a natural "choke point" where several of the lakes connect (Lake Superior, Huron and Michigan). Although this choke point would seem to offer an easy location to serve significant vessel traffic, the lack of local cargo operations mean vessel operators will be reluctant to fuel here, as it would reduce existing cargo loading and SIMOPS fueling efficiencies at dock.

Vessel traffic on the Great Lakes is subject to seasonal closure during the ice season. Additional high fuel use LNG customers such as rail, trucking, or mining users would be a buffer for the seasonality of the marine fleet and would help support the economics associated with multi-site liquefaction build-out. Alternately, any LNG liquefaction investor would need to develop payback models that account for an extended timeline for a marine-only project in multiple locations.

Great Lakes LNG Growth Opportunities

GNA estimated LNG market penetration rates for marine and rail fuel in the Great Lakes region by applying our own internal research and GLMRI insight on Great Lakes regional specifics to projection methodology developed by DNV GL for the domestic LNG vessel fleet. DNV GL's methodology is based on research from the industry's news sources including Clarkson's, Lloyds List, Fairplay, Tradewinds, Sea-

[49] "Shell to develop two additional natural gas for transport corridors in North America." Shell Global, March 5, 2013. http://www.shell.com/global/aboutshell/media/news-and-media-releases/2013/natural-gas-for-transport-corridors-05032012.html, accessed July 29, 2014.
[50] Piellisch, R. "Shell Throttles Back Its LNG Plans." Fleets&Fuels, March 24, 2014. http://www.fleetsandfuels.com/fuels/lng/2014/03/shell-throttles-back-its-lng-plans/, accessed July 29, 2014.
[51] Piellisch, R. "Utah's BLU Tackles LNG Bunkering." HHP Insight, August 21, 2014. http://hhpinsight.com/marine/2014/08/utahs-blu-tackles-marine-lng/ Accessed September 15, 2014.

web, Workboat, DNV GL's own internal research, and the judgment of experienced maritime professionals involved in the industry. The vessels in this analysis are assumed to use dual-fuel engine technologies similar to the six current North American LNG projects under development. These engines are capable of 95-99 percent diesel substitution rates (the rate at which diesel is replaced with natural gas in the engine). While dual-fuel engines allow for increased operational flexibility and a sense of comfort in that they can fall back to 100% fuel oil operation, in the long term we expect that operators will seek to maximize the amount of diesel substitution to achieve maximum cost savings. . For the purposes of this report, GNA estimated the LNG fuel substitution rates of these vessels to be 95 percent. For emerging vessel markets such as articulated tug-barges, pushboats, tugboats, and small passenger vessels, GNA estimated a more conservative substitution rate of 55 percent, based on experiences with Caterpillar's dynamic gas blending technology in other high horsepower market segments like the exploration and production engine markets.

GNA's rail analysis was developed based on conversations with railroads regarding LNG project potential, knowledge of the rail industry, knowledge of existing state of LNG technology and fueling, and timelines related to the railroads' previous energy conversion from steam propulsion to diesel operations in the mid-1900s. Substitution calculations assume a 70 percent displacement rate for dual fuel natural gas engines across the industry as a whole, accounting for a mix of EMD and GE engine technologies.

Although the following marine and rail 15-year growth estimates can give reasonable projections of future LNG use, actual LNG adoption rates will depend on market fluctuations, the price of LNG, fuel availability, regulatory issues, rates of technology adoption, and the decisions of individual end users and operators.

Table 10: Projected number of LNG vessels and fuel demand by 2029

Vessel Group	LNG-Fuelled Vessels by 2029	Annual LNG Demand by 2029 (gallons)
Carrier (Dry Bulk Laker)	6 converted lakers	12,505,207
Cargo and Container	3 converted cargo vessels	6,323,668
Passenger	1 newbuild 1 conversion	239,550
Pushboat and Tugboat	3 newbuilds	517,098
Total	**4 newbuilds** **10 conversions**	**19,585,524**

The highest potential LNG marine projects are conversions from among the 37 newer laker vessels, with long-range opportunity from cargo vessels, passenger vessels, and pushboats and tugs, as appropriate product and fueling infrastructure emerges. The lakers have the highest fuel use potential and investment payback opportunity, making them the best near-term marine opportunity. In the Great Lakes region, where lakers have very little turnover and new ship construction, these projects will largely be conversions. Altogether, these six projected lakers could generate approximately 46,000 gallons of LNG per day, over a nine month time period (lakers do not operate during the ice season). Given the timelines for conversion projects, the challenges with shipyard capacity in the U.S. and the timelines to build new liquefaction, the earliest these projects might emerge would be approximately 2018.

U.S. based marine and rail opportunities could collectively generate demand for 62.6 million gallons of LNG in the Great Lakes region by 2029

The entire line-haul railroad sector can be considered a high LNG potential sector. Therefore, GNA applied its analysis to all the line-haul rail fuel use in the Great Lakes region. The previous transition from steam to diesel in the US rail industry took approximately 30 years to complete. This is an average of about 3.3 percent per year conversion over the 30 year period. Assuming that conversion from diesel to LNG takes a similar path and timeframe to complete and that the adoption of LNG begins in earnest in 2018 due to FRA approvals and manufacturing timelines, GNA estimates that 33 percent of the locomotive fleet would be operating on LNG by 2029. Excluding growth in fuel use over this period, 33 percent conversion would equate to approximately 36 million diesel gallons, or 43 million LNG gallons of annual demand in 2029.[52]

Based on this analysis, U.S. based marine and rail opportunities could collectively generate demand for 62.6 million gallons of LNG in the Great Lakes region by 2029. While these projections provide insight into the broad regional trends for LNG, it is impossible to accurately predict where these vessel adoptions and rail projects will take place. However, a thorough assessment of high-opportunity vessel inventories, rail fuel use, local operations, infrastructure, and local end user insight provides the following insight into the best location-based targets for LNG project opportunities and information about where this near-term LNG demand growth will be centered, as described in the following section.

Geographic and End User Opportunities

Duluth, MN / Superior, MI

Duluth-Superior supports a unique confluence of laker, rail, and mining connectivity that make it one of the best opportunities for LNG in the Great Lakes region, and companies such as WesPac and BLU LNG have both publicly expressed interest in developing liquefaction here, with BLU now actively seeking USCG approvals for bunkering. Much of the iron ore, coal, and taconite from mines in Wyoming, Montana, Minnesota, and the Western U.S. are transported via train to the twin ports of Duluth-Superior, where they are loaded onto lakers for distribution throughout the region. There are eight lakers registered to Key Lakes, Inc., plus Duluth-Superior also receives vessel traffic from Interlake Steamship Company, which initiated an LNG project when the LNG plant in Sarnia was an active project, plus other vessels.

[52] Assuming a 70 percent substitution rate for dual-fuel natural gas engines

Duluth-Superior supports a unique confluence of laker, rail, and mining connectivity that make it one of the best opportunities for LNG in the Great Lakes region

Not only do the local lakers fit the profile for high-LNG potential (post-1950 ships, no recent rebuilds, no exemptions), but the local unit train rail operations haul single commodities on fixed point routes, lending themselves to simpler LNG operations. These dedicated unit trains run between the mines and the port, offering the ability to develop LNG fueling at both ends of a rail route, which is a less complex near-term LNG project than integrating a new fuel into a nationwide rail network. Overall, the rail diesel fuel sales in the state of Minnesota and Wisconsin totals 120 million gallons annually, much of which likely supports operations in and around the ports of Duluth-Superior and mining commodity transport.

There are two main point-to-point rail routes in the region:

- BNSF and UP deliver approximately 19 million tons of coal from the Powder River Basin in Wyoming and Montana every year. The coal is then loaded onto lakers for distribution on the waterways. There are four to six unit trains a day arriving that could be fueled with LNG in Wyoming or Montana and refueled in Superior. This route covers the same ground as Burlington Northern's (BN) LNG pilot project in the 1990s, and represents a new project development opportunity today. Between 1992 and 1995, BN operated two line-haul locomotives using LNG fuel.[53] The LNG powered train hauled 12,000 tons of coal on an approximate 1,700-mile, 3-day trip from mines in northwestern Wyoming and Montana to the shores of Lake Superior. Two locomotives operated as a pair and were fueled by an LNG tender car placed between them. Air Products & Chemicals, Inc. supported the project through the development of two 25,000-gallon LNG tender cars and an LNG fueling facility, located in Staples, MN. All LNG was supplied from this single fueling facility located about 100 miles west of Superior, WI.
- CN, BNSF and one private railroad (North Shore Mining) move approximately 43 million tons of iron ore from the Iron Range in northeastern Minnesota for transshipment to vessels.

The mines that produce and transport commodities to the port of Duluth-Superior represent another opportunity for LNG fuel cost sharing in a long-term project development scenario. Mines use a wide variety of high horsepower equipment running engines that use a significant amount of fuel each day. Ore-carrying trucks have a hauling capacity of 250 to 400 tons and work between 15 - 18 hours a day. The largest mine hauling trucks can each consume over 1,500 gallons of fuel each day[54], and energy costs are estimated to represent more than 15 percent of the total cost of production in the mining industry in the United States.

[53] "An Evaluation of Natural Gas-fueled Locomotives." BNSF Railway et. al., November 2007

[54] "Wyoming's LNG Roadmap." Report for the State of Wyoming prepared by Gladstein, Neandross & Associates, April 2014. http://www.gladstein.org/pdfs/GNA_Wyoming_LNG_Roadmap.pdf, page 37-38. Accessed August 8, 2014.

The major mining equipment engine manufacturers, Caterpillar and GE, are currently developing new natural gas fueled engines for the mining sector, with a few pilot projects underway. The State of Wyoming recently completed an assessment of natural gas powered opportunities in its high horsepower sector, with an emphasis on mining activity. Given the closed loop operations of the railroads running between these Wyoming mines and Duluth-Superior, LNG unit trains could potentially fuel at either point and transport fuel back to the other site for multimodal use.

Given the laker traffic, point-to-point rail, and mining connections in Duluth-Superior, project developers such as BLU and WesPac have publicly noted they are examining LNG adoption with shared liquefaction out of this location. On average, a laker uses approximately 5,000-8,000 gallons of residual fuel per day.[55,56] If the entire fleet of eight vessels registered in Duluth were to convert to LNG, they would each use approximately 8,000-13,000 gallons of LNG per day, which would not be enough to baseload a new LNG plant. However, considering that diesel line-haul locomotives typically carry 5,000 gallons of fuel in on-board tanks and that a unit train will often employ four and six locomotives, the daily fuel demand from coal trains arriving in Superior could be as much as 180,000 diesel gallons per day, or 218,000 gallons of LNG per day. This would bring the total LNG potential in Duluth to 322,000 gallons of LNG per day, at full conversion; a baseload volume well in excess of what is required to attract / justify the investment in a new LNG production plant.

South Lake Michigan

South Lake Michigan supports decentralized fueling throughout many of the steel mill harbors for Chicago-region vessel cargo. Although only four lakers are registered to the local ports, the area supports fueling for many vessels that exchange freight with the rail and trucking intermodal connections. Given that current fueling takes place via truck or barge, operators could similarly integrate LNG truck or barge fueling if a liquefaction facility was developed within a cost-effective transport distance. With BLU LNG's recent announcement that it is seeking USCG approval for local liquefaction, the industry may soon have access to local LNG.

Detroit, Michigan

Although no lakers are registered in Detroit, the city sits at a passage point between Lake Erie and Lake Huron that supports significant vessel traffic. The region is an existing bunkering location with multiple refineries on both sides of the the U.S. and Canadian border that supply marine fuel. Detroit is also located close to Sarnia, Ontario, which supports several bunkering docks. Existing fueling takes place via both land-based terminals and barges, so operators could similarly integrate LNG fueling if a liquefaction facility was developed within a cost-effective transport distance.

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[55] Assumption based on analysis of vessels movements of similar vessel sizes in Gulf of Mexico. Annual fuel use based on a 9-month operating season for Lakers. See Appendix 2 – Methodology for Fuel Use Assumptions for more information.

[56] "Natural Gas for Marine Vessels: U.S. Market Opportunities." American Clean Skies Foundation, April 2012. http://www.cleanskies.org/wp-content/uploads/2012/04/Marine_Vessels_Final_forweb.pdf, accessed August 8, 2014.

Buffalo / Williamsville, NY

The Buffalo region presents an emerging opportunity for LNG operations. The American Steamship Company has 15 lakers registered in Williamsville (Buffalo), although operations likely take place throughout the Great Lakes. The region also houses 13 rail yards. GNA estimates that these rail yards are associated with approximately 18 million gallons of diesel fuel use in line-haul locomotives annually, or 50,000 gallons per day. CSX and NS are the two Class I railroads operating rail yards in the region. Buffalo also represents the access point for ships traveling from the inner Great Lakes to Lake Ontario and the Saint Lawrence River for access to ocean going vessels. The region may also soon have access to LNG through a Canadian company in Thorold, Ontario, just across the Canadian border along the Welland Canal – the waterway that enables ships to safely bypass Niagara Falls. No construction is currently underway, but Northeast Midstream LLC received environmental compliance approval from the Ministry of the Environment in May 2014 for a new LNG plant. The plant is proposed to have production capacity of up to 360,000 gallons per day, with truck distribution of LNG.

Cleveland

Interlake Steamship Company is located in Cleveland and initiated an LNG conversion project for four vessels prior to the Shell LNG plant in Sarnia, Ontario being put on hold. Given this demonstrated interest in LNG and a 10 laker vessel population registered in the area, Cleveland represents another possible LNG project development opportunity, depending on the actual trade routes by Interlake and any other regional operators. In addition to Interlake's seven Cleveland-registered vessels, three other lakers registered here might be viable LNG targets. Rail may offer a potential cost-share opportunity for marine operations in the greater Ohio region overall. Line-haul locomotives in the Cleveland area use approximately 20 million gallons of diesel fuel in the each year, and annual rail fuel use throughout Ohio is approximately 175 million diesel gallons per year. It should be noted that CSX has significant switcher operations in Cleveland and other general operations throughout Ohio, and the company has noted it is examining compressed natural gas operations.

If the ten Laker vessels registered in Cleveland and Avon Lake, OH that were built after 1950 were to convert to LNG, they would use approximately 17.3 million gallons annually, which is equivalent to 64,000 gallons of LNG per day based on a 9-month operating year. This amount could be sufficient to base load a small LNG plant but may not be sufficient to support the costs of the associated marine bunkering infrastructure needed to distribute the fuel. Further coordination with the railroads and vessel operators with routes stopping in Cleveland would help determine the potential for load sharing a local LNG facility in the greater Cleveland area.

Conclusion

The concentration of marine and rail traffic in the Great Lakes region provides an opportunity for LNG project development efforts. However, the complexity of the freight operations presents a unique set of challenges. Marine operators can have changeable routes and fueling locations, depending on their cargo deliveries, and it's difficult to find clear demand clusters among just 37 high value target vessels. It's also exceptionally difficult to estimate marine project costs, given the highly individualized economics of laker conversions and questions about fuel supply locations and associated bunkering needs. Marine and rail operations are highly competitive, and highly efficient fueling operations factor directly into vessel operators' bottom line. Any long-term LNG fueling plan will likely need SIMOPS to be cost competitive with conventional marine fuel operations.

Although there is no single location along the Great Lakes that seems to support marine-dependent baseload at this time, there are promising locations where vessel and rail operations converge and might be able to support intermodal project opportunities:

- Duluth-Superior seems to offer a viable intermodal demand center, but will require significant coordination among rail and mining users. Local stakeholders should watch emerging fuel opportunities with BLU and other LNG developers.
- South Lake Michigan and Detroit may offer marine demand possibilities, given that the regions both support existing cargo and fueling operations. Stakeholders should monitor developments with the proposed BLU bunkering announcement.
- In the Buffalo region, the proposed LNG plant in Thorold, Ontario also offers another intriguing opportunity for regional supply, particularly if the plant is able to supply LNG via bunker barge throughout the region to serve multiple locations from a single supply source. However, the currently proposed location for the Thorold facility lacks waterfront access that would be suitable to transport bunker barges; thus, any LNG supply to a bunker barge would be via tanker trucks, therefore adding costs given the multiple points of LNG transloading between the production facility and on-board the vessel.
- Cleveland has 10 lakers registered locally and notable rail activity in the Cleveland area and Ohio overall. Although it's not likely a first-tier project development region, it bears further monitoring. Gas production in the local Utica and Marcellus shale plays support favorable gas process in the region and coordination among potential rail and marine users may help identify project development opportunities.

There is certainly investor interest in the Great Lakes, but, given the low numbers of highly specific marine vessels, project development work will likely require coordination with rail and other users to help recognize these potential LNG opportunities.

Inland Waterways Region

Overview

The U.S. has over 25,000 miles of navigable, inland waterways.[57] These waterways provide critical value to the economy by moving 630 million tons of cargo valued at $73 billion each year. Though inland waterways connect 38 states to open ocean, the states on the Gulf of Mexico, Midwest, and Ohio Valley are especially reliant on these waterways, key among them being the Mississippi River. These inland waterways are central to the nation's agricultural and energy commerce; the Mississippi River and its major tributaries carry 60 percent of U.S. grain, 22 percent of oil and gas shipments, and 20 percent of U.S. coal.[58] Nationally, inland waterways transport more than 60 percent of U.S. farm exports.[59] Along the lower Mississippi River, ocean going vessels are permitted access and can connect with the river barge traffic between Baton Rouge and the Gulf of Mexico, thereby making this region vital to both the domestic and foreign trade of the United States.

Extending over 2,000 miles north-to-south from Minnesota to Louisiana and east-to-west from Missouri to Pennsylvania, the Mississippi River System is home to thousands of marine vessels that help transport, deliver, or export cargo, liquid, and bulk materials. These waterways provide an incredibly efficient cargo transport system for bulk commodities, with operators connecting multiple barges together, which are then moved by tow and push boats. A single 15-barge tow can carry the cargo equivalent to about 225 rail cars or 870 tractor-trailer trucks[60]. These waterways also connect with major rail centers in locations like St. Louis and Memphis, which can then direct cargo for destinations well off the river pathways.

For the purposes of this analysis, the inland waterways region was defined to include following states: Alabama, Arkansas, Iowa, Illinois, Indiana, Kentucky, Louisiana, Minnesota, Missouri, Mississippi, Ohio, Oklahoma, Pennsylvania, Tennessee, Wisconsin, and West Virginia. The rationale for the selection of these states is that they are home to the Mississippi River and its largest tributaries, which are the Arkansas, Illinois, Missouri, Ohio (including the Allegheny and Monongahela), Red, and Tennessee Rivers. For states with vessels that may operate in another of this report's geographic target regions (such as Louisiana), special consideration was given to individual vessels to ensure correct identification in this study.

One of the key features of the Mississippi River System is this lock-and-dam design, managed by the U.S. Army Corps of Engineers. This design allows for vessels and cargo-laden barges to move between

[57] "Inland Waterway Navigation: Value to the Nation." US Army Corps of Engineers. http://www.sas.usace.army.mil/Portals/61/docs/lakes/thurmond/navigate.pdf, p. 1.
[58] Greenblatt, A. "Mississippi Blues: When the River Doesn't Run." National Public Radio, January 10, 2013. http://www.npr.org/2013/01/10/168950808/mississippi-blues-when-the-river-doesnt-run, accessed July 28, 2014.
[59] "Inland Waterway Navigation: Value to the Nation." US Army Corps of Engineers. http://www.sas.usace.army.mil/Portals/61/docs/lakes/thurmond/navigate.pdf, p. 3.
[60] "Inland Waterway Navigation: Value to the Nation." US Army Corps of Engineers. http://www.sas.usace.army.mil/Portals/61/docs/lakes/thurmond/navigate.pdf, p. 2

different sections of a river that run at different water levels. The lock-and-dam design is important for larger and heavier vessels, especially when navigating shallow or steep sections of the Mississippi River System. As such, the U.S. Army Corps of Engineers maintains 192 commercially active locks with 238 lock chambers.[61]

These locks impact the way that freight can move through the rivers, vessel sizes, traffic patterns, and fuel use. A single tow can consist of 40 or even 60 connected barges on the lower Mississippi, but must be broken down into smaller barge groupings to pass through the locks and dams in the Upper Mississippi, starting in St. Louis. Since many tows operate with 15, 20 or more than 40 barges, passing through smaller locks requires the tow to be "cut" into multiple sections to pass the lock.

Accordingly, the pushboats and tugboats operating north of the Melvin Price Locks and Dam (formerly known as Lock and Dam 26) were designated in this analysis as "above the locks" while those operating south of this location were designated as "below the locks". The vessels "above the locks" are typically smaller and have a different operational profile than "below the locks" vessels, particularly with respect to fuel use.

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61 "Inland Waterway Navigation: Value to the Nation." US Army Corps of Engineers. http://www.sas.usace.army.mil/Portals/61/docs/lakes/thurmond/navigate.pdf, p. 3.

Fuel Use

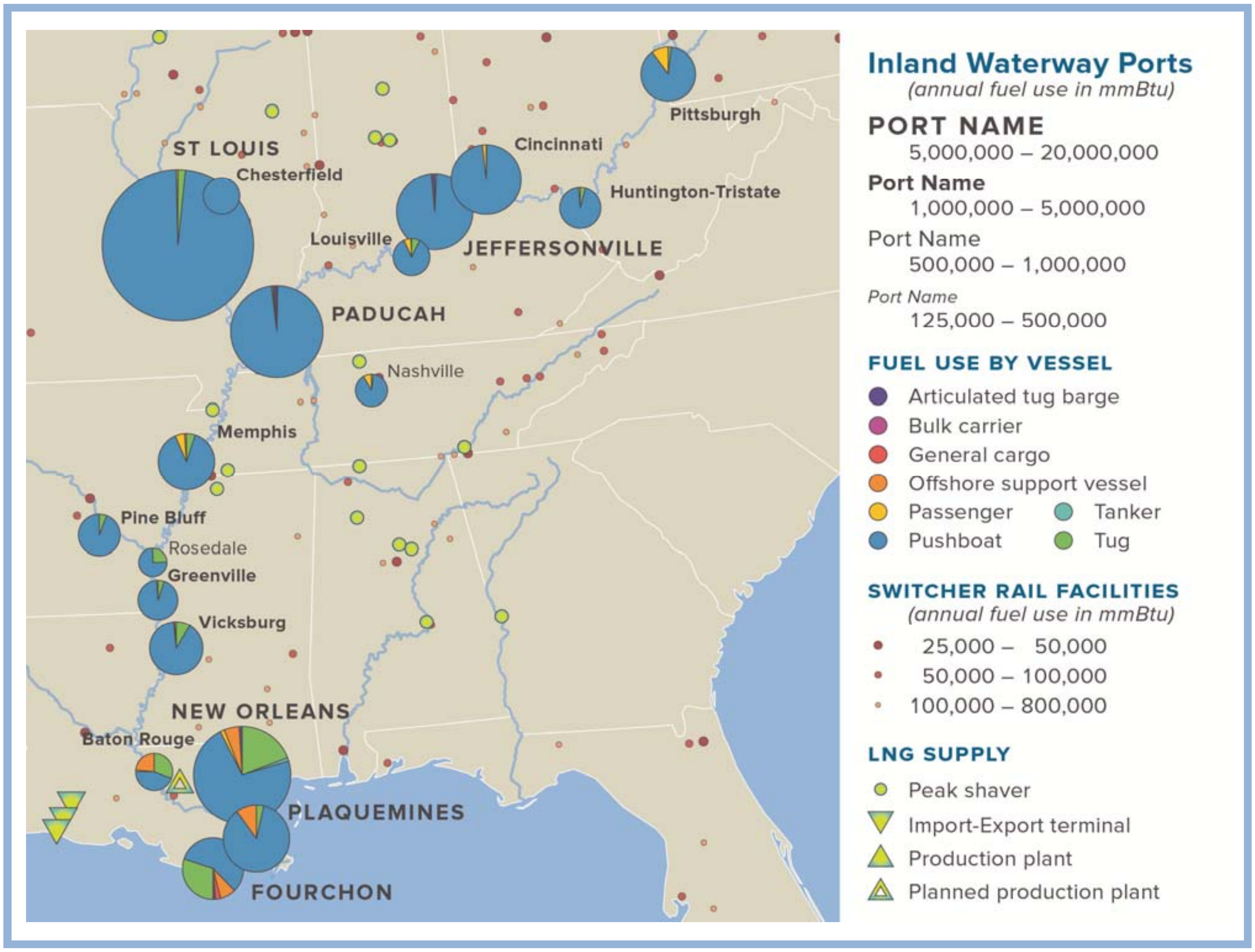

Figure 18: Inland Waterways Marine and Switcher Fuel Use with LNG Supply

Marine

There are 2,585 self-propelled vessels in the inland waterways region with a collective 5,184,000 horsepower.[62] The Mississippi River System is home to a significant portion of the U.S. vessel fleet, accounting for 28.8 percent of registered, U.S.-flagged vessels and 23.7 percent of the total horsepower. As shown in Figure 19, the 1,229 active low horsepower pushboats (< 6,000 hp) operating both above and below the locks make up the majority of the active vessel population and the fuel use. Their 144 high horsepower (> 6,000 hp) counterparts, while only 7 percent of the active vessels, consume 30 percent of the fuel in the region.

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[62] "National Summaries, Volume 1 (2012)." Waterborne Transportation Lines of the United States, US Army Corps of Engineers Navigation Data Center, 2012. http://www.navigationdatacenter.us/veslchar/pdf/wtlusvl1_12.pdf. accessed July 29, 2014.

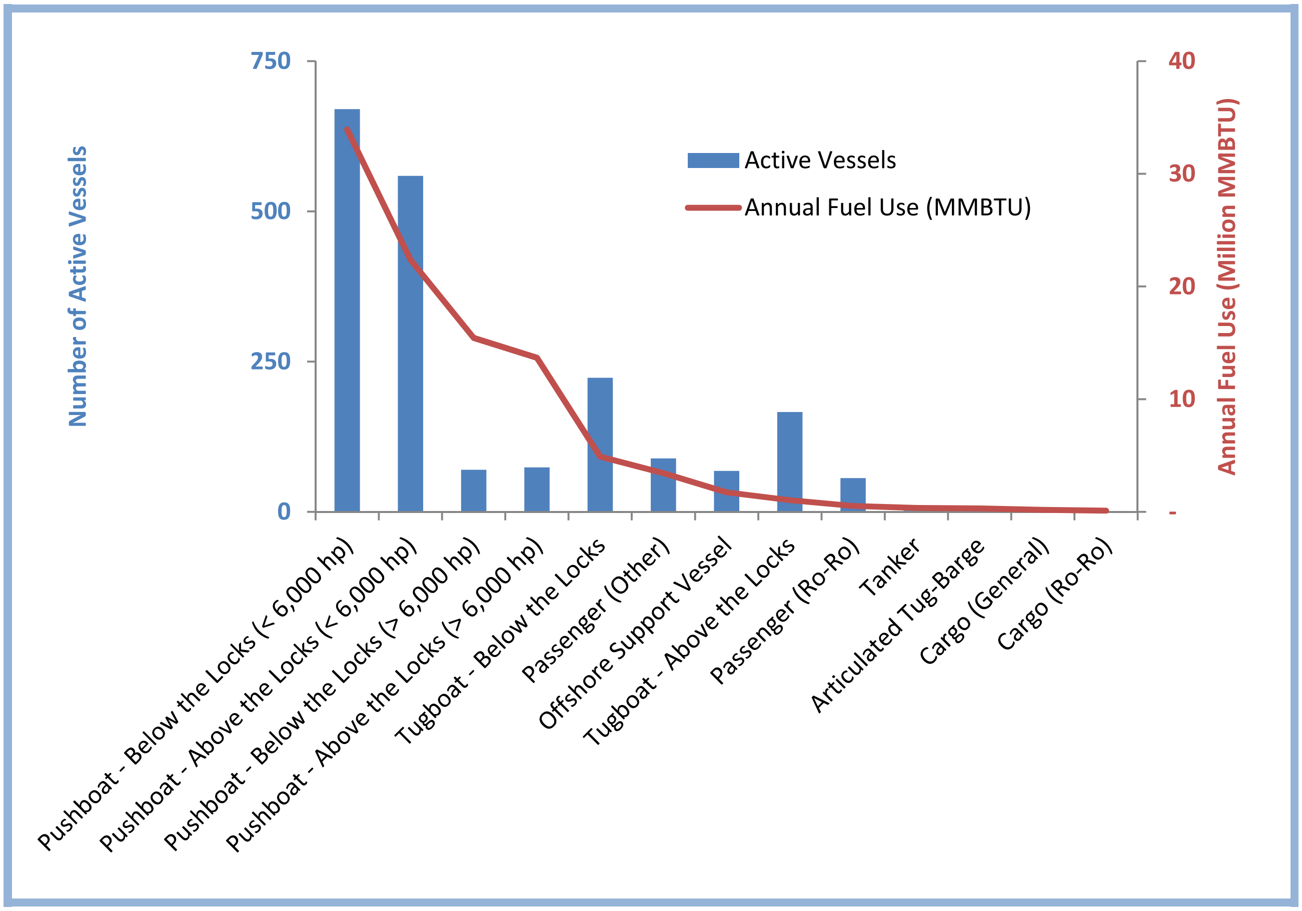

Figure 19: U.S.-flagged vessels active in the inland waterways and their cumulative fuel use[63]

The marine sector uses multiple types of fuels, spanning the different distillate, intermediate, and residual mixtures, each of which has different densities and weights. As such, it can be difficult to adequately quantify fuel use and demand when measuring in volumes. Thus, in order to present a consolidated and fuel-neutral view, this report's analysis of the marine sector displays fuel use and demand figures by their energy content (shown in MMBTU), rather than the volume of a specific fuel. This was then used to identify energy demand clusters and to project LNG demand scenarios.

Currently, there are no known projects working to build and deploy LNG vessels on the inland waterways, although several operators have and continue to look aggressively at the opportunity. For example, BLU LNG has indicated its interest in developing the inland waterways market segment and has hired four marine engineers who could manage future LNG conversion projects. Other manufacturers and fuel providers are also working with vessel owners to initiate pilot projects, many of which are looking at using a conversion strategy to retrofit existing vessels. Although current end user

[63] "National Summaries, Volume 1 (2012)." Waterborne Transportation Lines of the United States, US Army Corps of Engineers Navigation Data Center, 2012. http://www.navigationdatacenter.us/veslchar/pdf/wtlusvl1_12.pdf. accessed July 29, 2014.

projects are still in the conceptual stage, there is demonstrated interest among stakeholders in developing the inland waterways LNG markets. For the purpose of analysis, if all the inland waterways pushboats were to convert to LNG operations, they would generate an estimated annual demand of 628.6 million gallons of LNG, or 1.7 million gallons per day. This potential stems from a combination of high installed engine power and high fuel use. Even the smallest pushboats, operating above the locks, would still require approximately 264,000 gallons of LNG each year.

Despite the potential annual cost savings from LNG, there remain several technical, regulatory and economic challenges related to pushboat conversions and LNG tank placements. Conversions offer near-term project opportunities for high fuel use operators and those with conducive existing vessel designs. Broad adoption will likely depend on developing newbuild product for pushboats operators whose operations don't provide favorable economics for conversion strategies.

Table 11: Annual fuel use and LNG demand for select Inland Waterways vessels

Vessel Type	Number of Active Vessels	Annual Fuel Use *(MMBTU)*	Potential Annual LNG Demand *(LNG gallons)*
Pushboat - Below the Locks (< 6,000 hp)	670	33,940,855	249,832,313
Pushboat - Above the Locks (< 6,000 hp)	559	22,360,483	164,591,349
Pushboat - Below the Locks (> 6,000 hp)	70	15,427,116	113,556,127
Pushboat - Above the Locks (> 6,000 hp)	74	13,676,037	100,666,757
TOTAL	**1,373**	**85,404,491**	**628,646,546**

Although GNA's analysis can approximate the total potential regional demand for LNG marine fuel across the inland waterways as a whole, and even though the location-based demand centers on the map in Figure 18 correlate with freight hubs, the potential LNG demand centers do not necessarily correlate with actual current fueling locations along the waterways. These nuances and challenges to the analysis are discussed in further detail in the following sections.

Although international and domestic bulk vessels enter the lower Mississippi river to collect cargo from inland waterways barges, these ships are largely registered outside the study area, and so their local fuel use was not accurately represented in this regional analysis, apart from a few locally registered tankers. The Gulf of Mexico section of this report analyzes actual activity use data in the Gulf of Mexico waters and makes projections about international fleet growth for vessels operating in the Gulf, including bulk carriers. Accordingly, most demand associated with lower Mississippi bulk vessel trade has been captured elsewhere in this report.

Rail

GNA identified a total of 14 states with rail yards within 10 miles of significant inland waterways ports. In these 14 states, EIA reports that 941 million gallons of diesel fuel were sold to railroads for all uses, including line-haul locomotive fueling. The two largest states by fuel sales are Ohio and Pennsylvania. These two states touch the Great Lakes, as do Indiana, Illinois, and Minnesota. As a result, their associated railroad fuel sales support rail activities in both the Great Lakes and inland waterways regions. High fuel sales volumes in Kansas are likely attributed to the concentration of rail yards in Kansas City. The city effectively spans the state border between Kansas and Missouri and serves as a major rail interchange for UP, BNSF, KCS, and NS railroads.

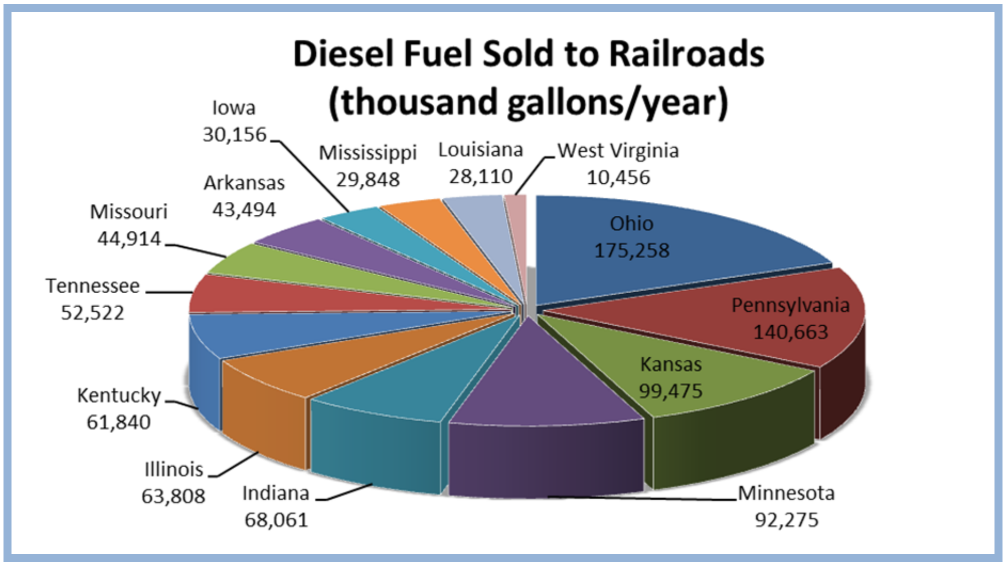

Figure 20: Diesel fuel sales by state to railroads – inland waterways region[64]

Of the EIA fuel sales, GNA estimates that total switcher locomotive fuel demand in the 14 inland waterways states accounts for 113 million gallons.[65] Due to economic and logistical challenges of natural gas in switcher locomotive applications, the Class I railroads have chosen to focus on line-haul locomotives for near-term LNG opportunities. Based on this, switchers are not considered a near- or medium-term LNG project development opportunity and their fuel use was removed from the analysis.

Although Class I switcher operations might not be a near-term opportunity for LNG, their activity is assumed to be indicative of line-haul locomotive activity and fueling opportunities. To identify key rail yards and regions for line-haul fueling opportunities, GNA estimated the total switcher fuel use at rail yards within 10 miles of significant ports on the inland waterways. Kansas City leads the region with 14 percent of total fuel use. This is not surprising given the very significant rail presence in the area. The twin cities of Minneapolis and St. Paul, Minnesota utilize an estimated 10 percent of the switcher fuel

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[64] US EIA, “Sales of Distillate Fuel Oil for Railroad Use”, 2013

[65] Bergin M., Harrell M., Janssen M., “Locomotive Emission Inventories for the United States from ERTAC Rail”, 2012.http://www.georgiaair.org/airpermit/downloads/planningsupport/regdev/locomotives/inventory_ertacrail_2012.pdf

each year. St. Louis hosts significant rail activity as well as marine activity and rounds out the top three areas for rail fuel use in the inland waterways. The largest switcher operator in the region is UP, but no one operator has more than about one-third of the estimated line-haul activity.

Table 12: Top 10 Inland Waterways rail yards (regional) and estimated switcher fuel use

Port City	Number of Rail Yards	Fraction of Inland Waterways Regional Switcher Fuel Use	Fraction of State Switcher Fuel Use
Kansas City Area	27	14%	38%
St. Paul Area	11	10%	85%
St. Louis Area	29	8%	15%
Oak Brook, IL	8	8%	20%
Chattanooga, TN	9	7%	28%
North Little Rock, AR	2	5%	21%
Cincinnati Area	8	4%	14%
Memphis, TN	14	4%	16%
Pine Bluff, AR	1	4%	16%
Nashville, TN	3	3%	14%

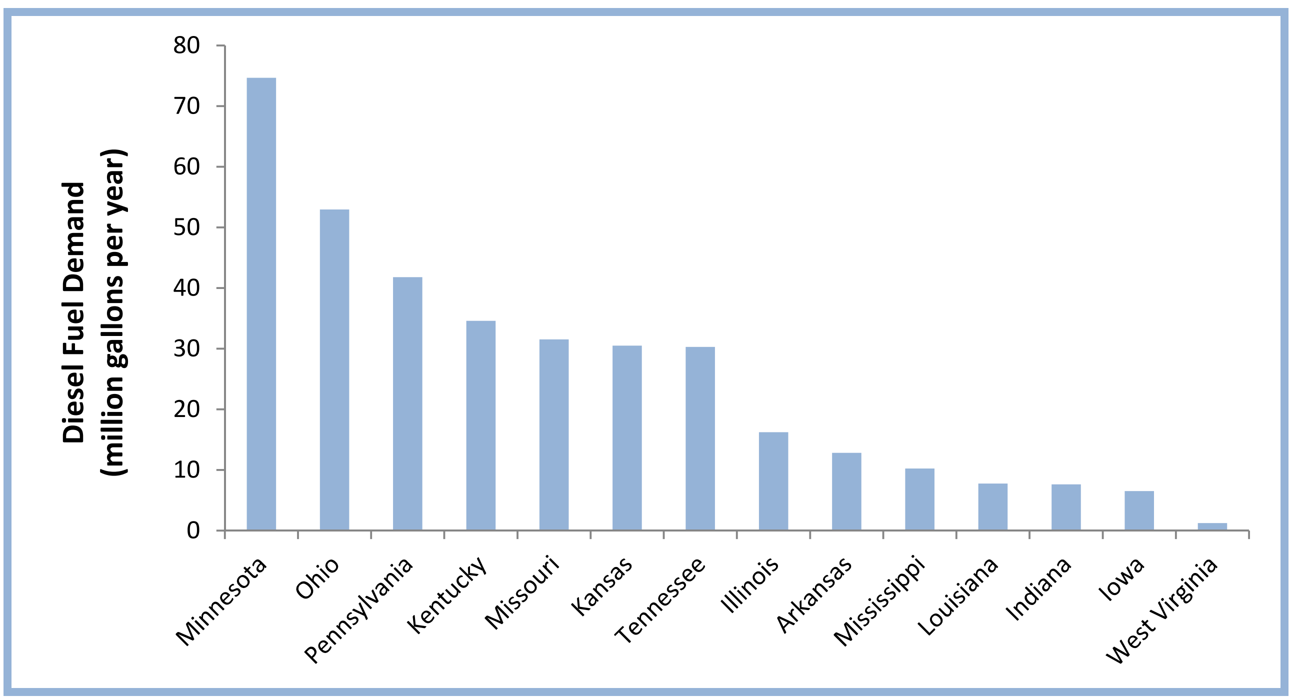

Figure 21: High opportunity railroad fuel use in the Inland Waterways Region

At full conversion, line-haul rail operations in the study region could represent 359 million gallons of current annual diesel demand, or 435 million gallons of potential LNG demand.[66] Given the concentration of rail operations in the region, many of the Class I railroads may be able to identify LNG opportunities in the region, including UP, BNSF, CSX, CN, NS, and KCS.

Fueling and Infrastructure

Fueling Operations

Fueling along the inland waterways is largely conducted via barge at hubs, and not in specific ports or at conventional bunkering facilities. These hubs occur at fixed locations along the rivers from New Orleans up to St. Louis, generally at barge interchange locations. The large barge operators (such as American Commercial Lines or Ingram Barge Co.) can provide their own fueling hubs or contract with fueling operators at set points along their routes.

All fueling is done from barges that operate as floating fuel stations, and generally takes place along the side of the river. These are full service fueling operations that take care of fuel, lube, water, waste disposal, and wastewater needs. "Mid streaming" fuel operations can also take place while the vessel is stopped in the middle of the river en route, although this practice is diminishing in use due to safety and risk considerations.

Major fueling hubs exist in the lower Mississippi river area (between New Orleans and Baton Rouge), Memphis, St. Louis, and Paducah. Less fueling takes place around St. Paul or Pittsburgh, and almost no fueling takes place in Chicago since the city is close enough to St. Louis that local depots are unnecessary (pushboats can fuel in St. Louis, travel to Chicago and return to St. Louis without having to refuel along the way). Each pushboat company will have its own specific fueling approaches, regional hubs, and specific barge-fueled locations and not all companies operate on all the rivers.

Existing and Planned LNG Infrastructure

There is no existing large-scale liquefaction along the inland waterways that can support a network-wide transition to LNG. However, there are several vessel fueling and rail intermodal hubs that have access to existing LNG fuel that might be capable of supporting pilot projects. Memphis and Paducah are located close to utility peak shaver facilities that may be able to provide enough LNG for pilot project development. Successful pilot projects could then help accelerate market interest and growth.

Operators in the lower Mississippi may also be able to take advantage of existing and emerging LNG fueling opportunities from the LNG export facilities in Louisiana and the recently announced Tenaska Bayou LNG project. Cheniere's Sabine Pass, LA export facility is under construction and scheduled for completion by the end of 2015, and LNG America is planning to distribute marine fuel from the Cheniere facility starting in early 2016. LNG America recently contracted with Jensen Maritime to design an LNG

[66] Assuming a 70 percent substitution rate for dual-fuel natural gas engines

bunker barge capable of delivering LNG from Sabine Pass to coastal storage and distribution terminals throughout the Gulf Coast region as well directly bunkering large ships.[67] LNG America is planning to use these barges to fill storage vessels and provide fueling at locations throughout Texas, Louisiana, Alabama and along the lower Mississippi river.

Memphis and Paducah are located close to utility peak shaver facilities that may be able to provide enough LNG for pilot project development... Operators in the lower Mississippi may also be able to take advantage of LNG fueling opportunities from LNG export facilities and proposed production plants in Louisiana.

Waller Marine and Tenaska fuels recently announced a plan in September 2014 to develop liquefaction and transportation sector fueling on approximately 80 acres at the Port of Baton Rouge.[68] The LNG proposed facility will be capable of producing 200,000 gallons of LNG each day, with capacity to expand, and is specifically targeting inland waterway markets. The facility also has access to Class 1 rail adjacent to the property, and will be developed with tractor truck fueling facilities for LNG-fueled trucks, loading facilities for transporting LNG via tanker truck, and a dock for the mooring of LNG bunker barges. Waller Marine will coordinate bunker barge design and construction while Tenaska will be the managing partner that will provide equity, development and management of the liquefaction facility. Both companies are jointly marketing LNG to users throughout the region. The partners are targeting operations in 2017, although the final project will likely depend on technical approvals and commercial fueling agreements before ultimately proceeding.

BLU LNG has also signaled its interest in supplying fuel for the inland waterways markets, though it is focusing on the Great Lakes regions and northern river connections. In August 2014, BLU LNG announced that it had two LNG bunkering permits under review for Duluth and South Lake Michigan with the USCG and hoped for approval in the fourth quarter of 2014.[69] A facility on South Lake Michigan may be able to provide fuel for operations above St. Louis.

Inland Waterways LNG Growth Opportunities

GNA estimated LNG market penetration rates for marine applications in the inland waterways region by applying our own internal research and projection methodology developed by DNV-GL for the domestic

[67] "Jensen Maritime Selected to Design Some of First LNG Bunker Barges in U.S." Crowley, February 24, 2014. http://www.crowley.com/News-and-Media/Press-Releases/Jensen-Maritime-Selected-to-Design-Some-of-First-LNG-Bunker-Barges-in-U.S, accessed July 21, 2014.

[68] Young, Renita D. "First Louisiana Natural Gas Liquefaction, Fueling Facility Planned for Port of Baton Rouge." Nola.com. The Times Picayune, 30 Sept. 2014. Web. 30 Sept. 2014. <http://www.nola.com/business/baton-rouge/index.ssf/2014/09/first_louisiana_natural_gas_li.html>

[69] Piellisch, R. "Utah's BLU Tackles LNG Bunkering." HHP Insight, August 21, 2014. http://hhpinsight.com/marine/2014/08/utahs-blu-tackles-marine-lng/ Accessed September 15, 2014.

LNG vessel fleet. DNV's estimates are based on research from the industry's news sources including Clarkson's, Lloyds List, Fairplay, Tradewinds, Sea-web, and Workboat, DNV GL's own internal research, and the judgment of experienced maritime professionals involved in the industry. The vessels in this analysis are assumed to use dual-fuel engine technologies similar to the six current North American LNG projects under development. These engines are capable of 95 to 99 percent diesel substitution rates. While dual-fuel engines allow for increased operational flexibility and a sense of comfort in that they can fall back to a 100 percent diesel operation, in the long term we expect that operators will seek to maximize the amount of diesel substitution to achieve maximum cost savings.

GNA's rail analysis was developed based on conversations with railroads regarding LNG project potential, knowledge of the rail industry, knowledge of existing state of LNG technology and fueling, and timelines related to the railroads' previous energy conversion from steam propulsion to diesel operations in the mid-1900s.

Although the following marine and rail estimates can give reasonable projections of future LNG use, actual LNG adoption rates will depend on market fluctuations, the price of LNG, fuel availability, regulatory issues, rates of technology adoption, and the decisions of individual end users and operators.

The LNG-fueled marine vessel fleet operating along the inland waterways is expected to add 81 newbuilds and convert another five vessels (Table 13). Sixty six (66) of the newbuilds are expected to be pushboats and tugboats, which could generate demand for 26.1 million gallons of LNG annually, equivalent to 71,000 LNG gallons per day. Another 14 newbuilds will be offshore support vessels based out of river ports in southern Louisiana, namely New Orleans and Belle Chasse. The remaining vessel types are large vessels that are not expected to have large fleet increases. However, even small shifts towards LNG can generate substantial demand, as shown by the expected addition of five LNG tankers in the regional marketplace by 2029.

Table 13: Projected number of Inland Waterways LNG vessels and fuel demand by 2029

Vessel Group	LNG-Fueled Vessels by 2029	Potential LNG Demand by 2029 *(LNG gallons)*
Cargo (General)	1 conversion	2,107,889
Pushboat and Tugboat	66 newbuilds	26,072,325
Offshore Support Vessel (Based in SE Louisiana)	14 newbuilds	4,491,250
Tanker	1 newbuild 4 conversions	13,018,792
Total	**81 newbuilds 5 conversions**	**45,690,257**

Much of the current fuel use is generated by pushboats and tugboats registered "below the locks." Since pushboat fueling largely takes place below St. Louis, this demand for LNG will also originate in fueling locations below the locks. There is currently no commercially available product for U.S. pushboats, and there are some technical challenges related to installing LNG tanks on the deck or any connected barges, as well as a lack of USCG approval for such an approach. Given the time required to work through such issues, GNA therefore anticipates that any growth in pushboat demand will arise starting in the early 2020s. There may be some early demonstration projects that take place in the interim period, but larger scale commercial deployments will not likely occur until this time. Tankers operating along the inland waterways already have product availability, and growth could emerge as early as 2018. Altogether, demand from these marine populations could total 45.7 million gallons per year by 2029.

Growth in pushboat demand [could] arise starting in the early 2020s. There may be some early demonstration projects that take place in the interim period… Tankers operating along the inland waterways already have product availability, and growth could emerge as early as 2018. Altogether, demand from these marine populations could total 45.7 million gallons per year by 2029

For rail demand projections, GNA assumed that conversion from diesel to LNG in rail will take a similar path and timeframe to complete as the conversion from steam to diesel locomotives did in the mid-1900's. Adoption of LNG is assumed to begin in earnest in 2018 due to FRA approvals and manufacturing timelines. GNA estimates that 33 percent of the locomotive fleet would be operating on LNG by 2029. Excluding growth in fuel use over this period, 33 percent conversion would equate to approximately 120 million diesel gallons, or 145 million LNG gallons of annual demand in 2029.[70] While this projected demand is nearly three times higher than the projected demand in the Great Lakes region, the inland waterways are a much larger geographic region and fuel demand is distributed over a greater area. In the Great Lakes region, the top two port areas represent more than half the total rail fuel demand. By contrast, six port areas in the inland waterways region make up half of the total rail fuel demand. Despite the greater geographic distribution of fuel demand, the top three areas for rail fuel use in the inland waterways region reflect over 30 million LNG gallons of potential fuel demand in 2029.

While these projections provide insight into possible regional growth trends, it is impossible to accurately predict where these vessel adoptions and rail projects will take place.

Geographic and End User Opportunities

It should be noted that reliance on registered vessel data presents a challenge specific to the overall inland waterways geographic analysis. In the absence of vessel movement activity data, GNA associated

[70] Assuming a 70 percent substitution rate for dual-fuel natural gas engines

vessel fuel use with vessel registration locations to provide a high level look at regional fuel use and capture approximate regional totals. However, for inland waterways operations, riverboat operators tend to travel along entire river networks and do not have standard “return to base” operations wherein the majority of their fueling occurs in Memphis or St. Louis. Instead, these vessels generally fuel somewhere along the lower Mississippi (between New Orleans and Baton Rouge), somewhere around Memphis, somewhere around St Louis, somewhere around Paducah, somewhere around St. Paul and somewhere around Pittsburgh, depending on specific operations.

Given the realities of marine fueling operations along the inland waterways, LNG projects will likely need LNG supply at several points along these corridors. This makes location-based conclusions more challenging and requires additional analysis with local operators to identify specific needs and opportunities to start building the LNG market via discrete projects along a single stretch of river.

Lower Mississippi River (southeastern Louisiana)

The lower Mississippi River stretches south of Memphis, Tennessee to the major ports in southern Louisiana. Pushboats and tugboats running north to south on the lower Mississippi River will typically call in one of the major river ports in Louisiana: Baton Rouge, New Orleans, Plauqemines or South Louisiana. Most pushboats and tugboats going north will fuel here at the start of their route. This corridor presents a high opportunity for LNG-fuelled marine vessels due to the overlap with the Gulf of Mexico market, which could provide a more stable return-to-base vessel population subset to support LNG infrastructure. This region also hosts many ocean going vessels engaging in bulk cargo trade exchanges with the barges, and many of these bulk vessels may also be LNG targets.

As discussed further in the Gulf of Mexico section of this report, the south Louisiana region is a prime target for LNG because of the high volume of offshore support vessels and large vessel traffic, from both international and domestic ships, and due to local LNG supply opportunities. The region has existing LNG merchant plants in Texas, export facilities that are under construction in Louisiana, and a proposed LNG facility in the Port of Baton Rouge. GNA’s analysis projects that the southern Louisiana river ports of Baton Rouge, New Orleans, Plaquemines and South Louisiana could contribute significantly to the 112 expected LNG-fueled offshore supply vessels operating in the Gulf of Mexico by 2029. There are two major players in the lower Mississippi River pushboat and tugboat market registered out of these ports (Blessey Marine Services, Inc. with 54 registered vessels in New Orleans and Marquette Transportation Gulf Inland with 49 registered vessels in New Orleans) who might be able to identify operationally feasible approaches to local LNG operations.

GNA identified few major rail fueling opportunities south of Memphis along the Mississippi river, though UP seems to have some operations in the region. This minimal activity may be due in part to competition from pushboats along this part of the river and the barge efficiencies as compared to rail, as well as increased freight distribution by on-highway truck in this part of the country. While the Port of New Orleans is unlikely to provide significant rail fuel demand based on current rail activity, it does provide an interconnection for six of the Class I railroads. The Port of Baton Rouge also has connectivity to Class I rail lines. Liquefaction at these ports could be a strategic location from which to provide fuel to LNG powered locomotives in this region and/or distribute LNG by rail car.

Middle Mississippi River (Memphis, TN to St. Louis, MO)

Project development in the Mississippi River corridor between Memphis, Tennessee and St. Louis, Missouri might benefit from targeting rail customers to develop enough baseload LNG demand for new LNG plant construction. Rail opportunities are significant in this area and could be used to build stable demand for these two large marine fueling hubs. St. Louis is the third largest area for rail fuel consumption in the region, with six of the Class I railroads operating rail yards in the area. St. Louis is also approximately 250 miles east of Kansas City, the largest area of rail activity in the region and an area that is second only to Chicago in terms of rail traffic. St. Louis and Kansas City are connected by road, rail, and the Missouri River; allowing for a range of options to transport LNG between the two regions. The Memphis area also has 14 switcher yards for several Class I railroads. In aggregate, Memphis, St. Louis, and Kansas City represent 26 percent of the inland waterways region's rail fuel use, approximately 93 million gallons of diesel fuel annually.

Rail opportunities are significant in this area and could be used to build stable demand for two large marine fueling hubs. In aggregate, Memphis, St. Louis, and Kansas City [which connects with St. Louis by road, rail and the Missouri River) represent 26 percent of the inland waterways region's rail fuel use, approximately 93 million gallons of diesel fuel annually.

Both the Memphis and St Louis regions have major river fueling hubs; however, most of the vessels are passing through and operate on long stretches of the river, fueling multiple times along the way. Memphis is an important fueling location for Mississippi River and Ohio River traffic. St Louis is an important point for boats that then continue onward to Chicago and St Paul.

Ohio River (Paducah, KY / Louisville, KY/Cincinnati, OH/Pittsburgh, PA)

The Ohio River stretches from its confluence with the Mississippi just north of Memphis eastward through Pittsburgh. The lower Ohio River traffic is centered at Paducah, Kentucky, where 86 pushboats and tugboats are registered, with another 90 vessels in Jeffersonville, Indiana and Louisville, Kentucky (87 of which are owned by American Commercial Lines). Many of these vessels run northeast into Pennsylvania to support coal barges, which provides some opportunity to build connectivity with the LNG corridor planned by Pittsburgh Clean Cities. The Paducah region supports some river boat fueling hubs, with less fueling happening in Pittsburgh.

The Port of Pittsburgh Commission and the Pittsburgh Region Clean Cities recently launched the Clean Fuels / Clean Rivers Consortium.[71] The consortium's goal is to build a natural gas marine corridor that extends from Morgantown, West Virginia through Pennsylvania and Ohio, targeting tow boats on the Allegheny, Monongahela, and Ohio Rivers. Funding has thus far been provided by the Richard King

[71] "Clean Fuels/Clean Rivers." The Power of 32, The Pittsburgh Foundation. http://www.powerof32.org/news-updates/show.php?44, accessed July 30, 2014.

Mellon Foundation, the Claude Worthington Benedum Foundation, as well as other private companies.[72,73] Clean Fuels/Clean Rivers expects to deliver a feasibility study in late 2014 that address the technological and economic assessment of converting towboats to LNG operations. In tandem with the study, the consortium is also planning a pilot project that would convert an existing towboat. Though the group doesn't have a specific vessel in mind, they state that a conversion could be done as early as the end of 2014.[74] While Pittsburgh and the surrounding region have access to inexpensive gas from the Marcellus Shale, it is unclear that their smaller pushboats and smaller local fueling operations will support a significant conversion at this time. However, given the support from local government and industry, it is worth working with stakeholders to expand on these opportunities to help benefit the range of inland waterway river traffic.

[The inland waterways] could require 68 million gallons of LNG annually by the year 2029. However, translating potential LNG fuel projections into real tangible demand could require some significant coordination among multiple marine operators, line-haul rail and infrastructure providers to develop an effective infrastructure network along the major operational routes of the pushboats and tugboats.

Neither Louisville nor Pittsburgh appear to be amongst the top areas in the region for rail fueling activity that might support co-located marine project development. This could change as the railroads are continually improving their networks. Because of the potential overlap with marine opportunities, this area bears further monitoring.

Conclusion

The inland waterways marine and rail markets offer some unique opportunities and singular challenges for LNG project development efforts. This part of the study region could require 68 million gallons of LNG annually by the year 2029. However, translating potential LNG fuel projections into real tangible demand could require some significant coordination among multiple marine operators, line-haul rail and infrastructure providers to develop an effective infrastructure network along the major operational routes of the pushboats and tugboats.

Infrastructure might emerge more easily in the lower Mississippi River due to demand from other Gulf Coast markets and the existence of local liquefaction, as indicated by the recent Tenaska Bayou LNG announcement in the Port of Baton Rouge. However, it is more challenging to develop upriver LNG

[72] "Grants Approved in 2013." Richard King Mellon Foundation. http://foundationcenter.org/grantmaker/rkmellon/grantlist2013_reg_econ_dev.html, accessed July 30, 2014.
[73] "Existing Grants." Claude Worthington Benedum Foundation, 2012. http://www.benedum.org/grants/grantsearch.cfm?&criteria=&srcstate=&srcarea=Economic%20Development&srcyear=2012&startrec=16, accessed July 30, 2014.
[74] "Clean Fuels/Clean Rivers." The Power of 32, The Pittsburgh Foundation. http://www.powerof32.org/news-updates/show.php?44, accessed July 30, 2014.

infrastructure to support the pass-through boats along their full waterway routes. Rail users in Memphis and St Louis offer intriguing opportunities to help baseload marine demand; however, the upriver marine and rail segments have particularly fierce competition, thereby potentially inhibiting cooperative fueling projects when one segment would instead prefer to take advantage of the LNG fuel cost saving advantages in advance of their competitor.

Beyond fuel supply, the conversion of the existing fleet of vessels in this segment of the study area will prove challenging. There is little room on the deck of most push and tug boats and finding sufficient space for large LNG tanks continues to present challenges to the industry. While some have proposed to have an adjacent barge with an LNG tank feeding fuel across to the push boat, the logistics of such an operation will be challenging, as will be gaining USCG approvals for such a concept. While newbuilds likely present better opportunities for LNG market development due to the ability to integrate an LNG storage tank below the deck, there is currently no clear timeline from LNG pushboat manufacturers on having such a commercially available product.

While conversion of this market to operate on LNG will not be easy, there are some clear locations where increased coordination and cooperating among stakeholders could benefit multiple users and where new sources of LNG fuel supply can help to further develop the overall market. The lower Mississippi has LNG export facility access and LNG America should be able to deliver LNG within this region beginning in 2016. Tenaska Bayou LNG may come online in 2017 to directly support this market, pending final commercial and technical developments. In the interim, LNG can be delivered via tanker truck from existing and planned merchant LNG plants outside of Houston and Dallas, Texas. Memphis has access to some existing municipal utility peak shavers that are able to distribute LNG fuel to non-core pipeline customers and could thus support initial pilot projects in the study area. Pittsburgh is trying to build an LNG corridor and can access LNG across the state. Existing LNG supplies in Memphis and Pittsburgh may not be enough to support long-term growth, but it may be able to help build pilot projects that could help propel technology and associated interest and growth.

Gulf of Mexico Region

Overview

The Gulf Coast region comprises 16,000 miles of coastlines in five U.S. states: Alabama, Florida, Louisiana, Mississippi, and Texas.[75] The region is home to a population of 58.5 million people and has experienced a higher than average growth rate over the past few years, led by Texas (4.8 percent since 2010) and Florida (3.75 percent). In addition to the Mississippi River outlet in southeast Louisiana, the Gulf Coast region also includes the Gulf Intracoastal Waterway, a protected shipping channel for barge traffic that runs 1,050 miles between Brownville, Texas and Carrabelle, Florida.[76] Along with the economic activity driven by energy activities and the fish and shrimp industries, the Gulf Coast Region is also buoyed by tremendous cargo volume. In fact, of the 10 busiest international ports by cargo volume, two are in the Gulf Coast region (South Louisiana and Houston) and seven of the U.S.'s top 10 ports by cargo volume are in the Gulf Coast (Table 14).[77]

Table 14: Top ten U.S. ports by cargo volume (tons) and vessel calls

Rank	Port	ANGA Region	Cargo Volume (tons) [78]	Vessel Calls (2011)[79,80]
1	South Louisiana	Gulf Coast	252,069,033	4,089[81]
2	Houston, TX	Gulf Coast	238,185,582	7,218
3	New York, NY and NJ	Outside of Scope	132,039,959	4,661
4	New Orleans, LA	Gulf Coast	79,342,141	2,942
5	Beaumont, TX	Gulf Coast	78,515,010	270
6	Long Beach, CA	Outside of Scope	77,385,055	~2,700*
7	Corpus Christi, TX	Gulf Coast	69,001,357	979
8	Los Angeles, CA	Outside of Scope	61,819,495	~2,700*
9	Baton Rouge, LA	Gulf Coast	59,992,818	Unknown
10	Plaquemines, LA	Gulf Coast	58,280,348	Unknown

** Ports of Los Angeles and Long Beach cumulatively received 5,364 calls. Thus, each location only received a portion of the 5,364 shown.*

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[75] "General Facts about the Gulf of Mexico." Gulf of Mexico Program, U.S. Environmental Protection Agency. http://www.epa.gov/gmpo/about/facts.html, accessed July 31, 2014.

[76] "History of the Gulf Intracoastal Waterway." U.S. Army Corps of Engineers. http://web.archive.org/web/20051208070639/http://www.usace.army.mil/inet/usace-docs/misc/nws83-9/entire.pdf, accessed July 28, 2014.

[77] "General Facts about the Gulf of Mexico." Gulf of Mexico Program, U.S. Environmental Protection Agency. http://www.epa.gov/gmpo/about/facts.html, accessed July 31, 2014.

[78] "U.S. Waterway Data: Principal Ports of the United States." U.S. Army Corps of Engineers Navigation Data Center. http://www.navigationdatacenter.us/data/datappor.htm, accessed July 28, 2014.

[79] "Vessel Calls Snapshot, 2011". U.S. Department of Transportation Maritime Administration, November 2013. http://www.marad.dot.gov/documents/Vessel_Calls_at_US_Ports_Snapshot.pdf, accessed July 31, 2014.

[80] "Table 3-6: Top 50 U.S. Ports by Port Calls and Vessel Type: 2011." United Stated Department of Transportation. http://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/state_transportation_statistics/state_transportation_statistics_2012/html/table_03_06.html, accessed July 31, 2014.

[81] Nodar, J. "Going With The Grain." Gulf Shipper, November 24, 2008. http://www.bluetoad.com/article/Going+With+The+Grain/72051/0/article.html, accessed July 31, 2014.

The Gulf of Mexico is a national hub of energy resources and infrastructure, which includes a large marine component for both production operations support and energy transport. Offshore platforms produce 23 percent of total U.S. crude oil and seven percent of total U.S. natural gas dry production. In addition, over 40 percent of the U.S.'s refining capacity and 30 percent of the U.S.'s natural gas processing plant capacity is located along the Gulf Coast.[82]

Fuel Use

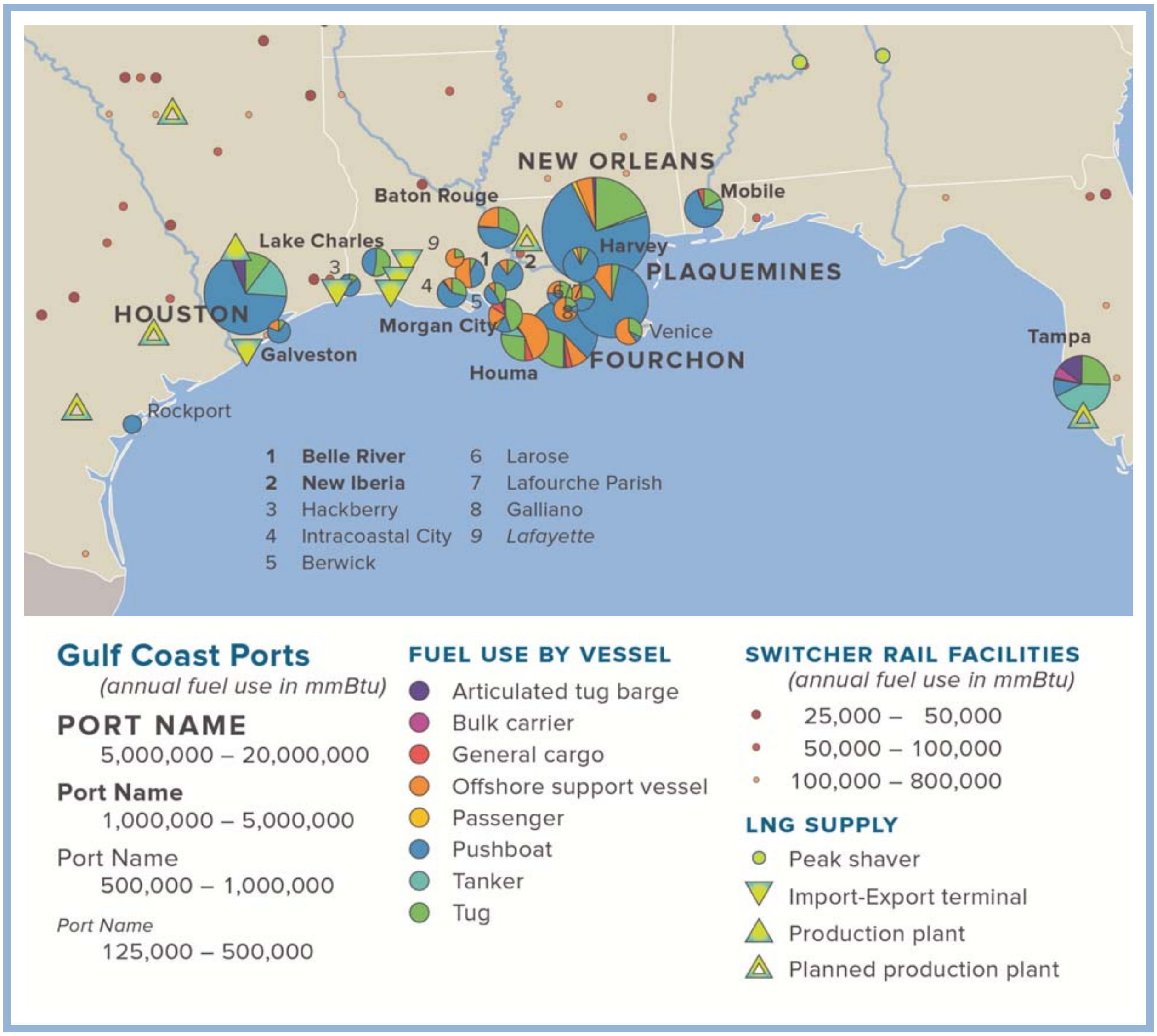

Figure 22: Gulf of Mexico Marine and Switcher Fuel Use with LNG Supply

[82] "Gulf of Mexico Fact Sheet." U.S. Energy Information Administration. http://www.eia.gov/special/gulf_of_mexico/, accessed July 28, 2014.

Marine

Marine shipping is a key transportation mode in the Gulf of Mexico, particularly for the production and shipment of oil and gas products generated by the U.S. petrochemical industry. The domestic and international cargos are sustained by a large fleet of pushboats and tugboats, which operate either in harbor as assist vessels or in open water to support oil and gas production activities. The other large portion of vessels is offshore support vessels, which deliver equipment, materials, and personnel to the more than 3,000 oil and gas platforms in the Gulf of Mexico.[83]

There are 2,648 registered, U.S.-flagged vessels based in the Gulf of Mexico, 93 percent of which are offshore support vessels, open water pushboats, and open water tugboats. The marine fuel demand and projection analyses that follow for the Gulf of Mexico vessel fleet differs from the analyses presented for the Great Lakes and inland waterways sections of this report due to the inclusion of available vessel movement data, which was generated from the Automatic Identification System (AIS). The AIS system data for Gulf Coast vessels enabled GNA to identify vessel-specific activity and calculate associated fuel use, focusing on the verified vessel activity among the active registered fleet.

To identify the exact fuel demand across the study region, the following analysis looked at all vessel movements within 200 miles of the Gulf Coast of the U.S. over the course of a year (2013). Each vessel's activity was then linked to both the Sea-web database of U.S.-flagged vessels and the U.S. Army Corps of Engineers database of U.S.-flagged registered vessels. For a detailed description of the methodology, please see Appendix 4 – Gulf of Mexico Specific Data.

The marine sector uses multiple types of fuels, spanning the different distillate, intermediate, and residual mixtures, each of which has different densities and weights. As such, it can be difficult to adequately quantify fuel use and demand when measuring in volumes. Thus, in order to present a consolidated and fuel-neutral view, this report's analysis of the marine sector displays fuel use and demand figures by their energy content (shown in MMBTU), rather than the volume of a specific fuel. This was then used to identify energy demand clusters and to project LNG demand scenarios.

[83] "The Gulf Region's Contribution to U.S. Energy Production." National Oceanic and Atmospheric Administration. http://stateofthecoast.noaa.gov/energy/gulfenergy.html, accessed July 28, 2014.

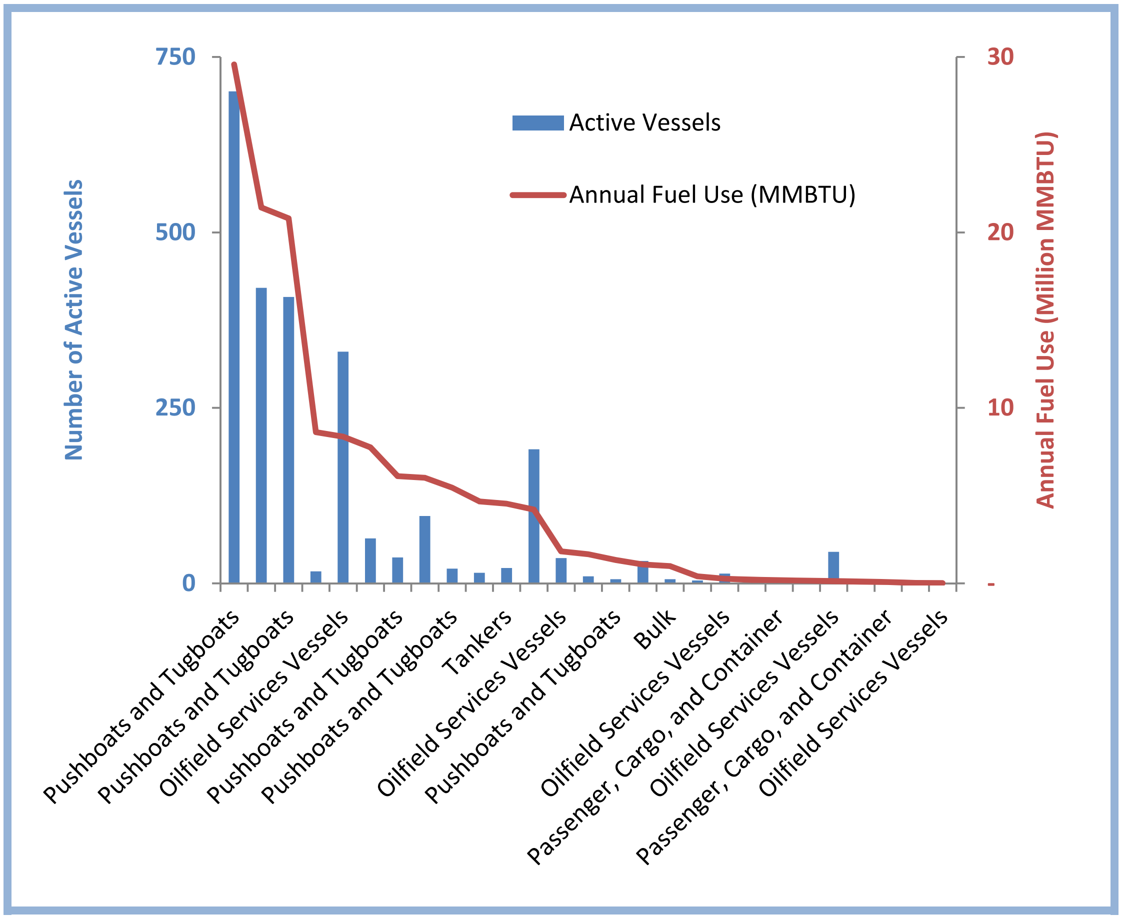

Figure 23: U.S.-flagged vessels active in the Gulf of Mexico and their cumulative fuel use

Based on GNA's analysis of energy use from the active vessels in the Gulf of Mexico, if the entire fleet were to convert to LNG operations, these vessels would generate a demand for 1.16 billion gallons of LNG annually. Of this figure, there are 9 key vessel types, shown in Table 15, that account for 80 percent of the total demand in the Gulf of Mexico.

Table 15: Annual fuel use and LNG demand for select Gulf of Mexico vessels

Vessel Type	Number of Active Vessels	Annual Fuel Use *(MMBTU)*	Annual LNG Demand *(Gallons)*
Pushboat - Open Water (< 6,000 hp)	701	29,575,614	216,887,835
Pushboat - Harbors and Inland Waterways (< 6,000 hp)	421	21,419,722	157,077,963
Tugboat - Open Water (< 6,000 hp)	408	20,803,523	152,559,173
Container Ship	17	8,621,528	109,206,023
Offshore Support Vessel / Platform Supply Ship	330	8,357,786	105,865,283
Articulated Pusher Tug	64	7,747,500	56,815,002
Tugboat - Open Water (> 6,000 hp)	37	6,111,729	44,819,347
Pushboat - Open Water (> 6,000 hp)	21	5,452,200	39,982,797
Tanker (Chemical or Product)	22	4,536,880	57,467,141
TOTAL	**2,021**	**112,626,482**	**940,680,562**

Using the vessel population and activity data, the Gulf of Mexico offers opportunities for LNG market development efforts among several key vessel types.

Offshore support vessels / platform supply ships generate a total annual fuel use of 7,357,786 MMBTU, averaging 25,327 MMBTU per vessel. In 2013, 330 offshore support vessels operated throughout the Gulf of Mexico, with 302 vessels (92 percent) operating from the Louisiana Gulf Coast. Harvey Gulf's six new LNG-fueled OSVs are a signal of progress in this market and demonstrate a key opportunity in the LNG-fuelled OSV segment over the next 15 years. OSVs present a unique opportunity for future LNG fuel use based on the quantity of active vessels, their centralized operations around Port Fourchon, Louisiana, the demonstrated leadership in this application by Harvey Gulf and its partners, and similar opportunities for the exploration and production (E&P) companies operating in the Gulf to help to simulate demand for natural gas as a marine fuel.

Although there is interest in LNG among OSV owners, demand growth will necessitate modifications to standard chartering arrangements. In general, the E&P companies that charter OSVs also pay for fuel, meaning that OSV owners cannot recover their investments in LNG vessels through fuel cost savings. As demonstrated by Harvey Gulf and Shell, a long-term arrangement with higher charter rates between the E&P company (in this case Shell) and the OSV operator (Harvey Gulf) can allow vessel owners to purchase LNG-powered ships. With a long-term charter commitment between the parties, an OSV owner can repay their investment and secure long-term business while the E&P can reduce its overall operational costs through fuel cost savings, thus creating a win-win scenario.

Offshore service vessels present a unique opportunity for future LNG fuel use based on the quantity of active vessels, their centralized operations around Port Fourchon, Louisiana, the demonstrated leadership in this application by Harvey Gulf and its partners, and similar opportunities for the exploration and production (E&P) companies operating in the Gulf to help to simulate demand for natural gas as a marine fuel.

Domestic carriers' container ships and chemical/product tankers will play a key role in Gulf Coast demand for LNG over the next 15 years. In 2013, 22 U.S.-flagged chemical / product tankers and 17 U.S.-flagged container ships were active in the Gulf of Mexico and used an estimated 13,158,408 MMBTU, which is equivalent to 166,673,164 gallons of LNG. The key vessel operators of these vessels in the Gulf of Mexico are Maersk A/S (nine container ships), Overseas Shipholding Group, Inc. (nine chemical / product tankers among parent and daughter companies) and Crowley Petroleum Service, Inc. (four chemical / product tankers). Crowley has initiated an LNG project out of Jacksonville (a combination container Roll-on/Roll-Off) ship that will access the fueling infrastructure being developed for TOTE. Similar infrastructure in the Gulf would offer expansion opportunities for Crowley. Both chemical and container vessel inventories are expected to grow significantly in the Gulf over the next 15 years, with some projections showing a 10 percent year-over-year growth rate for tankers and a six percent year-over-year growth rate for containerships[84]. Finally, it is expected that 30 percent of new containerships entering the market will be LNG-powered, while 20 percent of new tankers will be LNG-powered.[85] Thus, these vessel types, though accounting for less fuel demand in the current market, are expected to play a substantial role in the long term development of the Gulf Coast market for LNG marine fuel.

Low horsepower (< 6,000 hp) pushboats and tugboats present high potential for medium-term LNG projects based on the size of the overall population, and location and operations in the Gulf. These vessels can operate in open water, harbors, and along inland waterways. The inland waterways vessels included in this Gulf Coast analysis include the vessels operating on the Gulf Intracoastal Waterway and exclude those operating along the Mississippi River, as those vessels are included in the inland waterways chapter of this study. The Gulf Coast's low horsepower pushboats and tugboats account for over 71 percent of the total region-wide fuel use. Operators have signaled some willingness to consider LNG projects for newbuilds with fully integrated LNG tank designs. However, this product is not yet available in the U.S. marketplace, and manufacturers have indicated that the timelines are in the 2020 timeframe, dependent on end user demand.

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[84] See Appendix 3 – Methodology for Long Term Growth Rate Potential for additional background on growth rate projections

[85] See Appendix 3 – Methodology for Long Term Growth Rate Potential for additional background on growth rate projections

High horsepower (> 6,000 hp) pushboats and tugboats, generate a relatively large portion of the long-term potential demand for LNG, though they have a small overall population. For instance, the high horsepower tugboats that operate in open water account for only 1.8 percent of the total fleet but generate 4.8 percent of the demand for LNG. Although this sector presents tremendous potential based on fuel demand, there is hesitancy in the market due to costs and technical feasibility of LNG conversion projects, particularly related to LNG tank placement on vessels with very limited deck space and related Coast Guard approvals. Like with smaller pushboats and tugs, operators might consider new build projects, however, there is no commercially available product currently offered in the North American marketplace.

"Jones Act vessels" above 10,000 deadweight tons (DWT) also present a key opportunity, given their size, fuel use, and operations. The Jones Act applies to vessels operating between U.S. ports and required them to be built in the U.S., owned and crewed by U.S. citizens, and U.S. flagged. Because Jones Act vessels operate primarily between U.S. ports, this category is a useful way to target vessels subject to the low-sulfur fuel requirements of the U.S. ECA for most or all of their operations. The largest Jones Act vessels burn more fuel, and are therefore most likely to benefit from low-cost LNG versus more costly distillates as an emission solution. The few containerships, tankers, and vehicle carriers that are large Jones Act vessels (Table 16) are likely to represent vessels that can realize significant economic benefit from the use of LNG.

Table 16: Jones Act vessels above 10,000 deadweight tons (DWT) operating in the Gulf of Mexico[86]

Vessel Type	Vessel Owner	Number of Vessels
Containership	Horizon Lines LLC	1
General Cargo	National Shipping of America	1
Dry Bulk	LCI Shipholdings	1
	Teco Ocean Shipping	1
Tanker	American Petroleum	6
	American Shipping Co.	6
	Chevron Shipping Co.	1
	OSG Ship Management Inc.	1
	Seabulk International	3
	Sulphur Carriers	1
Grand Total		**22**

[86] "U.S.-Flag Oceangoing Privately Owned Jones Act Fleet, Year-End 2010." U.S. Department of Transportation, Maritime Administration. http://www.marad.dot.gov/documents/us-flag_fleet_10000_dwt_and_above.xls, accessed August 4, 2014.

The Gulf Coast attracts large vessels operating under both domestic and international flags. It is important to note that the demand analysis above only covers U.S.-flagged vessels and thus does not factor in the current conventional fuel demand generated by international vessels calling on ports throughout the Gulf of Mexico. These ocean going vessels are typically much larger than U.S.-flagged vessels and use high quantities of fuel in their operation. While their fuel use may present an attractive opportunity for LNG, these vessels only have to comply with ECA regulations for the 200 miles offshore from the Gulf Coast. Once outside of this area, the vessels can resume burning higher sulfur and less expensive fuels. Thus, they are less likely to present near-term LNG demand. However, given Europe's emphasis on LNG marine and emissions reductions and the availability of low cost natural gas in the United States, the industry is starting to see opportunities emerge with cross-Atlantic natural gas powered ocean going vessels like Denmark's Evergas. Accordingly, the 15-year LNG demand growth projections for the Gulf Coast presented in this analysis do include some considerations for international vessel growth with local fueling.

Current and Planned Gulf of Mexico LNG Vessel Activity

Currently, Harvey Gulf International Marine, LLC is the only Gulf Coast operator with LNG vessels on order and under construction. Harvey Gulf recently invested $350 million in the construction of six 310 foot long platform supply vessels. The first LNG vessel, the Harvey Energy, will be officially launched in the fourth quarter 2014 and will be the first U.S.-flagged vessel (non LNG tanker) to operate on LNG. Harvey Power, the second LNG-fueled vessel in the fleet, will soon be deployed by the shipyard in order to commence sea trials before delivery to Harvey Gulf. All six new LNG-fueled vessels are certified by the American Bureau of Shipping as achieving the "ENVIRO+ Green Passport," qualifying them as the most environmentally friendly vessels in the Gulf of Mexico.

Additionally, three other companies have announced intent to build new LNG marine vessels that will operate in the Gulf: LNG America, LLC; Minyan Marine, LLC; and SEACOR Marine LLC. Minyan Marine LLC ("Minyan Marine"), based out of Houston, TX, announced in late 2013 that they are designing the world's first LNG-fueled articulate tug/barge (AT/B). The vessel features a unique design in which the LNG fuel tanks are located on the barge, rather than co-located with the engines on the tug. The fuel will then by transferred from the barge via a proprietary system developed by Argent Marine. The tanks will be capable of storing sufficient fuel for the vessel to make round trips between ports in the Gulf of Mexico and destinations on either East of West coasts. Furthermore, this unique design allows the tug to operate apart from the barge, if needed, as an ocean towing tug. As the vessel is still in design, there is no timetable for expected delivery.

SEACOR Marine LLC ("SEACOR") operates a fleet of 115 offshore support vessels plus construction vessels that support the oil and gas exploration and production industry. The company's numerous subsidiaries (SEACOR Liftboats, SEACOR Offshore, and Seabulk International, and Seabulk Tankers) operate globally, including the Gulf of Mexico, Latin America, North Sea, West Africa, Southeast Asia and the Middle East. In 2013, Seabulk Tankers (a subsidiary of SEACOR Marine LLC) announced that it had awarded a contract to General Dynamics NASSCO to design and construct three (3) LNG-conversion-ready carriers.[87] These 610 foot long vessels will have deadweight of 50,000 tonnes and a 330,000 barrel cargo capacity. The tankers will have engines capable of conversion to dual fuel operations and Seabulk Tankers expects delivery of the first of these vessels by late 2016.

Rail

The Gulf of Mexico is bounded by just five states; Texas, Louisiana, Mississippi, Alabama, and Florida. In total, US EIA reports that 733 million gallons of diesel fuel were sold to railroads in these five states. Texas dominates fuel sales with 483 million gallons, making it the largest seller of fuel to railroads in the country. Mississippi and Alabama are both Gulf Coast states as well as inland waterway states, with their rail fuel sales serving both markets. Houston is a significant line-haul locomotive fueling hub, as are some inland facilities, particularly in the Dallas-Fort Worth area, that are not close to Gulf Coast ports but have significant rail connections to the Gulf Coast region. Total switcher locomotive fuel demand in the five Gulf Coast states accounts for only 57 million gallons[88] of the 733 million gallons sold.

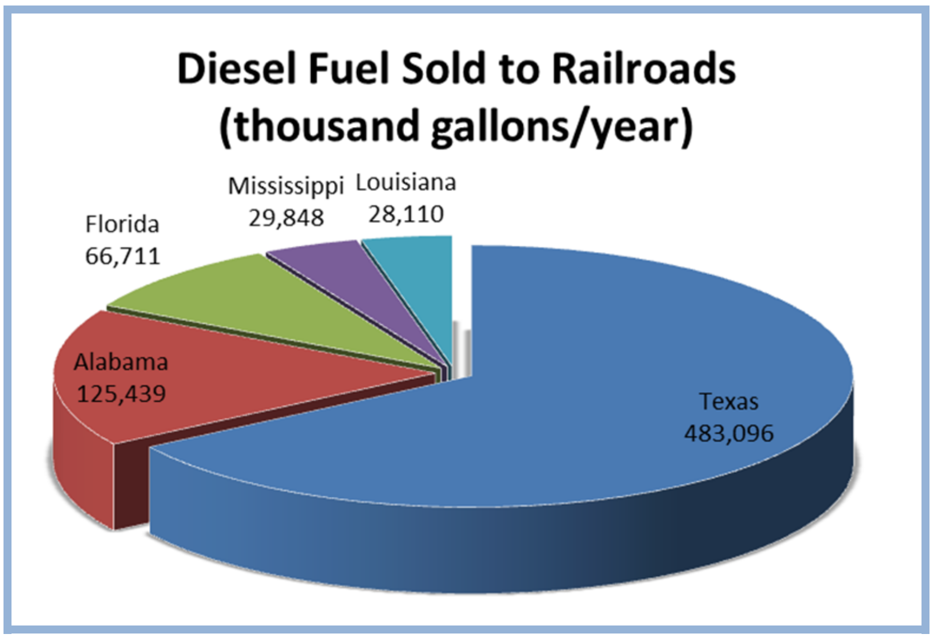

Figure 24: Diesel fuel sales by state to railroads – Gulf of Mexico Region[89]

[87] "General Dynamics NASSCO to Construct Up to Two Follow-on Product Tankers for Seabulk Tankers, Inc." General Dynamics NASSCO, November 12, 2013. http://www.nassco.com/breaking-news/2013/11/general-dynamics-nassco-to-construct-up-to-two-follow-on-product-tankers-for-seabulk-tankers-inc/, accessed July 21, 2014.

[88] Bergin M., Harrell M., Janssen M., "Locomotive Emission Inventories for the United States from ERTAC Rail", 2012. http://www.georgiaair.org/airpermit/downloads/planningsupport/regdev/locomotives/inventory_ertacrail_2012.pdf

[89] US EIA, "Sales of Distillate Fuel Oil for Railroad Use", 2013

Five of the seven Class I railroads are listed as the primary operator of one or more of the rail yards in the region, with CN and CP absent from the region. UP is the largest consumer of switcher fuel, approximately two thirds of the switcher fuel demand in the region.

To identify key rail yards and regions for line-haul fueling opportunities, GNA estimated the total switcher fuel use at rail yards within 10 miles of significant ports on the inland waterways. As shown in Table 17, the top four Gulf Coast rail yards are all in Texas. Combined, they represent an estimated 80 percent of the regional rail fuel demand and highlight the central role that Texas plays in freight rail activity within the region.

Houston, TX leads the region with 34 percent of total rail fuel use. Over 90 percent of the fuel demand in Houston is associated with UP rail yards. Houston is also home to the Port of Houston, a major Gulf port, as discussed above. Haltom City, a suburb in the Dallas-Fort Worth area, is second on the list. UP is the dominant fuel user here, but BNSF also has a major presence south of Dallas, in Temple, TX. Galveston rounds out the top three areas for rail fuel use in the Gulf Coast region and sits at the mouth of the Houston ship channel.

Outside of Texas, the Mobile, AL region as well as Pensacola and Gibsonton (Tampa), FL are the most significant centers of rail activity on the Gulf Coast.

Table 17: Top 10 Gulf of Mexico rail yards (regional) and estimated switcher fuel use

Port City	Number of Rail Yards	Fraction of Gulf of Mexico Regional Switcher Fuel Use	Fraction of State Switcher Fuel Use
Houston, TX	27	34%	15%
Haltom City, TX (DFW)	11	26%	12%
Galveston Area. TX	4	10%	4%
Beaumont, TX	15	9%	4%
Mobile Area, AL	9	5%	18%
Pensacola, FL	2	3%	13%
Gibsonton, FL	8	3%	12%
Baytown, TX	14	3%	1%
Orange, TX	1	3%	1%
Lafayette, LA	3	1%	4%

At full conversion, line-haul rail operations in the study region would represent 677 million gallons of current annual diesel demand, or 810 billion gallons of potential LNG demand per year.[90]

[90] Assuming a 70 percent substitution rate for dual-fuel natural gas engines

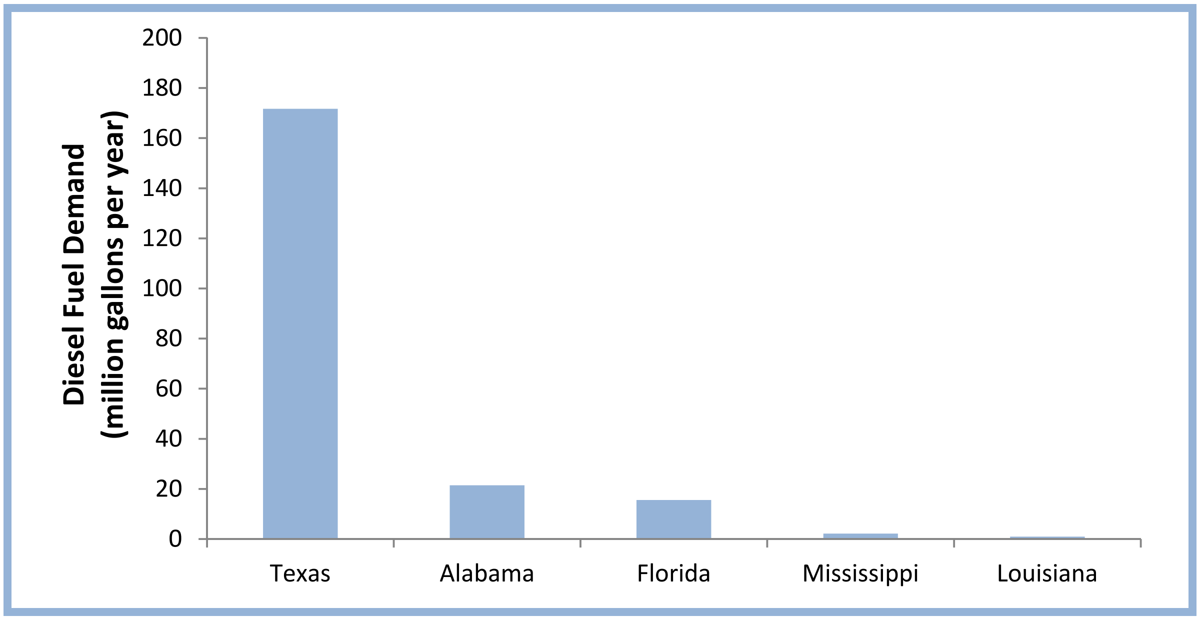

Figure 25: High opportunity railroad fuel use in the Gulf of Mexico Region

Fueling and Infrastructure

Vessels in the Gulf use both dedicated bunkering facilities (with land-based and water-side bunkering) and bunker barges at satellite locations for their fueling needs. While the Gulf's major bunkering hubs for international vessels are the Port of Houston and the Mississippi River ports of Baton Rouge, New Orleans, and South Louisiana, the fueling needs and locations of the domestic and international fleet are diverse, and any long-term LNG fueling plan will need to be flexible to meet the needs of the region.

The Gulf Coast's existing natural gas infrastructure, first-mover LNG marine investments, and the specific nature of certain high-LNG potential vessel populations have created very favorable market growth conditions for marine LNG projects. The Gulf Coast offers a unique opportunity to build a marine market around existing, large-scale, waterfront liquefaction at the multiple export facilities that are under development. This region is home to three of the six proposed LNG export facilities that have FERC approvals (as of the writing of this report.) Although there are dozens of proposed LNG export facilities throughout the United States and not all will be developed, facilities that have FERC approvals are the most likely to be constructed.

The Gulf Coast's existing natural gas infrastructure, first-mover LNG marine investments, and the specific nature of certain high-LNG potential vessel populations have created very favorable market growth conditions for marine LNG projects.

Table 18: Proposed Export Facilities in Gulf of Mexico with FERC Approvals

Proposed LNG Export Facility	Location	Status
Cheniere Energy	Sabine Pass, LA	FERC approval, Under Construction, Operational Q4 2015/Q1 2016
Sempra	Hackberry, LA	FERC approval, Planned
Freeport LNG	Quintana, TX	FERC approval, Planned

Given the immense storage and production capacities at these sites (Cheniere's Sabine Pass location has 15 Bcf storage capacity and will have initial daily processing capacity of 1 Bcf/day and ultimate capacity of 4 Bcf/day at full build out), they will likely provide the lowest cost LNG that could potentially be produced. Further, the cost to provide the infrastructure for domestic markets such as commercial marine vessels will be very small compared to the total project cost, as well as the cost of a new LNG plant developed to serve the domestic market. The ability to fill bunker barges at these locations with very low cost LNG and to transport these barges throughout the region, either for direct bunkering into ships or for distribution of the LNG into satellite fuel storage locations, can reduce the overall barriers related to fuel access and can ultimately make smaller vessel deployment projects more cost-effective.

The Cheniere facility is under construction and is scheduled for completion by the end of 2015, and LNG America is planning to distribute marine fuel from the Cheniere facility starting in early 2016. LNG America recently contracted with Jensen Maritime to design an LNG bunker barge (Figure 26) capable of delivering LNG from Sabine Pass to coastal storage and distribution terminals throughout the Gulf Coast region as well directly bunkering large ships.[91] LNG America expects delivery of the vessels by late 2015, following the implementation of its recent engineering contract with Taylor-Wharton for the cryogenic topside of the barge.[92] The barge should be able to supply fuel throughout coastal Texas and Louisiana with favorable economics. LNG America is planning to use these barges to fill storage vessels and provide fueling at locations throughout Texas, Louisiana, Alabama and along the lower Mississippi river. This will enable the company to support growing LNG markets in Port Fourchon, Houston, and the inland waterways using this "hub and spoke" model.

[91] "Jensen Maritime Selected to Design Some of First LNG Bunker Barges in U.S." Crowley, February 24, 2014. http://www.crowley.com/News-and-Media/Press-Releases/Jensen-Maritime-Selected-to-Design-Some-of-First-LNG-Bunker-Barges-in-U.S, accessed July 21, 2014.
[92] R Piellisch, "LNG America Taps TW for LNG Barge." HHP Insight, August 21, 2014. http://hhpinsight.com/marine/2014/08/lng-america-taps-tw-for-lng-barge/ Accessed September 15, 2014

Figure 26: Artist's rendering of LNG America's Bunker Barge[93]

Waller Marine and Tenaska fuels also recently announced a plan in September 2014 to develop liquefaction and transportation sector fueling on approximately 80 acres at the Port of Baton Rouge[94]. The proposed facility will be capable of producing 200,000 gallons of LNG each day, with capacity to expand. The site is in an ideal location to serve marine users throughout the ports of southern Louisiana along the Mississippi and through the lower inland waterways. The facility also has access to Class 1 rail adjacent to the property, and will be developed with tractor truck fueling facilities for LNG-fueled trucks, loading facilities for transporting LNG via tanker truck, and a dock for the mooring of LNG bunker barges. Waller Marine, which specializes in marine design and engineering, has been examining LNG investment options in the region for several years. To enable this LNG liquefaction project, Waller secured the location in the Port of Baton Rouge and entered in to a partnership with Omaha-based Tenaska NG, in which Tenaska will provide project crucial financing. Waller Marine will coordinate bunker barge design and construction while Tenaska will be the managing partner that will provide equity, development and management of the liquefaction facility. Both companies are jointly marketing LNG to users throughout the region. The partners are targeting operations in 2017, although the final project will likely depend on technical approvals and commercial fueling agreements before ultimately proceeding.

Another first mover in the region is Harvey Gulf, which recently broke ground on a $25 million LNG shore-to-ship fueling facility. Located in Port Fourchon, LA, this facility is expected to come online on late 2014 and will be capable of fueling both vessels and on-highway vehicles (Figure 27). Harvey Gulf's

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[93] "LNG America Selects the American Bureau of Shipping (ABS) as the Classification Society for its First LNG Bunker Barges." BusinessWire, May 22, 2014. http://www.businesswire.com/news/home/20140522005146/en/LNG-America-Selects-American-Bureau-Shipping-ABS#.U818FmdOVfy, accessed July 21, 2014.

[94] Young, Renita D. "First Louisiana Natural Gas Liquefaction, Fueling Facility Planned for Port of Baton Rouge." Nola.com. The Times Picayune, 30 Sept. 2014. Web. 30 Sept. 2014. <http://www.nola.com/business/baton-rouge/index.ssf/2014/09/first_louisiana_natural_gas_li.html>

LNG facility will consist of two separate sites, each having three 90,000 gallon LNG storage tanks (540,000 gallons of total capacity) that will be able to transfer 500 gallons of LNG per minute to marine vessels. As Harvey Gulf begins to generate data on project economics, it may demonstrate the value in developing proprietary LNG fueling infrastructure for other OSV companies.

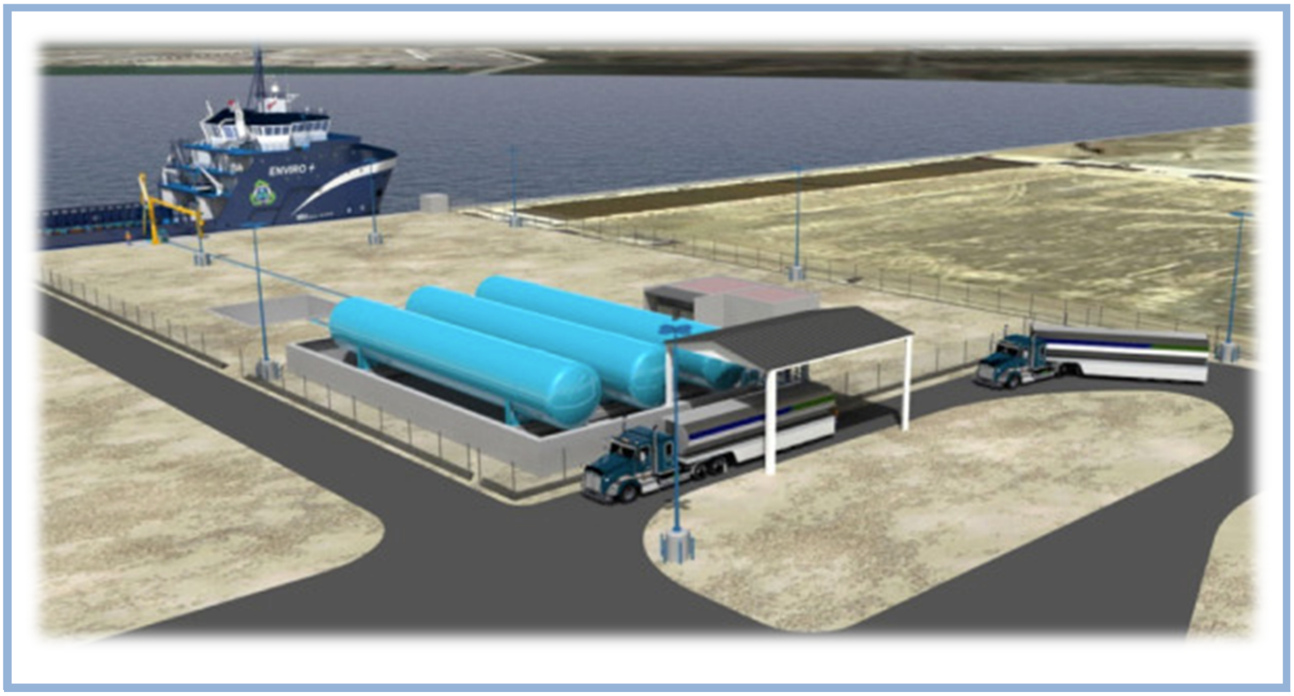

Figure 27: Artist's rending of Harvey Gulf International Marine's LNG facility at Port Fourchon, Louisiana[95]

Gulf of Mexico LNG Growth Opportunities

Domestic Demand Opportunities

GNA estimated LNG market penetration rates in the Gulf of Mexico region by applying our own internal research and the projection methodology developed by DNV-GL for the domestic LNG vessel fleet. DNV's estimates are based on research from the industry's news sources including Clarkson's, Lloyds List, Fairplay, Tradewinds, Sea-web, and Workboat, DNV GL's own internal research, and the judgment of experienced maritime professionals involved in the industry. The vessels in this analysis are assumed to use dual-fuel engine technologies similar to the six current North American LNG projects under development. These engines are capable of 95-99 percent diesel substitution rates (the rate at which diesel is replaced with natural gas in the engine). While dual-fuel engines allow for increased operational flexibility and a sense of comfort in that they can fall back to 100 percent fuel oil operation, in the long term we expect that operators will seek to maximize the amount of diesel substitution to achieve

[95] "Harvey Gulf LNG is for Trucks Too." Fleets & Fuels, February 23, 2014. http://www.fleetsandfuels.com/fuels/lng/2014/02/harvey-gulf-lng-in-louisiana/, accessed July 21, 2014.

maximum cost savings. For the purposes of this report, GNA estimated the LNG fuel substitution rates of these vessels to be 95 percent. For emerging vessel markets such as articulated tug-barges, pushboats, tugboats, and small passenger vessels, GNA estimated a more conservative substitution rate of 55 percent, based on experiences with Caterpillar's dynamic gas blending technology in other high horsepower market segments like the exploration and production engine markets.

As described in the Great Lakes region analysis, GNA assumes that conversion from diesel to LNG in line-haul rail will take a similar path and timeframe to complete as the conversion from steam to diesel locomotives did in the mid-1900's. Adoption of LNG is assumed to begin in earnest in 2018 due to FRA approvals and manufacturing timelines. GNA estimates that 33 percent of the locomotive fleet would be operating on LNG by 2029. Excluding growth in fuel use over this period, 33 percent conversion would equate to approximately 71 million diesel gallons, or 116 million LNG gallons of annual demand in 2029.[96] Given current geographical use, much of this growth would likely be centered in Texas.

These estimates can give approximate targets, but actual LNG adoption rates will depend on market fluctuations, the price of LNG, fuel availability, regulatory issues, rates of technology adoption, and the decisions of individual ship owners and operators.

In the long-term, the conversions and newbuilds of cargo, carriers, containerships, and tankers will drive the LNG demand in the Gulf of Mexico at an estimated 260 million gallons LNG annually. Additionally, newbuilds in the pushboat/tugboat and offshore support vessel markets will provide 54.8 million gallons LNG annually by the year 2029. Offshore service vessels could be an important subset of vessels that helps jump start regional investments in bunker barges and satellite infrastructure, given their near-term market potential. Given the availability of commercially available offshore service vessel product and anticipated supply by 2016, this market could begin to grow in the 2017-2018 timeframe, using nearly 36 million gallons per year by 2029.

Table 19: Projected number of domestic LNG vessels and fuel demand by 2029

Vessel Group	LNG-Fuelled Vessels by 2029	Annual LNG Demand by 2029 *(gallons)*
Cargo, Carrier, and Container	9 newbuilds 15 conversions	106,602,521
Pushboat and Tugboat	68 newbuilds	18,891,329
Offshore Support Vessels	112 newbuilds	35,930,003
Tanker	15 newbuilds 44 conversions	153,621,745
Total	**204 newbuilds 59 conversions**	**315,045,598**

[96] Assuming a 95 percent substitution rate for dual-fuel natural gas engines

While these projections provide insight into the broad regional trends, it is impossible to accurately predict where these vessel adoptions and rail projects will take place. However, a thorough assessment of high-opportunity vessel inventories, rail fuel use, local operations, infrastructure, and local end user insight can provide insight about the best location-based targets for LNG project opportunities and information about where this near-term LNG demand growth will be centered.

International Marine Demand Opportunities

The Gulf Coast will also see a growth in LNG demand from the international fleet conducting trade in the region, particularly from European ocean going vessels. While Europe's natural gas isn't as inexpensive as local fuel in the United States, environmental regulations and extensive investments in bunkering have made LNG an economically and operationally viable choice. With emerging LNG fuel opportunities in the United States, ocean going vessel operators are beginning to factor U.S. gas prices into their project economics when considering LNG versus other ECA compliance approaches. Typically, vessels traveling from Europe to the U.S. will need bunker fuel on both sides of the Atlantic. Due to the abundance of natural gas in the U.S., the international shipping industry anticipates that they will be able to access low-cost LNG at competitive prices when bunkering in North America, helping make the case for LNG conversions and new builds.

The first international LNG fueled vessels in the Gulf will likely be the Evergas ethane gas carriers, with the company noting its explicit desire to take advantage of inexpensive U.S. gas and to burn as little diesel as possible. These ships are scheduled to begin service in 2015 and will require LNG bunkering in the Port of Philadelphia and the Port of Houston.

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Another international vessel opportunity is the bulk carriers that move agricultural products, petroleum, and other commodities from the lower Mississippi to international locations. This segment of ships owners is actively examining LNG, especially those ships that have access to LNG bunkering elsewhere. These bulk carriers have more flexible charters and less logistics expense than container ships, which have tight schedules and cannot afford to forgo SIMOPS fueling. In contrast, bulkers often wait locally to receive loads from barges traveling from inland waterway locations for up to ten days, during which time they could hire an LNG bunker vessel for remote fueling.

Table 20 outlines DNV GL's analysis for LNG growth in the Gulf Coast from the international fleet and displays the breakdown of the segments of the international fleet considered in this report and the projected growth rates for each vessel type. DNV then identified he portion of the global fleet that operates in the Gulf. Since LNG growth will predominantly come from newbuilds, a conservative estimate assumes that LNG will power 10 percent of all newbuilds. This yields a number of 21 international LNG-fueled vessels calling in the Gulf of Mexico by 2029. It is expected that for every 3 newbuilds, there will be two LNG-fueled conversions, generating further demand for LNG from the international fleet.

Table 20: Projected growth of LNG-fueled of international vessels calling the Gulf of Mexico by 2029[97]

Vessel Type	International Vessels by 2029	International Newbuilds by 2029	International Newbuilds Calling in the Gulf of Mexico	LNG-Fueled International Newbuilds Calling in the Gulf of Mexico	# of LNG-Fueled International Conversions Calling in the Gulf of Mexico
Chemical / Product Tankers	13,446	1,864	132	13	9
Bulk Carriers	11,022	1,528	51	5	3
Container	9,597	1,331	23	2	1
LNG / LPG Tanker[98]	1,440	200	6	1	1
Total	**30,582**	**4,923**	**212**	**21**	**14**

These ocean-going ships require approximately 3,000 m^3 of LNG fuel capacity, on average, for global voyages and LNG substitution is expected to be 95 percent. It is estimated they will need LNG bunkering every two weeks, or 26 bunkering operations per year, per ship. Depending on the vessel type, the bunkering locations will vary widely across the globe. Therefore, this analysis assumes a value of 13 annual bunkering operations per ship in the Gulf of Mexico. These estimates render a total forecasted LNG demand by 2029 of 343 million gallons (Table 21).

[97] DNV's estimates are based on research from the industry's news sources including Clarkson's, Lloyds List, Fairplay, Tradewinds, Sea-web, and Workboat, DNV GL's own internal research, and the judgment of experienced maritime professionals involved in the industry. For the detailed analysis of the international fleet, please see Appendix 5 – International Vessels in the Gulf of Mexico.

[98] LNG / LPG Tankers traditionally use boil off gases from the cargo to fuel their propulsion systems. It is expected that this trend will continue. Thus, LNG / LPG tankers are not assumed to generate a large amount of LNG demand in the Gulf of Mexico. However, they are included in this analysis due to their large quantities of fuel use as well as the recent emergence of Evergas' LNG-fueled tankers.

Table 21: Projected LNG demand by 2029 from international vessels calling in the Gulf of Mexico[99]

Fleet	International Vessels Calling in the Gulf of Mexico by 2029	Estimated LNG Capacity (m^3)	Annual Bunkering Events in the Gulf of Mexico per Ship	Annual LNG Demand by 2029 (m^3)	Annual LNG Demand by 2029(gallons)
International	**35**	**3,000**	**13**	**1,296,750**	**342,562,465**

Geographic and End User Opportunities

Port Fourchon and Galliano, LA

Port Fourchon, LA supports the Gulf Coast region's offshore activities in two key ways. First, Port Fourchon is located in close proximity to the Louisiana Offshore Oil Port ("LOOP"). The LOOP handles 10 percent of U.S. domestic oil, 10 percent of U.S. foreign oil, and is connected to 50 percent of the U.S.'s refining capacity.[100] In addition, it is the only U.S. deep-water facility capable of conducting cargo operations with Ultra Large and Very Large Crude Carriers. Second, offshore supply vessels from Port Fourchon service 90 percent of deep water and 45 percent of shallow water oil and gas rigs in the Gulf of Mexico with over 270 supply boats transiting the port every day. [101]

Port Fourchon and Galliano are two Louisiana towns located near the southern terminus of Louisiana Highway 1. Both towns are located along the Gulf Intracoastal Waterway, providing direct access south to the Gulf of Mexico and north to the Mississippi River. Port Fourchon is the more beneficially located of the two towns, lying at the confluence of the Gulf Intracoastal Waterway and the Gulf of Mexico. Galliano is located approximately 25 miles north of Port Fourchon on the Gulf Intracoastal Waterway. Due to its location, there is less vessel activity in Galliano in Port Fourchon.

The approximately 250 companies based in Port Fourchon service over 90 percent of all the deepwater oil production in the Gulf of Mexico. On a daily basis, nearly 300 offshore supply vessels traverse the port's channels and 1,200 trucks travel to and from the port. The key companies operating out of Port Fourchon and Galliano, LA are listed in Table 22 below.

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[99] DNV's estimates are based on research from the industry's news sources including Clarkson's, Lloyds List, Fairplay, Tradewinds, Sea-web, and Workboat, DNV GL's own internal research, and the judgment of experienced maritime professionals involved in the industry. For the detailed analysis of the international fleet, please see Appendix 5 – International Vessels in the Gulf of Mexico.
[100] "About Us." The Greater Lafourche Port Commission. http://www.portfourchon.com/explore.cfm/aboutus/portfacts/, accessed July 31, 2014.
[101] "About Us." The Greater Lafourche Port Commission. http://www.portfourchon.com/explore.cfm/aboutus/portfacts/, accessed July 31, 2014.

Table 22: Key owner / operators in Port Fourchon and Galliano, LA[102]

Vessel Owner / Operator	Number of Vessels Registered in Port Fourchon and Galliano, LA
Edison Chouest Offshore	60
Harvey Gulf International Marine	19
Hornbeck Offshore Services, LLC	17
Gulfmark Americas, Inc.	16

Port Fourchon is the only port in along the Gulf Coast in which an LNG bunkering facility has been sited and is being built (for Harvey Gulf).

Ports of Baton Rouge, New Orleans, South Louisiana, and Plaquemines

The Port of Greater Baton Rouge operates 85 miles of Mississippi River waterfront with main facilities located in Port Allen, Louisiana at the confluence of the Mississippi River and Gulf Intracoastal Waterway. The port handled 59.9 million tons of commodities, approximately 2.4 percent of the U.S.'s total.[103] The site may also soon have local liquefaction to support marine users that operate in and around the Port of Baton Rouge and throughout these southern Louisiana ports from Waller Marine and Tenaska fuels, and will also have connectivity to Class I rail. Although there are no significant Class I fueling operations in the port, the availability of LNG and the ability to distribute fuel by rail to Class I yards in other areas may help support project development opportunities.

The Port of New Orleans is a two-mile long deepwater port consisting of four terminal complexes. The facilities include 22 million square feet of cargo handling area as well as six million square feet of covered storage. The Uptown River Cargo Terminal Complex, Cruise Terminal, and Downtown River Cargo Terminal Complex are located along the Mississippi River. The Inner Harbor Cargo Complex is located on the Industrial Canal (formally known as the Inner Harbor Navigation Canal), a manmade waterway running north to south from Lake Pontchartrain to the Mississippi River. Protected by locks at both ends, the Industrial Canal also provides access to the Gulf Intracoastal Waterway. Up to 2009, the Industrial Canal also served as the entryway to the Mississippi River Gulf Outlet (MRGO). However, the MRGO was permanently closed to shipping on April 22, 2009 after a storm surge barrier was installed, due to the impacts of Hurricane Katrina.

The Port of New Orleans provides intermodal rail access to six Class I railroads. Rail within the port is handled by a dedicated short line railroad – the New Orleans Public Belt Railroad. This railroad moves train cars to and from the port docks and builds trains that are then picked up by the Class I operators. As such, the location is not a major fueling location for the Class I railroads. That said, the

[102] "National Summaries, Volume 1 (2012)." Waterborne Transportation Lines of the United States, US Army Corps of Engineers Navigation Data Center, 2012. http://www.navigationdatacenter.us/veslchar/pdf/wtlusvl1_12.pdf, accessed July 29, 2014.

[103] "Tonnage of selected U.S. Ports in 2012." U.S. Army Corps of Engineers, Navigation Data Center. http://www.navigationdatacenter.us/wcsc/portname12.html, accessed August 7, 2012.

interconnection between six Class I railroads and the potential colocation of fuel demand from the Gulf Coast and Inland Waterways marine vessels could allow for distribution of LNG by rail to the Class I yards in other areas.

The Port of South Louisiana handles over 10.2 percent of the U.S.'s commodity tonnage, the most of any port in the U.S.[104] The port itself consists of five port-owned and numerous private facilities in three Louisiana parishes and covers 54 miles of the Mississippi River between Baton Rouge and New Orleans. Due to a large availability of land, multiple companies have sought to develop LNG liquefaction facilities at the Port of South Louisiana.[105]

Finally, the Port of Plaquemines presents an opportunity for LNG-fueled vehicles as well. Though the registered fleet in Belle Chasse, LA is considerably lower than the other Louisiana ports, the Port of Plaquemines handles a considerable amount of commodity tonnage, roughly 58.3 million tons per year. The port's main imports include coke, crude oil, fuel oil, gasoline, heating oil, and natural gas while exports include coal, grain, soybeans, and wheat.[106] Due to its prime location on the Mississippi River, the Port of Plaquemines is considered a potential target for development of LNG bunkering infrastructure.

Table 23: Key vessel owner / operators at the Ports of Baton Rouge, New Orleans, and South Louisiana[107]

Vessel Type	Vessel Owner / Operator	Number of Registered Vessels
Pushboat - Below the Locks (< 6,000 hp)	Blessey Marine Services	54
Pushboat - Below the Locks (< 6,000 hp)	Marquette Transportation	49
Tugboat - Below the Locks	Florida Marine Transporters	43
Pushboat - Below the Locks (< 6,000 hp)	Canal Barge Company	23
Tugboat - Below the Locks	Blessey Marine Services	22
Offshore Support Vessel	Belle Chasse Marine Transportation	20

104 "Tonnage of selected U.S. Ports in 2012." U.S. Army Corps of Engineers, Navigation Data Center. http://www.navigationdatacenter.us/wcsc/portname12.html, accessed August 7, 2012.
105 Isaacson, L. "Natural gas incites business boom for Port of South Louisiana." WorldNow, June 23, 2014. http://raycomgroup.worldnow.com/story/25848628/natural-gas-leads-to-business-boom-for-port-of-south-louisiana,,accessed July 22, 2014.
106 "Port District." Port of Plaquemines. http://www.portofplaquemines.com/port-district, accessed September 30, 2014.
107 "National Summaries, Volume 1 (2012)." Waterborne Transportation Lines of the United States, US Army Corps of Engineers Navigation Data Center, 2012. http://www.navigationdatacenter.us/veslchar/pdf/wtlusvl1_12.pdf, accessed July 29, 2014.

Ports of Houston and Galveston, TX

Located along the 25-mile Houston Ship Channel, the Port of Houston (PHA) provides vessels with direct access to both the Gulf of Mexico and Intracoastal Waterway. Nearly 10 percent of the U.S.'s commodity tonnage passes through the Port of Houston annually, much of which consists of petroleum products from oil and gas exploration and production activities. It is worth noting that the PHA not only occupies a small footprint along the Houston Ship Channel, but the cargo handled by the port's facilities only constitutes 15 percent of the total ship moves in and out of the channel. The vast majority of the activity that takes place in the region is to and from the private facilities that are located all along the ring the Houston Ship Channel. These are made up almost entirely of refineries, chemical manufacturers and other industrial plants associated with the oil and gas industry.

Pushboats and tugboats dominate the local vessel population (Table 24). Kirby Inland Marine, LP is the largest owner / operator of pushboats in the region. Fleets of this size present good targets for LNG conversion because they both afford the incremental cost of newbuilds as well as take advantage of economies of scale. The Port of Houston is also a major bunkering hub for marine vessels, providing large quantities of marine fuel to both domestic and international vessels. As an existing fueling center, the Port of Houston thus becomes a key target for future LNG fueling operations. Also, of key note to long-term demand for LNG in the Gulf of Mexico, Conoco Phillips and Seariver Maritime own / operate eight tankers that are registered out of Houston, TX.

Table 24: Key vessel owner / operators at the Ports of Houston and Galveston, TX[108]

Vessel Type	Vessel Owner / Operator	Number of Registered Vessels
Pushboat - Open Water (< 6,000 hp)	Kirby Inland Marine	118
Pushboat - Open Water (< 6,000 hp)	Higman Barge Line	55
Pushboat - Open Water (< 6,000 hp)	Buffalo Marine Service	16
Pushboat - Open Water (< 6,000 hp)	Genesis	14
Offshore Support Vessel	Columbia Star	12
Tanker	Conoco Phillips	5
Tanker	Seariver Maritime	3

Over 70 percent of the projected rail-based LNG fuel demand is concentrated in Texas, with Houston and Dallas-Fort Worth representing more than half the region's rail fuel demand or 71 million LNG gallons of potential fuel demand in 2029. UP is the dominant operator in these two areas and would be a key partner for long-term project development.

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[108] "National Summaries, Volume 1 (2012)." Waterborne Transportation Lines of the United States, US Army Corps of Engineers Navigation Data Center, 2012. http://www.navigationdatacenter.us/veslchar/pdf/wtlusvl1_12.pdf, accessed July 29, 2014.

Houston is also home to a major seaport and is less than 50 miles from Galveston via a major shipping channel, the Houston-Galveston area is likely a top contender for aggregating demand across rail and marine sectors. If only the rail fuel use in the Houston-Galveston area were considered, potential fuel demand in 2029 is 51 million LNG gallons. If LNG were to be distributed to Dallas-Fort Worth, approximately 250 miles to the north, it would likely be distributed by truck or rail car. Combining fuel demand for all three areas, total LNG demand in 2029 could reach 83 million LNG gallons annually.

Conclusion

The Gulf of Mexico is a prime location for LNG marine project development. There are multiple vessel types in the domestic fleet that have a high potential for LNG new builds and conversion. Over the next 15 years, approximately 263 domestic vessels could transition to LNG operations, using 315 million gallons of LNG each year. Rail fuel use could add an additional 85 million gallons of LNG annually to the region, bringing the potential domestic demand to 400 million gallons by 2029. These vessel inventories, fuel use, and diverse locations can help support sustainable infrastructure growth throughout the region. This broad marine infrastructure network can also be developed with favorable economics, compared to other regions. The Gulf Coast offers a unique opportunity to build a domestic marine market around existing, large-scale, waterfront liquefaction at the multiple export facilities that are under development. Given the immense storage and production capacities at these sites and the capacity to barge fuel throughout the region, the investment economics are markedly improved over other marine locations. Some of the key LNG opportunities are highlighted below:

Over the next 15 years, approximately 263 domestic vessels could transition to LNG operations, using 315 million gallons of LNG each year.

- Port Fourchon and Galliano, LA: Though these locations are not major commodity ports in the Gulf of Mexico, the private facilities offer some of the best opportunities for near-term project development because of their dense OSV population, existing vessel technology, and developing infrastructure. In addition, Port Fourchon also features the U.S.'s first deployment of marine operations using LNG by Harvey Gulf.
- Ports of Houston and Galveston, TX: The oil and gas industry's presence in the Gulf of Mexico plays a large role in operations at the Ports of Houston and Galveston. The Port of Houston is a key bunkering hub for international ocean going vessels from Asia and Europe. As such, large cargo, container, and tanker vessels calling at these ports generate demand for large quantities of marine fuel, but also require support from pushboats and tugboats. There are also a considerable number of offshore support vessels, though not in the quantities found in Port Fourchon and Galliano. Project development here could build upon local demand to grow bunkering operations that support international vessels.
- Ports of southeastern Louisiana (Baton Rouge, New Orleans, South Louisiana and Plaquemines): The major ports in southeastern Louisiana feature a large population of high potential vessels,

including pushboats, tugboats, and offshore support vessels. These ports also handle a considerable portion of the U.S.'s commodity tonnage, which means that large cargo, carrier, and container vessels also visit these ports, including international vessels. A proposed liquefaction facility by Tenaska Bayou LNG could therefore support a significant localized marine population. Rail line connectivity to these ports and to the proposed LNG facility could also support locomotive project development, though rail users would likely transport the fuel via rail to fueling yards outside of the local port area.

Long-term demand in the Gulf of Mexico's marine sector will be driven by conversions and newbuilds of cargo, carriers, containerships, and tankers, which is estimated to reach 260 million gallons of LNG annually by 2029. Pushboats, tugboats, and offshore support vessels are also important to generating LNG demand in the Gulf of Mexico, as these vessels operate entirely within the North American ECA and in close proximity to their home docks. These vessels thus represent a "captive fleet" and present a considerable more reliable source of LNG demand. As such, these smaller vessels are expected to generate a demand for 54.8 million gallons LNG annually by 2029.

Offshore support vessels could be an important subset of vessels that helps jump start regional investments in bunker barges and satellite infrastructure, given their near-term market potential. With the availability of commercially available offshore service vessel product and anticipated supply by 2016, this market could begin to grow in the 2017-2018 timeframe, using nearly 36 million gallons per year by 2029. To realize such demand, charting agreements between the E&P companies contracting for OSV services must be structured to reflect the tremendous fuel cost savings of natural gas compared to diesel as well as the higher incremental cost of the LNG powered vessel.

This combination of domestic baseload, cost-effective infrastructure, proposed export and liquefaction facilities, and low-cost natural gas also make the Gulf Coast an incredibly attractive destination for international LNG bunkering, particularly for European and bulker vessels. Although this study projects that there could be 35 international vessels operating in the Gulf by 2029 and the associated fuel use could reach 343 million LNG gallons per year, it is challenging to plan infrastructure around vessels with worldwide operations and intermittent local fueling. This potential international demand should be considered incremental to domestic baseload, albeit a huge increment that hints at the potential for the United States to be the low cost LNG bunkering center for the world. International vessels could call anywhere in the Gulf, with some concentrations at the mouth of the Mississippi, where bulkers exchange goods with inland waterways vessels, and Houston, which supports bunkering and trade with European and South American chemical, energy and cargo vessels. The Cheniere/LNG America partnership is thus being developed to allow for intermittent bunkering of large international vessels operating on LNG while the LNG export project provides the required baseload for the overall production facility. The proposed Tenaska Bayou LNG

This combination of domestic baseload, cost-effective infrastructure, proposed export and liquefaction facilities, and low-cost natural gas… make the Gulf Coast an incredibly attractive destination for international LNG bunkering

facility and its Waller LNG Fueling subsidiary is also being developed to support ships and rail connections at the mouth of the Mississippi.

Within Texas, rail could represent a sufficiently large volume of fuel demand to develop infrastructure around, even in the absence of marine user baseload. However, there is rail fuel demand located around the Houston and Galveston ports that could be paired with infrastructure projects designed to support marine bunkering of LNG. The Dallas-Fort Worth and Temple regions also house significant rail fuel use, but these regions would likely be better served with rail-focused LNG project efforts given the local demand and distance from coastal operations.

The Gulf Coast region offers a number of extremely positive LNG project development factors. As is being demonstrated by the pioneering Harvey Gulf LNG OSV project, industry leaders working to advance the natural gas market can find innovative approaches to realize important project cost and environmental savings, while leveraging the energy demand of the fuel-intensive high horsepower sector to drive investment in LNG production and supply chain infrastructure. As it is typically the case that the company chartering a commercial marine vessel will pay for the fuel consumed by that vessel, there are multiple incentives for natural gas E&P companies leverage their own operations to drive LNG fuel demand in this region.

In addition to innovative chartering arrangements for LNG powered commercial marine vessel service, regulatory questions must be addressed to allow for efficient vessel fueling operations when using LNG. Given the tight schedules and high operating costs of large vessels such as international containerships, bulk carriers, and tankers, it is important that such operators be able to load cargo and freight while simultaneously taking on LNG fuel in a bunkering operation (i.e. SIMOPS). Approval of SIMOPS is ultimately a decision that will be made by each USCG Captain of the Port based upon local and project specific considerations. At this time, no specific guidance on the SIMOPS issue has been formally issued by any USCG Captain of the Port in the Gulf of Mexico. Without any kind of precedence on this issue, it remains an unknown and thus a potential economic risk factor to those considering adoption of LNG.

Given the enormous potential LNG domestic and international demand of 743 million gallons each year by 2029, and the significant operational fuel cost savings and environmental benefits that can result from LNG operations, there are tremendous incentive for stakeholders to work cooperatively to find solutions to current uncertainties in the market. Harvey Gulf and Shell have already demonstrated innovative solutions to facilitate the deployment of the first LNG powered commercial marine vessels in North America, and the USCG is working aggressively on a variety of LNG marine projects throughout the U.S. to evaluate and approve such things as SIMOPS and other important operational issues. There is little doubt that, as the LNG marine industry continues to mature, Gulf Coast users will develop approaches that can then replicated and repeated by others.

Conclusion

Opportunities

The Gulf of Mexico, Great Lakes and inland waterways regions each present compelling opportunities for LNG growth across the marine and rail sectors. Within 15 years, the domestic marine market could potentially add 363 vessels and support international LNG bunkering for 35 high-demand ocean going vessels, generating total demand of 723 million LNG gallons a year. The railroad transition to LNG will likely be well underway and using approximately 274 million gallons per year by 2029. Based on GNA's analysis, the marine and rail users in the three study regions could collectively consume 1 billion gallons of LNG each year by this time, or approximately 76 BCF of natural gas per year.

Table 25: Forecasted LNG-fueled marine vessels in target regions by 2029

Vessel Type	Great Lakes LNG Vessels	Inland Waterways LNG Vessels	Gulf of Mexico LNG Vessels	Total LNG Vessels
Articulated Tug-Barge - U.S.-Flagged	-	-	2	**2**
Cargo (General) - U.S.-Flagged	3	1	7	**11**
Carrier (Dry Bulk) - U.S.-Flagged	6	-	4	**10**
Carrier (Dry Bulk) - International	-	-	8	**8**
Containership - U.S.-Flagged	-	-	13	**13**
Containership - International	-	-	3	**3**
Offshore Support Vessel - U.S.-Flagged	-	14	112	**126**
Passenger (Ro-Ro) - U.S.-Flagged	2	-	-	**2**
Pushboat - U.S.-Flagged	1	52	43	**96**
Tanker (Chemical / Product) - U.S.-Flagged	-	5	59	**64**
Tanker (Chemical / Product) - International	-	-	22	**22**
Tanker (LNG / LPG) - International	-	-	2	**2**
Tugboat - U.S.-Flagged	2	14	23	**39**
Total	**14**	**86**	**298**	**398**

Table 26: Forecasted annual LNG demand in target regions by 2029

	Great Lakes LNG Fuel Demand *(gallons)*	Inland Waterways LNG Fuel Demand *(gallons)*	Gulf of Mexico LNG Fuel Demand *(gallons)*	Total Forecasted Demand by 2029 *(gallons)*
Articulated Tug-Barge - U.S.-Flagged	-	-	1,364,040	**1,364,040**
Cargo (General) - U.S.-Flagged	6,323,668	2,107,889	14,755,226	**23,186,784**
Carrier (Dry Bulk) - International	-	-	78,299,992	**78,299,992**
Carrier (Dry Bulk) - U.S.-Flagged	12,505,207	-	8,336,805	**20,842,012**
Containership - International	-	-	29,362,497	**29,362,497**
Containership - U.S.-Flagged	-	-	83,510,490	**83,510,490**
Offshore Support Vessel - U.S.-Flagged	-	4,491,250	35,930,003	**40,421,254**
Passenger (Ro-Ro) - U.S.-Flagged	239,550	-	-	**239,550**
Pushboat - U.S.-Flagged	219,486	24,506,601	13,580,295	**38,306,382**
Tanker (Chemical / Product) - International	-	-	215,324,978	**215,324,978**
Tanker (Chemical / Product) - U.S.-Flagged	-	13,018,792	153,621,745	**166,640,537**
Tanker (LNG / LPG) - International	-	-	19,574,998	**19,574,998**
Tugboat - U.S.-Flagged	297,612	1,565,725	3,946,994	**5,810,330**
TOTAL MARINE (gal per year)	**19,585,524**	**45,691,257**	**Domestic – 315,045,598 Int'l – 342,562,465**	**722,883,844**
TOTAL RAIL (Gal/Year)	**43,000,000**	**145,000,000**	**85,000,000**	**273,000,000**
TOTAL COMBINED (Gal/Year)	**62,585,524**	**190,691,257**	**742,608,063**	995,883,844

The Gulf Coast region offers the most immediate market development opportunity among the study regions. Offshore supply vessels and the E&P companies that charter these vessels present a near-term demand center in the Ports of Fourchon, Galliano and throughout the Gulf. Supply challenges are minimized in the Gulf compared to other study regions because cost-effective LNG supply will be available from LNG America via the Cheniere export facility in 2016 to help support initial regional market growth. The ability to secure LNG without new liquefaction developments and to transport it economically via barge across a large geographic region will allow the market to scale quickly and flexibly, which should enable substantial growth in high fuel use domestic and international bulk cargo, tankers, and container vessels that will operate and fuel in Houston and the throughout the southern Louisiana ports. Other sources of LNG may come online after 2017 from the proposed export and production facilities throughout the region.

The near-term growth outlook in the Great Lakes and inland waterways is more nuanced. In the Great Lakes, an individual laker certainly uses enough fuel to warrant an LNG payback analysis; however, with so few lakers traveling such individualized operations, building liquefaction baseload is a challenge without other intermodal users. There are a few locations that offer some opportunities to aggregate marine and intermodal demand, but clustering users will require concerted on the ground market development efforts, route analysis, and a broader examination of international users. BLU LNG is attempting to develop projects in Duluth, where marine, rail and mining end users are clustered, and South Lake Michigan, where marine users fuel during Chicago region freight operations. Detroit may offer another opportunity to capture a larger population of vessel users at an existing bunkering location. Buffalo's proximity to a proposed Ontario LNG plant warrants further examination, particularly with Canadian vessels.

The inland waterways present a medium-term opportunity. Higher horsepower pushboats and tugs would likely realize favorable project economics with LNG vessels. Conversions offer near-term project opportunities for high fuel use operators and those with conducive existing vessel designs. Broad adoption will likely depend on a combination of conversion projects for applicable vessels that have a 10 year or more remaining asset life and developing newbuild product for pushboats operators where conversion strategies are not favorable from either an economics perspective or in terms of engine and/or on-board fuel storage considerations. Unfortunately, however, newbuild natural gas powered pushboats and tugs are unlikely to be commercially available before the early 2020s timeframe. With enough market interest, that timeframe and demonstrations could be accelerated.

The Gulf Coast region offers the most immediate market development opportunity among the study regions. Offshore supply vessels and the E&P companies that charter these vessels present a near-term demand center in the Ports of Fourchon, Galliano and throughout the Gulf. Supply challenges are minimized in the Gulf compared to other study regions because cost-effective LNG supply will be available from LNG America via the Cheniere export facility in 2016 to help support initial regional market growth.

Although some pushboat end users have initiated discussions with manufacturers and fuel providers, a single vessel's need for fuel along long riverway stretches creates logistical and supply challenges for LNG to get a foothold. Export facilities in the Gulf of Mexico or a proposed production facility in the Port of Baton Rouge will likely be able to supply vessels in the lower Mississippi, but vessels will still need reliable fueling access along routes that take them to St. Louis, Pittsburgh, and locations in between. Rail users might provide enough demand in St. Louis and Memphis to warrant co-located liquefaction development; however, rail and marine fueling operations aren't always a natural fit, based on both physical locations and competition for the same freight customers. There is some existing LNG supply in the Memphis and Paducah regions that could support pilot projects that could help seed an initial marketplace, but liquefaction would need to be developed to supply key fueling locations along the South Mississippi, Memphis, St. Louis and Paducah for long-term regional growth. None of these challenges are insurmountable, but they will certainly require commitment on the part of multiple stakeholders to overcome the inertia about "the way things are done" and to take on some risk so they can ultimately benefit from the rewards of long-term cost savings and environmental benefits of LNG operations.

Regions and marketplaces outside the three study areas offer other models for LNG growth. TOTE and Sea Star Lines will each provide enough demand through their container ships to support the development of new liquefaction in Tacoma, WA and Jacksonville, FL respectively. Crowley recently announced LNG plans for its Jacksonville operations that will build upon the TOTE infrastructure and create more cost-effective fueling for all parties. Although there are a limited market of users that have these high fuel use operations that travel point-to-point along set routes, LNG commitments from more large-scale ocean going vessels like TOTE, Crowley, and Horizon can literally change the marketplace. Companies with routes to Alaska and the Caribbean should be high priority targets, especially any Caribbean routes originating from the Gulf Coast.

Europe has led the world in developing LNG fueling infrastructure to support the marine market, working through bunkering best practices and plans to support a broad array of offshore service vessels, ferries, ocean going vessels, and other ships. These continent-wide planning exercises and best practices not only offer a model but also a market for growth. The U.S. has the lowest cost gas in the world and is situated across the ocean from a population of transatlantic vessels that are eager to use inexpensive North American natural gas. Although it is challenging to plan infrastructure growth around vessels with worldwide operations and intermittent bunkering, the market opportunity is tremendous. International vessels like Evergas could be using 343 million gallons of LNG each year within the Gulf Coast within 15 years. Evergas has been explicit about its desire to take advantage of inexpensive U.S. gas by burning as little diesel and European gas as possible. The U.S. has an opportunity to build on demand from operators like Evergas to make the North America the world's port for bunkering. This will require more research into potential international end users originating from ports with LNG infrastructure. This will also require LNG readiness plans and coordination among industry stakeholders in target ports along the Gulf Coast and elsewhere to ensure availability of fuel for international LNG bunkering.

North American railroads offer another huge opportunity to grow LNG demand and nationwide liquefaction capacity. The North American Class I railroads burned approximately 4.1 billion gallons of diesel in 2013 and have signaled their eagerness and willingness to adopt natural gas. Given that the marketplace is limited to only seven Class I railroads that fuel in centralized locations across regional operations, these railroads could both generate enough demand and exert enough control over operations and logistics to support a rapid and cost-effective transition to LNG. Railroads don't typically share their fuel sources with other transportation users. However, there may be opportunities to share intermodal liquefaction for unit trains or short haul operations or to transport LNG economically as cargo to support marine LNG customers. Although these arrangements may not work in the long term, they could be enough to jump start local markets of high horsepower users, helping build a stronger natural gas fueling marketplace overall.

Recommendations

Although educated estimates can project up to 1 billion gallons per year in annual LNG marine and rail demand by 2029, this growth is not a given. Actual growth rates will depend on fuel availability, technology availability, regulatory certainty, and the willingness of operators to adapt in order to adopt LNG opportunities. Operators in the Great Lakes and inland waterways are facing challenges with all of these factors. The Gulf has some advantages related to supply and technology, but industry must still address the operational barriers of charter arrangements in the offshore supply vessel marketplace and challenges with regulatory questions facing would-be marine and rail users.

Offshore support vessels present a near-term opportunity to build a domestic market for marine LNG. However, current chartering arrangements between the vessel owners and the oil and gas companies that hire the boats create disincentives for LNG. Leaders need to be willing to modify current chartering practices to share the costs, risks and savings. GNA's experience has shown that extended contract timeframes and/or shared investments in upgrades/conversion costs can often allow for the recovery of incremental project capital costs before fuel cost savings can then be shared amongst the parties.

North America is in a unique position to become the world's leading bunkering hub for LNG. The U.S. has access to the least expensive natural gas in the world and policymakers should be working to aggressively promote growth opportunities for clean, low-cost natural gas markets.

Within the rail sector, the FRA has yet to approve a design for an LNG tender car, although the AAR has convened a technical advisory group and is working with FRA on LNG tender car design standards. This process is likely to take another several years, and large-scale manufacturing of tender cars will be unlikely until standards are finalized. This has significantly reduced the speed with which the Class I railroad industry can ramp up their testing and, ultimately, commercial use of natural gas. Continued active engagement from all stakeholders will be critical to support a final LNG tender car design and approvals by the FRA.

Stakeholders should also continue to work with the USCG to support its guidance development process, thereby helping develop technology and fueling guidelines that aid LNG market growth in the maritime sector. In targeted project development regions, industry should work with the Captain of the Port and other relevant stakeholders to help identify local best practices for LNG operations. These coalitiondriven educational efforts could help support more cost-effective SIMOPS bunkering procedures that pave the way for improved LNG economics and increased LNG project adoption.

Ultimately, North America is in an incredibility unique position to become the world's leading bunkering hub for LNG. The U.S. has access to the least expensive natural gas in the world and policymakers should be working to aggressively promote growth opportunities for clean, low-cost natural gas markets. Europe has more expensive gas than the United States, and yet the continent has developed a harmonized regulatory framework for LNG as fuel and cargo and outlined a plan to build distribution networks of LNG via its inland waterway ports. This sort of domestic leadership and vision in the United States could help overcome both supply and regulatory challenges. Businesses and communities in gas producing and energy consuming states both stand to benefit from the economic and environmental opportunities presented by a large-scale transition to natural gas in our high horsepower sectors, and by facilitating the development of a worldwide marketplace. With this kind of strategic planning, policy-making and effort, the tremendous potential LNG demand identified within this analysis and report would ultimately be a starting point for significant additional growth of the LNG fuel market for the rail and marine sectors in the United States and beyond.

Appendix 1 – Vessel Fuel Use Assumptions

Table 27: Vessel Fuel Use Assumptions

Vessel Type	Average Installed Engine Power *(kW)*	Annual Fuel Use *(MT HFOe per vessel)*	Annual LNG Demand *(Gallons per vessel)*	LNG Substitution Rate	Actual LNG Demand *(Gallons per vessel)*	Source
Articulated Tug-Barge	5,508	2,502	1,240,036	55%	682,020	Assumption based on in-use data from similar vessel type and size used in Gulf Coast operations.
Cargo (General)	7,891	4,477	2,218,831	95%	2,107,889	Assumption based on in-use data from similar vessel type and size used in Gulf Coast operations.
Cargo (Ro-Ro)	4,184	2,502	1,240,036	95%	1,178,034	Assumption based on in-use data from similar vessel type and size used in Gulf Coast operations.
Carrier (Dry Bulk)	9,608	4,427	2,193,896	95%	2,084,201	Assumption based on in-use data from similar vessel type and size used in Gulf Coast operations.
Container ship	34,341	13,643	6,761,983	95%	6,423,884	Assumption based on in-use data from similar vessel type and size used in Gulf Coast operations.
Offshore Support Vessel	2,937	681	337,688	95%	320,804	Assumption based on in-use data from similar vessel type and size used in Gulf Coast operations.
Passenger (Cruise)	1,170	662	328,255	95%	311,842	Assumption based on in-use data from similar vessel type and size used in Gulf Coast operations.
Passenger (Other)	2,306	1,037	513,779	55%	282,578	Assumption based on in-use data from similar vessel type and size used in Gulf Coast operations.
Passenger (Ro-Ro)	2,232	254	126,079	95%	119,775	Assumption based on in-use data from similar vessel type and size used in Gulf Coast operations.
Pushboat - Above the Locks (< 6,000 hp)	1,529	1,070	535,152	55%	294,334	"Economic Guidance Memorandum 05-06: Shallow Draft Vessels Operating Costs, Fiscal Year 2004 (2004)." U.S. Army Corps of Engineers Planning Community Toolbox, FY 2004, page 9.

						http://planning.usace.army.mil/toolbox/library/EGMs/egm05-06.pdf, accessed July 29, 2014. For low horsepower vessels, analysis assumes 2,000 hp engine consuming 909.38 gallons per day operating 340 days per year.
Pushboat - Above the Locks (> 6,000 hp)	5,131	4,974	2,486,827	55%	1,367,755	"Economic Guidance Memorandum 05-06: Shallow Draft Vessels Operating Costs, Fiscal Year 2004 (2004)." U.S. Army Corps of Engineers Planning Community Toolbox, FY 2004, page 9. http://planning.usace.army.mil/toolbox/library/EGMs/egm05-06.pdf, accessed July 29, 2014. For high horsepower vessels, analysis assumes 6,880 hp engine consuming 4,225.85 gallons per day operating 340 days per year.
Pushboat - Below the Locks (< 6,000 hp)	1,691	1,357	678,376	55%	373,107	"Economic Guidance Memorandum 05-06: Shallow Draft Vessels Operating Costs, Fiscal Year 2004 (2004)." U.S. Army Corps of Engineers Planning Community Toolbox, FY 2004, page 9. http://planning.usace.army.mil/toolbox/library/EGMs/egm05-06.pdf, accessed July 29, 2014. For low horsepower vessels, analysis assumes 2,200 hp engine consuming 1,152.76 gallons per day operating 340 days per year.
Pushboat - Below the Locks (> 6,000 hp)	5,444	5,933	2,966,461	55%	1,631,554	"Economic Guidance Memorandum 05-06: Shallow Draft Vessels Operating Costs, Fiscal Year 2004 (2004)." U.S. Army Corps of Engineers Planning Community Toolbox, FY 2004, page 9. http://planning.usace.army.mil/toolbox/library/EGMs/egm05-06.pdf, accessed July 29, 2014. For high

						horsepower vessels, analysis assumes 7,300 hp engine consuming 5,040.89 gallons per day operating 340 days per year.
Pushboat - Open Water (< 6,000 hp)	1,102	798	399,066	55%	219,486	"Economic Guidance Memorandum 05-06: Shallow Draft Vessels Operating Costs, Fiscal Year 2004 (2004)." U.S. Army Corps of Engineers Planning Community Toolbox, FY 2004, page 9. http://planning.usace.army.mil/toolbox/library/EGMs/egm05-06.pdf, accessed July 29, 2014. For low horsepower vessels, analysis assumes 1,478 hp engine consuming 678.13 gallons per day operating 340 days per year.
Pushboat - Open Water (> 6,000 hp)	7,063	6,923	3,461,714	55%	1,903,943	"Economic Guidance Memorandum 05-06: Shallow Draft Vessels Operating Costs, Fiscal Year 2004 (2004)." U.S. Army Corps of Engineers Planning Community Toolbox, FY 2004, page 9. http://planning.usace.army.mil/toolbox/library/EGMs/egm05-06.pdf, accessed July 29, 2014. For high horsepower vessels, analysis assumes 9,472 hp engine consuming 5,882.47 gallons per day operating 340 days per year.
Tanker	9,140	5,530	2,740,798	95%	2,603,758	Assumption based on in-use data from similar vessel type and size used in Gulf Coast operations.
Tugboat - Above the Locks	839	168	83,282	55%	45,805	"Current Methodologies in Preparing Mobile Source Port-Related Emission Inventories." U.S. Environmental Protection Agency, April 2009. http://www.epa.gov/sectors/sectorinfo/sectorprofiles/ports/ports-emission-inv-april09.pdf, accessed July 29, 2014. Analysis assumes harbor tug with 711 kW

						total installed power engine operating 1,130 hours annually with a load factor of 31%. This data is based on Harbor Craft operations at the Port of Los Angeles and Long Beach.
Tugboat - Below the Locks	1,812	592	293,385	55%	161,362	"Current Methodologies in Preparing Mobile Source Port-Related Emission Inventories." U.S. Environmental Protection Agency, April 2009. http://www.epa.gov/sectors/sectorinfo/sectorprofiles/ports/ports-emission-inv-april09.pdf, accessed July 29, 2014. Analysis assumes assist tug with 1,540 kW total installed power engine operating 1,861 hours annually with a load factor of 31%. This data is based on Harbor Craft operations at the Port of Los Angeles and Long Beach.
Tugboat - Open Water (< 6,000 hp)	1,671	546	270,556	55%	148,806	"Current Methodologies in Preparing Mobile Source Port-Related Emission Inventories." U.S. Environmental Protection Agency, April 2009. http://www.epa.gov/sectors/sectorinfo/sectorprofiles/ports/ports-emission-inv-april09.pdf, accessed July 29, 2014. Analysis assumes assist tug with 1,540 kW total installed power engine operating 1,861 hours annually with a load factor of 31%. This data is based on Harbor Craft operations at the Port of Los Angeles and Long Beach.
Tugboat - Open Water (> 6,000 hp)	5,788	2,147	1,064,318	55%	585,375	"Current Methodologies in Preparing Mobile Source Port-Related Emission Inventories." U.S. Environmental Protection Agency, April 2009. http://www.epa.gov/secto

						rs/sectorinfo/sectorprofiles/ports/ports-emission-inv-april09.pdf, accessed July 29, 2014. Analysis assumes assist tug with 1,540 kW total installed power engine operating 1,861 hours annually with a load factor of 31%. This data is based on Harbor Craft operations at the Port of Los Angeles and Long Beach.
Vehicle Carrier	14,508	8,367	4,147,049	95%	3,939,697	Assumption based on in-use data from similar vessel type and size used in Gulf Coast operations.

Appendix 2 – Methodology for Fuel Use Assumptions

A key aspect of the assignment given to GNA by ANGA was to create an estimate of the possible market for LNG among the vessels operating in the Gulf of Mexico. In the absence of actually collecting individual company and vessel information, GNA developed an analytic technique to project a reasoned projection of the possible marine market for LNG. The following pages describe this methodology.

GNA utilizes the following approach to identify the fuel use characteristics of individual vessel types operating in the Gulf of Mexico. These characteristics include information on vessel type, engine size, design speed, average operating speed, and average time underway. From these data, it is possible to estimate fuel consumption on a vessel-by-vessel basis.

The analysis is built on three data sources:

1) The Automatic Identification System (AIS) is an automatic tracking system used on ships and by vessel traffic services for identifying and locating vessels by electronically exchanging data with other nearby ships, AIS base stations, and satellites.
    a. There are 13,865 individual vessel movement records in this dataset that cover the period from December 1, 2012 through November 30, 2013.
    b. The dataset includes both U.S.-flagged and international vessels.
    c. AIS's important data elements include amount of time underway within 200 miles of the Gulf Coast and the average operating speed, each of these are valuable indicators of fuel consumption.
2) The IHS Fairplay Sea-web database combines comprehensive data regarding ships, owners and operators, shipbuilders, fixtures, casualties, and port information.
    a. There are 6,434 vessels in this dataset.
    b. The dataset covers only U.S.-flagged, self-propelled vessel types, including bulk, cargo, fishing, inland waterways, miscellaneous (includes pushboats and tugboats), passenger, offshore, tankers.
    c. Sea-web's important data elements include vessel type, engine specifications, fuel used, and port location.
3) The US Army Corps of Engineers' (USACE) Navigation Data Center produces annual reports of the US waterways, characterizing the vessels and companies in operation.
    a. There are 40,521 vessels in this dataset.
    b. The dataset covers US-flagged vessels that are both self- or non-self-propelled. This dataset thus includes barges, pleasure craft, among other standard vessel types mentioned above.
    c. USACE's important data elements include company contact information and principal commodities.

The next task was to align all three of the data sources because each database contains different, yet important information. This process was completed using the following methodology:

1) Start with the AIS records as the base data, since it holds time and speed info.

2) Merge AIS records and Sea-web records by using the IMO number, which is present in both data sets.
3) Where records had duplicate IMO or MMSI numbers but the names were misspelled, correct the spelling and delete duplicates.
4) Merge this data with the USACE records by using the vessel name, which is present in all data sets.
5) The new master list now includes 1,275 unique U.S.-flagged vessels.
6) Remove vessels that had duplicate IMO numbers and vessel names.
    a. This removes any double-counting possibilities.
7) Remove vessels with invalid IMO numbers.
    a. This removes pleasure craft, non-motorized, and vessels with unverifiable data.
8) Remove vessels without speed or engine power data
    a. This removes vessels for which fuel use analyzing cannot be performed.
9) Remove vessels that are currently laid up our out of service.
10) The new master list included 1,024 unique U.S.-flagged vessels that were active during 2013 in the Gulf of Mexico.

Appendix 3 – Methodology for Long Term Growth Potential

The baseline fleet population is derived from the vessels identified in the U.S. Army Corps of Engineer's Waterborne Transportation Lines of the United States database. However, not all of these vessels are in active service. Thus, the following activity rates (also known as fleet utilization rates were applied:

Table 28: Utilization rates for U.S. vessels

Vessel Type	Utilization Rate	Source 1	Source 2
Articulated Tug-Barge	80%	Beagle, R. "An Overview of Trends in the Tug Market." Marcon International, Inc., May 2007. http://www.marcon.com/library/articles/2007/Tug%20Trends%20-%20Final%20color.pdf, accessed August 4, 2014.	"Tug Market Report." Marcon International, Inc., May 2013. http://www.marcon.com/library/market_reports/2013/tg05-13.pdf, accessed August 4, 2014.
Cargo (General)	99%	"Review of Maritime Transport, 2013." United Nations Conference on Trade and Development, 2013. http://unctad.org/en/publicationslibrary/rmt2013_en.pdf, accessed August 5, 2014.	
Cargo (Ro-Ro)	99%	"Review of Maritime Transport, 2013." United Nations Conference on Trade and Development, 2013. http://unctad.org/en/publicationslibrary/rmt2013_en.pdf, accessed August 5, 2014.	
Carrier (Dry Bulk)	83%	"The Platou Report, 2013." RS Platou, 2013. http://www.platou.com/dnn_site/LinkClick.aspx?fileticket=1%2BbboNTqMMA%3D&tabid=84, accessed August 5, 2014.	
Containership	72%	Rodding, B. "The Container Ship Market - Any Light in the Tunnel?" RS Platou Oslo. http://www.platou.com/dnn_site/LinkClick.aspx?fileticket=NzME0ukw4kM%3D&tabid=309, accessed August 6, 2014.	
LNG Tanker	96%	"The Platou Report, 2013." RS Platou, 2013. http://www.platou.com/dnn_site/LinkClick.aspx?fileticket=1%2BbboNTqMMA%3D&tabid=84, accessed August 5, 2014.	
Offshore Support Vessel	30%	DNV's "LNG as a Ship Fuel" section	
Passenger (Cruise)	98%	"Review of Maritime Transport, 2013." United Nations Conference on Trade and Development, 2013. http://unctad.org/en/publicationslibrary/rmt2	

		013_en.pdf, accessed August 5, 2014.	
Passenger (Other)	98%	"Review of Maritime Transport, 2013." United Nations Conference on Trade and Development, 2013. http://unctad.org/en/publicationslibrary/rmt2013_en.pdf, accessed August 5, 2014.	
Passenger (Ro-Ro)	98%	"Review of Maritime Transport, 2013." United Nations Conference on Trade and Development, 2013. http://unctad.org/en/publicationslibrary/rmt2013_en.pdf, accessed August 5, 2014.	
Pushboat - Above the Locks (< 6,000 hp)	80%	Beagle, R. "An Overview of Trends in the Tug Market." Marcon International, Inc., May 2007. http://www.marcon.com/library/articles/2007/Tug%20Trends%20-%20Final%20color.pdf, accessed August 4, 2014.	"Tug Market Report." Marcon International, Inc., May 2013. http://www.marcon.com/library/market_reports/2013/tg05-13.pdf, accessed August 4, 2014.
Pushboat - Above the Locks (> 6,000 hp)	80%	Beagle, R. "An Overview of Trends in the Tug Market." Marcon International, Inc., May 2007. http://www.marcon.com/library/articles/2007/Tug%20Trends%20-%20Final%20color.pdf, accessed August 4, 2014.	
Pushboat - Below the Locks (< 6,000 hp)	80%	Beagle, R. "An Overview of Trends in the Tug Market." Marcon International, Inc., May 2007. http://www.marcon.com/library/articles/2007/Tug%20Trends%20-%20Final%20color.pdf, accessed August 4, 2014.	"Tug Market Report." Marcon International, Inc., May 2013. http://www.marcon.com/library/market_reports/2013/tg05-13.pdf, accessed August 4, 2014.
Pushboat - Below the Locks (> 6,000 hp)	80%	Beagle, R. "An Overview of Trends in the Tug Market." Marcon International, Inc., May 2007. http://www.marcon.com/library/articles/2007/Tug%20Trends%20-%20Final%20color.pdf, accessed August 4, 2014.	
Pushboat - Open Water (< 6,000 hp)	80%	Beagle, R. "An Overview of Trends in the Tug Market." Marcon International, Inc., May 2007. http://www.marcon.com/library/articles/2007/Tug%20Trends%20-%20Final%20color.pdf, accessed August 4, 2014.	"Tug Market Report." Marcon International, Inc., May 2013. http://www.marcon.com/library/market_reports/2013/tg05-13.pdf,

			accessed August 4, 2014.
Pushboat - Open Water (> 6,000 hp)	80%	Beagle, R. “An Overview of Trends in the Tug Market.” Marcon International, Inc., May 2007. http://www.marcon.com/library/articles/2007/Tug%20Trends%20-%20Final%20color.pdf, accessed August 4, 2014.	
Tanker	84%	"The Platou Report, 2013." RS Platou, 2013. http://www.platou.com/dnn_site/LinkClick.aspx?fileticket=1%2BbboNTqMMA%3D&tabid=84, accessed August 5, 2014.	
Tugboat - Above the Locks	80%	Beagle, R. “An Overview of Trends in the Tug Market.” Marcon International, Inc., May 2007. http://www.marcon.com/library/articles/2007/Tug%20Trends%20-%20Final%20color.pdf, accessed August 4, 2014.	“Tug Market Report.” Marcon International, Inc., May 2013. http://www.marcon.com/library/market_reports/2013/tg05-13.pdf, accessed August 4, 2014.
Tugboat - Below the Locks	80%	Beagle, R. “An Overview of Trends in the Tug Market.” Marcon International, Inc., May 2007. http://www.marcon.com/library/articles/2007/Tug%20Trends%20-%20Final%20color.pdf, accessed August 4, 2014.	“Tug Market Report.” Marcon International, Inc., May 2013. http://www.marcon.com/library/market_reports/2013/tg05-13.pdf, accessed August 4, 2014.
Tugboat - Open Water (< 6,000 hp)	80%	Beagle, R. “An Overview of Trends in the Tug Market.” Marcon International, Inc., May 2007. http://www.marcon.com/library/articles/2007/Tug%20Trends%20-%20Final%20color.pdf, accessed August 4, 2014.	“Tug Market Report.” Marcon International, Inc., May 2013. http://www.marcon.com/library/market_reports/2013/tg05-13.pdf, accessed August 4, 2014.
Tugboat - Open Water (> 6,000 hp)	80%	Beagle, R. “An Overview of Trends in the Tug Market.” Marcon International, Inc., May 2007. http://www.marcon.com/library/articles/2007/Tug%20Trends%20-%20Final%20color.pdf, accessed August 4, 2014.	
Vehicle Carrier	84%	"The Platou Report, 2013." RS Platou, 2013. http://www.platou.com/dnn_site/LinkClick.aspx?fileticket=1%2BbboNTqMMA%3D&tabid=84, accessed August 5, 2014.	

After application of the utilization rate, the analysis applied annual growth rates. These were determined from industry knowledge and other sources as cited in the table below.

Table 29: Annual growth rates for U.S. vessels

Vessel Type	Great Lakes Annual Growth Rates	Inland Waterways and Gulf of Mexico Annual Growth Rates	Source
Articulated Tug-Barge	1.50%	1.5%	DNV - Tug/Pushboats
Cargo (General)	0.35%	8.0%	For Great Lakes, we know from industry experience that Lakers add 1 new vessel to the fleet every 10 years. For the other regions, DNV - Bulk Carriers
Cargo (Ro-Ro)	0.35%	0.5%	For Great Lakes, we know from industry experience that 1 large vessel is built every 10 years. For the other regions, DNV - Ro-Ro/Vehicle
Carrier (Dry Bulk)	0.35%	8.0%	For Great Lakes, we know from industry experience that 1 large vessel is built every 10 years. For the other regions, DNV - Bulk Carriers
Containership	0.35%	6.0%	For Great Lakes, we know from industry experience that 1 large vessel is built every 10 years. For the other regions, DNV - Bulk Carriers
LNG Tanker	2.00%	2.0%	DNV - LNG/LPG
Offshore Support Vessel	0.00%	4.0%	For the Great Lakes, there is unlikely to be growth in OSVs. For other regions, DNV - Offshore Supply
Passenger (Cruise)	-1.00%	-1.0%	DNV - Ferry
Passenger (Other)	-1.00%	-1.0%	DNV - Ferry
Passenger (Ro-Ro)	0.50%	0.5%	DNV - Ro-Ro/Vehicle
Pushboat - Above the Locks (< 6,000 hp)	1.50%	1.5%	DNV - Tug/Pushboats
Pushboat - Above the Locks (> 6,000 hp)	1.50%	1.5%	DNV - Tug/Pushboats
Pushboat - Below the Locks (< 6,000 hp)	1.50%	1.5%	DNV - Tug/Pushboats
Pushboat - Below the Locks	1.50%	1.5%	DNV - Tug/Pushboats

(> 6,000 hp)			
Pushboat - Open Water (< 6,000 hp)	1.50%	1.5%	DNV - Tug/Pushboats
Pushboat - Open Water (> 6,000 hp)	1.50%	1.5%	DNV - Tug/Pushboats
Tanker	0.35%	10.0%	For Great Lakes, we know from industry experience that 1 large vessel is built every 10 years. For the other regions, DNV - Bulk Carriers
Tugboat - Above the Locks	1.50%	1.5%	DNV - Tug/Pushboats
Tugboat - Below the Locks	1.50%	1.5%	DNV - Tug/Pushboats
Tugboat - Open Water (< 6,000 hp)	1.50%	1.5%	DNV - Tug/Pushboats
Tugboat - Open Water (> 6,000 hp)	1.50%	1.5%	DNV - Tug/Pushboats
Vehicle Carrier	0.50%	0.5%	DNV - Ro-Ro/Vehicle

From the utilization rate and growth rate, the analysis now generates the number of vessels that will enter the marketplace over the next 15 years (newbuilds). For each vessel type, we expect that a certain portion of these newbuilds will be LNG-fueled, as identified below.

Table 30: LNG-fueled newbuild rates of U.S. vessels

Vessel Type	LNG Newbuild Rates	Source 1
Articulated Tug-Barge	15.0%	DNV - Tug/Pushboats
Cargo (General)	5.0%	DNV - Bulk Carriers
Cargo (Ro-Ro)	10.0%	DNV - Ro-Ro/Vehicle
Carrier (Dry Bulk)	5.0%	DNV - Bulk Carriers
Containership	30.0%	DNV - Container Ship
LNG Tanker	10.0%	DNV - LNG/LPG
Offshore Support Vessel	25.0%	DNV - Offshore Supply
Passenger (Cruise)	10.0%	DNV - Ferry
Passenger (Other)	10.0%	DNV - Ferry
Passenger (Ro-Ro)	10.0%	DNV - Ro-Ro/Vehicle
Pushboat - Above the Locks (< 6,000 hp)	15.0%	DNV - Tug/Pushboats
Pushboat - Above the Locks (> 6,000 hp)	15.0%	DNV - Tug/Pushboats
Pushboat - Below the Locks (< 6,000 hp)	15.0%	DNV - Tug/Pushboats
Pushboat - Below the Locks (> 6,000 hp)	15.0%	DNV - Tug/Pushboats
Pushboat - Open Water (< 6,000 hp)	15.0%	DNV - Tug/Pushboats
Pushboat - Open Water (> 6,000 hp)	15.0%	DNV - Tug/Pushboats

Tanker	20.0%	DNV - Shuttle Tankers
Tugboat - Above the Locks	15.0%	DNV - Tug/Pushboats
Tugboat - Below the Locks	15.0%	DNV - Tug/Pushboats
Tugboat - Open Water (< 6,000 hp)	15.0%	DNV - Tug/Pushboats
Tugboat - Open Water (> 6,000 hp)	15.0%	DNV - Tug/Pushboats
Vehicle Carrier	10.0%	DNV - Ro-Ro/Vehicle

For the vessels that will be converted to LNG, the analysis used the estimates outlined below in determining the number LNG-fueled conversions. These conversion rates are defined as the percentage of newbuilds that have entered the market by 2029. For instance, for Lakers, we expect that for every newbuild (any fuel) that enters the market in the next 15 years, there will be 3 LNG-fueled conversions. This is based on industry knowledge, confidential business information, and confirmed orders for LNG conversions.

Table 31: LNG conversion rates for U.S. vessels

Vessel Type	Great Lakes LNG Conversion Rates of Existing Vessels *(as a rate of Newbuilds by 2029)*	Inland Waterways and Gulf of Mexico LNG Conversion Rates of Existing Vessels *(as a rate of Newbuilds by 2029)*	Justification
Articulated Tug-Barge	0%	0%	Due to feasibility concerns of LNG tank storage space and lack of Federal guidance, pushboats and tugboats are unlikely to convert vessels. This market will be driven by LNG newbuilds.
Cargo (General)	300%	25%	For the Great Lakes, large vessels stay in service for extended time periods and there is a very low newbuild rate. Thus, they are more likely to convert and are expected to have 3 conversions for every newbuild. This is based on the three suspected conversion projects underway (Interlake plus two unnamed vessel operators). For the other regions, the conversion rate is based on the current order book for 4 conversion / LNG-ready vessels out of total order of 17 vessels.
Cargo (Ro-Ro)	300%	25%	For the Great Lakes, large vessels stay in service for extended time periods and there is a very low newbuild rate. Thus, they are more likely to convert and are expected to have 3 conversions for every newbuild. This is based on the three suspected conversion projects underway (Interlake plus two unnamed vessel

			operators). For the other regions, the conversion rate is based on the current order book for 4 conversion / LNG-ready vessels out of total order of 17 vessels.
Carrier (Dry Bulk)	300%	25%	For the Great Lakes, Lakers stay in service for extended time periods and there is a very low newbuild rate. Thus, they are more likely to convert and are expected to have 3 conversions for every newbuild. This is based on the three suspected conversion projects underway (Interlake plus two unnamed vessel operators). For the other regions, the conversion rate is based on the current order book for 4 conversion / LNG-ready vessels out of total order of 17 vessels.
Containership	300%	25%	For the Great Lakes, large vessels stay in service for extended time periods and there is a very low newbuild rate. Thus, they are more likely to convert and are expected to have 3 conversions for every newbuild. This is based on the three suspected conversion projects underway (Interlake plus two unnamed vessel operators). For the other regions, the conversion rate is based on the current order book for 4 conversion / LNG-ready vessels out of total order of 17 vessels.
LNG Tanker	60%	60%	The conversion rate is based on the current order book for 12 LNG-ready vessels out of total order of 20 vessels.
Offshore Support Vessel	0%	0%	Offshore support vessels are specially designed vessels and would thus require substantial conversion costs and time. Thus, it is unlikely to see LNG conversions in this market and it will be driven by LNG newbuilds. This is supported by the current order book for 16 OSVs, all LNG newbuilds.
Passenger (Cruise)	10%	10%	The conversion rate is based on the current order book for 2 conversions out of total order of 17 vessels.
Passenger (Other)	10%	10%	The conversion rate is based on the current order book for 2 conversions out of total order of 17 vessels.
Passenger (Ro-Ro)	10%	10%	The conversion rate is based on the current order book for 2 conversions out of total order of 17 vessels.
Pushboat - Above the Locks (< 6,000 hp)	0%	0%	Due to feasibility concerns of LNG tank storage space and lack of Federal guidance, pushboats and tugboats are unlikely to convert vessels. This market will be driven by LNG newbuilds.
Pushboat - Above the Locks (> 6,000 hp)	0%	0%	Due to feasibility concerns of LNG tank storage space and lack of Federal guidance, pushboats and tugboats are unlikely to convert vessels. This market will be driven by LNG newbuilds.
Pushboat - Below the Locks (< 6,000	0%	0%	Due to feasibility concerns of LNG tank storage space and lack of Federal guidance, pushboats and tugboats

hp)			are unlikely to convert vessels. This market will be driven by LNG newbuilds.
Pushboat - Below the Locks (> 6,000 hp)	0%	0%	Due to feasibility concerns of LNG tank storage space and lack of Federal guidance, pushboats and tugboats are unlikely to convert vessels. This market will be driven by LNG newbuilds.
Pushboat - Open Water (< 6,000 hp)	0%	0%	Due to feasibility concerns of LNG tank storage space and lack of Federal guidance, pushboats and tugboats are unlikely to convert vessels. This market will be driven by LNG newbuilds.
Pushboat - Open Water (> 6,000 hp)	0%	0%	Due to feasibility concerns of LNG tank storage space and lack of Federal guidance, pushboats and tugboats are unlikely to convert vessels. This market will be driven by LNG newbuilds.
Tanker	60%	60%	The conversion rate is based on the current order book for 12 LNG-ready vessels out of total order of 20 vessels.
Tugboat - Above the Locks	0%	0%	Due to feasibility concerns of LNG tank storage space and lack of Federal guidance, pushboats and tugboats are unlikely to convert vessels. This market will be driven by LNG newbuilds.
Tugboat - Below the Locks	0%	0%	Due to feasibility concerns of LNG tank storage space and lack of Federal guidance, pushboats and tugboats are unlikely to convert vessels. This market will be driven by LNG newbuilds.
Tugboat - Open Water (< 6,000 hp)	0%	0%	Due to feasibility concerns of LNG tank storage space and lack of Federal guidance, pushboats and tugboats are unlikely to convert vessels. This market will be driven by LNG newbuilds.
Tugboat - Open Water (> 6,000 hp)	0%	0%	Due to feasibility concerns of LNG tank storage space and lack of Federal guidance, pushboats and tugboats are unlikely to convert vessels. This market will be driven by LNG newbuilds.
Vehicle Carrier	300%	25%	For the Great Lakes, large vessels stay in service for extended time periods and there is a very low newbuild rate. Thus, they are more likely to convert and are expected to have 3 conversions for every newbuild. This is based on the three suspected conversion projects underway (Interlake plus two unnamed vessel operators). For the other regions, the conversion rate is based on the current order book for 4 conversion / LNG-ready vessels out of total order of 17 vessels.

Appendix 4 – Gulf of Mexico Specific Data

Table 32: Active vessels in the Gulf of Mexico

Vessel Group	Vessel Type	Vessel Count
Bulk	Bulk Carrier	6
Oilfield Services Vessels	Anchor Handling Tug Supply	32
	Crew Boat	4
	Crew/Supply Vessel	96
	Diving Support Vessel	14
	Offshore Construction Vessel, jack up	45
	Offshore Support Vessel / Platform Supply Ship	330
	Offshore Tug/Supply Ship	36
	Pipe Carrier	1
	Well Stimulation Vessel	2
Passenger, Cargo, and Container	Container Ship	17
	Cargo (General)	10
	Passenger Ship	4
	Passenger/Cruise	3
	Passenger/Ro-Ro Ship (Vehicles)	2
	Cargo (Ro-Ro)	2
	Vehicles Carrier	15
Pushboats and Tugboats[109]	Articulated Pusher Tug	64
	Pushboat - Harbors and Inland Waterways (< 6,000 hp)	421
	Pushboat - Harbors and Inland Waterways (> 6,000 hp)	6
	Pushboat - Open Water (< 6,000 hp)	701
	Pushboat - Open Water (> 6,000 hp)	21
	Tugboat - Harbors and Inland Waterways (< 6,000 hp)	191
	Tugboat - Harbors and Inland Waterways (> 6,000 hp)	0
	Tugboat - Open Water (< 6,000 hp)	408
	Tugboat - Open Water (> 6,000 hp)	37
Tankers	Chemical/Products Tanker	22
	Molten Sulphur Tanker	1
Grand Total		**2,491**

[109] For vessels in the vessel group aside from articulated pusher tugs, the fleet population is based on an 80% utilization rate of the registered vessel inventory.

Table 33: Gulf of Mexico's active vessel engine power, fuel use, and LNG demand[110]

Vessel Group	Vessel Type	Total kW Main Engine	Annual Fuel Use *(MT HFOe / vessel)*	Annual LNG Demand *(Gallons / vessel, 100% LNG Substitution[111])*
Bulk	Bulk Carrier	9,608	4,427	2,193,896
Oilfield Services Vessels	Anchor Handling Tug Supply	7,096	905	448,734
	Crew Boat	5,656	2,729	1,352,529
	Crew/Supply Vessel	4,116	1,687	836,124
	Diving Support Vessel	2,930	507	251,108
	Offshore Construction Vessel, jack up	1,203	69	34,098
	Offshore Support Vessel / Platform Supply Ship	2,937	681	337,688
	Offshore Tug/Supply Ship	4,498	1,361	674,421
	Pipe Carrier	2,560	311	154,257
	Well Stimulation Vessel	3,134	1,286	637,432
Passenger, Cargo, and Container	Container Ship	34,341	13,643	6,761,983
	Cargo (General)	7,891	4,477	2,218,831
	Passenger Ship	2,306	1,037	513,779
	Passenger/Cruise	1,170	662	328,255
	Passenger/Ro-Ro Ship (Vehicles)	2,232	254	126,079
	Cargo (Ro-Ro)	4,184	2,502	1,240,036
	Vehicles Carrier	14,508	8,367	4,147,049
Pushboats and Tugboats	Articulated Pusher Tug	5,508	3,257	1,614,063
	Pushboat - Harbors and Inland Waterways (< 6,000 hp)[112]	1,691	1,357	678,376
	Pushboat - Harbors and Inland Waterways (> 6,000 hp)[113]	5,444	5,933	2,966,461

[110] Engine power and fuel use assumptions are based on the analysis outlined in the Appendix 2 – Methodology for Fuel Use Assumptions section, unless otherwise noted.

[111] The 100% LNG Substitution represents full conversion of MT HFOe. The LNG figures in this table represent the full conversion of energy potential from MT HFOe to LNG. However, based on GNA's knowledge of the industry, we do not expect that these vessels will use LNG for 100% of their fueling needs. Please see Table 27 for the LNG fuel substitution rate for each vessel type.

[112] "Economic Guidance Memorandum 05-06: Shallow Draft Vessels Operating Costs, Fiscal Year 2004 (2004)." U.S. Army Corps of Engineers Planning Community Toolbox, FY 2004, page 9. http://planning.usace.army.mil/toolbox/library/EGMs/egm05-06.pdf, accessed July 29, 2014. For low horsepower vessels, analysis assumes 2,200 hp engine consuming 1,152.76 gallons per day operating 340 days per year.

	Pushboat - Open Water (< 6,000 hp)	2,257	1,135	562,541
	Pushboat - Open Water (> 6,000 hp)[114]	7,063	6,923	3,461,714
	Tugboat - Harbors and Inland Waterways (< 6,000 hp)[115]	1,812	592	293,385
	Tugboat - Harbors and Inland Waterways (> 6,000 hp)	-	-	-
	Tugboat - Open Water (< 6,000 hp)	3,542	1,372	679,854
	Tugboat - Open Water (> 6,000 hp)	7,819	4,444	2,202,425
Tankers	Chemical/Products Tanker	9,226	5,548	2,749,624
	Molten Sulphur Tanker	7,238	5,138	2,546,634

Table 34: Annual fuel demand for HFOe and LNG in the Gulf of Mexico

Vessel Group	Vessel Type	Annual Fuel Demand *(MT HFOe)*	Annual LNG Demand *(Gallons, 100% LNG Substitution[116])*	% of Total Demand
Bulk	Bulk Carrier	26,559	13,163,373	0.7%
Oilfield Services Vessels	Anchor Handling Tug Supply	28,973	14,359,488	0.8%
	Crew Boat	10,916	5,410,116	0.3%
	Crew/Supply Vessel	161,954	80,267,859	4.4%
	Diving Support Vessel	7,093	3,515,514	0.2%

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[113] Data Source: "Economic Guidance Memorandum 05-06: Shallow Draft Vessels Operating Costs, Fiscal Year 2004 (2004)." U.S. Army Corps of Engineers Planning Community Toolbox, FY 2004, page 9. http://planning.usace.army.mil/toolbox/library/EGMs/egm05-06.pdf, accessed July 29, 2014. For high horsepower vessels, analysis assumes 7,300 hp engine consuming 5,040.89 gallons per day operating 340 days per year.

[114] "Economic Guidance Memorandum 05-06: Shallow Draft Vessels Operating Costs, Fiscal Year 2004 (2004)." U.S. Army Corps of Engineers Planning Community Toolbox, FY 2004, page 9. http://planning.usace.army.mil/toolbox/library/EGMs/egm05-06.pdf, accessed July 29, 2014. For high horsepower vessels, analysis assumes 9,472 hp engine consuming 5,882.47 gallons per day operating 340 days per year.

[115] ""Current Methodologies in Preparing Mobile Source Port-Related Emission Inventories." U.S. Environmental Protection Agency, April 2009. http://www.epa.gov/sectors/sectorinfo/sectorprofiles/ports/ports-emission-inv-april09.pdf, accessed July 29, 2014. Analysis assumes assist tug with 1,540 kW total installed power engine operating 1,861 hours annually with a load factor of 31%. This data is based on Harbor Craft operations at the Port of Los Angeles and Long Beach.

[116] The 100% LNG Substitution represents full conversion of MT HFOe. The LNG figures in this table represent the full conversion of energy potential from MT HFOe to LNG. However, based on GNA's knowledge of the industry, we do not expect that these vessels will use LNG for 100% of their fueling needs. Please see Table 27 for the LNG fuel substitution rate for each vessel type

	Offshore Construction Vessel	3,096	1,534,392	0.1%
	Offshore Support Vessel / Platform Supply Ship	224,843	111,437,140	6.1%
	Offshore Tug/Supply Ship	48,987	24,279,144	1.3%
	Pipe Carrier	311	154,257	0.0%
	Well Stimulation Vessel	2,572	1,274,864	0.1%
Passenger, Cargo, and Container	Container Ship	231,938	114,953,708	6.3%
	Cargo (General)	44,769	22,188,311	1.2%
	Passenger Ship	4,147	2,055,118	0.1%
	Passenger/Cruise	1,987	984,764	0.1%
	Passenger/Ro-Ro Ship (Vehicles)	509	252,157	0.0%
	Cargo (Ro-Ro)	5,004	2,480,072	0.1%
	Vehicles Carrier	125,510	62,205,735	3.4%
Pushboats and Tugboats	Articulated Pusher Tug	208,425	103,300,004	5.7%
	Pushboat - Harbors and Inland Waterways (< 6,000 hp)	571,297	285,596,296	15.8%
	Pushboat - Harbors and Inland Waterways (> 6,000 hp)	35,598	17,798,766	1.0%
	Pushboat - Open Water (< 6,000 hp)	795,649	394,341,519	21.8%
	Pushboat - Open Water (> 6,000 hp)	145,383	72,695,994	4.0%
	Tugboat - Harbors and Inland Waterways (< 6,000 hp)	113,072	56,036,535	3.1%
	Tugboat - Harbors and Inland Waterways (> 6,000 hp)	-	-	0.0%
	Tugboat - Open Water (< 6,000 hp)	559,660	277,380,312	15.3%
	Tugboat - Open Water (> 6,000 hp)	164,419	81,489,722	4.5%
Tankers	Chemical/Products Tanker	122,052	60,491,727	3.3%
	Molten Sulphur Tanker	5,138	2,546,634	0.1%
	GRAND TOTAL	**3,649,859**	**1,812,193,522**	**100.0%**

Appendix 5 – International Vessels in the Gulf of Mexico

Table 35: Projected growth of international vessels calling the U.S. by 2029[117]

Vessel Type	International Vessels	Projected Annual Growth Rate	Number of Vessels by 2029	Number of Newbuilds	% of Newbuilds Calling In U.S. Ports	Newbuilds Calling in U.S.
Bulk Carriers	9,494	1%	11,022	1,528	7.2%	110
Car Carrier	750	1%	871	121	9.0%	11
Container	8,266	1%	9,597	1,331	17.8%	237
Cruise Ships	358	1%	416	58	22.0%	13
LNG/LPG	1,240	1%	1,440	200	4.3%	9
OSV	6,387	1%	7,415	1,028	10.0%	103
Reefer Ship	881	1%	1,023	142	5.0%	7
Tankers	11,582	1%	13,446	1,864	11.8%	220
Total	**38,958**		**45,230**	**6,272**		**710**

Table 36: Projected number of LNG-fueled LNG vessels calling in the Gulf of Mexico by 2029[118]

Vessel Type	Newbuilds Calling in U.S.	% of Newbuilds Calling in Gulf of Mexico	Newbuilds Calling in Gulf of Mexico	% of Newbuilds that will be LNG-fueled	Number of LNG-Fueled Newbuilds	Number of LNG-Fueled Conversions
Bulk Carriers	110	46.3%	51	10.0%	5	3
Car Carrier	11	9.5%	1	10.0%	-	-

[117] DNV's estimates are based on research from the industry's news sources including Clarkson's, Lloyds List, Fairplay, Tradewinds, Sea-web, and Workboat, DNV GL's own internal research, and the judgment of experienced maritime professionals involved in the industry

[118] DNV's estimates are based on research from the industry's news sources including Clarkson's, Lloyds List, Fairplay, Tradewinds, Sea-web, and Workboat, DNV GL's own internal research, and the judgment of experienced maritime professionals involved in the industry

Container	237	9.9%	23	10.0%	2	1
Cruise Ships	13	37.0%	5	10.0%	1	1
LNG/LPG	9	70.7%	6	10.0%	1	1
OSV	103	75.0%	77	10.0%	8	5
Reefer Ship	7	41.0%	3	10.0%	-	-
Tankers	220	60.0%	132	10.0%	13	9
Total	710		298		30	20

Table 37: Projected LNG demand from international vessels calling in the Gulf of Mexico[119]

Fleet	Number of Vessels	Estimated Capacity (m3)	Annual Bunkering Events per Ship	% of Bunkering Events in Gulf of Mexico	Annual LNG Demand (m3)	Annual LNG Demand (gallons)
International	35	3,000	26	50%	1,296,750	342,562,465

[119] DNV's estimates are based on research from the industry's news sources including Clarkson's, Lloyds List, Fairplay, Tradewinds, Sea-web, and Workboat, DNV GL's own internal research, and the judgment of experienced maritime professionals involved in the industry