MARAD Great Lakes Natural Gas Feasibility and Design Study
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MARAD Great Lake Natural Gas Feasibility and Design Study

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Executive Summary

In August 2011, GLMRI entered into a five year cooperative agreement with the U.S. Department of Transportation (DOT) Maritime Administration (MARAD) to address environmental issues confronting shipping and marine transportation. MARAD requested that during the first year, GLMRI research the feasibility of converting the existing steam propelled vessels to using natural gas (NG), either compressed (CNG) or liquefied (LNG), as their primary fuel source. The conversion of these vessels would entail repowering to new diesel engines and replacing the existing fuel oil bunker tanks with NG storage tanks.

Throughout the 1940s and 1950s, the U.S. Great Lakes commercial fleet of almost 200 vessels transitioned from coal as a primary fuel to oil (Diesel and/or IFO-38/180, depending on engine type and size). The change was a major undertaking that impacted all segments of the maritime industry. Some vessels elected to not only change fuel but also repowered from steam to diesel engines. The new fuel was adopted by other modes of transportation and for home heating fuel altered trade on the Lakes as the east to west shipments of coal diminished to a small fraction of their former volume. The entire supply chain of trains, coaling docks, and barges virtually disappeared and tankers began carrying crude and refined products from the head of the Lakes to other ports. Crew requirements aboard vessels were transformed along with operating procedures. There were some in the industry who adopted the change early and those who resistant to change. New coal fired vessels such as the *S.S. Badger*, were being launched in the 1950s even as other vessels in adjacent Great Lakes yards were being converted to oil.

This major transformation of the Great Lakes maritime industry occurred for several key reasons that parallel the current situation with NG. Oil had become abundant as new fields in the Middle East were discovered. The oil supply chain serving multiple markets of the economy was being rapidly developed. New marine engineering and shipyard technology for oil fired ships had been developed that improved operations and lowered costs. During the shift from coal to oil, the U.S. Maritime Commission, the forerunner of MARAD, took a leadership role. The Commission supported relevant research and development, transferred technology from the coasts and even entire vessels to the Great Lakes. The Commission worked with other agencies to ensure that new regulations and training of mariners promoted a culture of safety with the new fuel. The transition was expensive, time consuming and created new dangers such as oil spills along with petroleum health and safety hazards. Entire industries, such as coal tippling docks ceased to operate and their employees were released. The high capital costs for conversion and development of the supply chain resulted in winners and losers in the market place. The transformation 60 years ago took place because of changing market forces, active government support and the vision by both the private and public sector to seek the long range benefits.

This preliminary public/private research by GLMRI has occurred because of cooperative leadership from MARAD, with urging and support by the Lake Carriers' Association. The research teams have concluded that:

- The peer reviewed engineering study has determined that the conversion of the AAA class of steamships on the Great Lakes from oil fired steam ships to diesel engines running on NG can, from an engineering perspective, be accomplished.
    - The general research findings are transferable to the other steam and diesel powered vessels on the Great Lakes. However, vessel specific conversion plans would be necessary.
    - The majority of the Great Lakes fleet would have the greatest operating flexibility and cargo carrying capacity using LNG as their primary fuel.
    - The business case for conversion was beyond the scope of this study.
- The peer reviewed engineering study has determined that the conversion of the S.S. *Badger's* historic Skinner steam engine to using NG as a fuel can, from an engineering standpoint, be accomplished.
    - The repowering of the *Badger* to diesel engines would increase energy efficiency but with the loss of the national historic register steam engines.
    - CNG as well as LNG may be viable options for this vessel on its fixed route.
    - The operating schedule of the vessel may be adversely impacted if fueling is not allowed during loading and unloading.
    - The business case for conversion was beyond the scope of this study.
- The conversion of Great Lakes' vessels from oil or coal to NG will significantly reduce their environmental impact.
    - The referenced converted vessels move beyond compliance with Emission Control Area (ECA) regulations and eliminate the need to dispose of the hazardous waste from stack scrubbers.
    - Operating the *S.S. Badger* on NG would result in not only meeting air emission regulations but would also eliminate the need to dispose of coal ash.
    - Trucks transiting on cross-lake ferries burning NG while using the latest diesel engine technology may realize environmental advantages compared to all highway movements.
- Safe and economically viable regulations specific to vessels using NG as a fuel need to be fully developed.
- The NG supply chain for all modes of transportation is in its infancy and currently could not supply a major fleet transition of the vessels to NG.
    - At present there are no approved fueling docks for transferring NG.
    - The existing supply of LNG in the Great Lakes to serve vessels is limited but there is industry interest and potential for new liquefaction plants in key locations. The marine industry was the focus of this study but rail, highway, mining, agriculture and transit are all interested in expanding the use of NG as a transportation fuel.
    - The adoption of NG by multiple modes could reduce cost by realizing economies of scale and the transfer of diesel technology between modes.

- European countries such as Norway are significantly more advanced in using NG as a marine fuel and tapping into their expertise could reduce costs and time.
    - The shipyard, supply chain, training and regulations that have evolved over a decade of use provide extremely useful insight and possible adoption in the U.S.
- A program of public outreach and education is essential for stakeholder understanding of the potential benefits and issues related to conversion of marine vessels to NG.
    - Many stakeholders have misconceptions of NG or lack any detailed knowledge to make informed decisions.
    - Most stakeholders are unaware that U.S. flag NG carriers have used NG as a marine fuel for over four decades with an exemplary safety record, or that it is being used in Europe for passenger and car/truck ferries as well as Coast Guard Cutters.

Recommendations:

- MARAD's continued leadership role in this public/private partnership is essential to moving forward with the transition. MARAD is able to interact cooperatively with other key government agencies and can engage foreign agencies who are also involved with developing NG as a marine fuel.
- Research is required to determine how the findings of this Great Lakes study can be utilized and expanded for inland rivers and coastwise trades.
- Studies need to be accomplished on the feasibility of converting existing Great Lakes diesel powered ships to using NG.
- Shipyards need to be supported in order to gain the expertise and technology needed to build, maintain and repair NG fueled vessels.
- A comparative environmental study should be conducted to assess the total fuel cycle, i.e. from well to stack, for diesel fuel and NG.
- The research into the development of the NG supply chain for marine use needs to continue. Through MARAD's leadership other modal agencies as well as private enterprise can be part of a collaborative process that looks at supply chain synergies.
- The U.S. Coast Guard (USCG) is seeking input from all concerned parties and MARAD's LNG Task Force can continue to be a resource on regulatory issues concerning NG fueling, operations, and training in the maritime industry.
- Public outreach and education should continue and where appropriate expanded. Efforts need to be made to cooperate with NG suppliers to other modal markets to ensure efficient broad coverage that embraces all modes.
- There is a need to support those interested in adopting improved technology early since they are taking the greatest risk. Support could be financial and/or institutional. (An example of a successful MARAD program for the Great Lakes was the Merchant Marine Act of 1970 that provided incentives for companies converting to diesel and building 1000 foot ships.)

- Shippers will be a key factor in companies adopting NG. Studies are necessary to assess how improving the environmental footprint of the marine segment of a supply chain improves the shipper's supply chain and their green image. Environmental agencies and classification societies enhance shipper support of environmental improvement from adopting NG. This can be accomplished through the formal recognition to marine carriers such as the ABS Energy Management Certification and the Clean Excellence Award from the EPA in Transportation Efficiency Innovations. MARAD can be proactive in this process.
- Repowering the existing Great Lakes steam ships to diesels fueled by NG appears to have significant environmental and economic benefits. Alternatively, given the age of the vessels, a government-industry partnership could pursue visionary research efforts to design the Great Lakes fleet of the future. Designs that utilize not only NG as a fuel but also integrated diesel electric technology, the latest safety features, integrated bridge navigation systems and designs addressing emerging climate change issues on the Lakes. Those vessel designs should take advantage of lower unit costs by adopting series production and state of the art shipbuilding technology. The designs would not only encompass the existing Great Lakes trades but be adaptable for new Lakes markets with technology transferable to the rivers and coastwise markets.

Introduction

In August 2011, GLMRI entered into a five year cooperative agreement with MARAD to address environmental issues that face shipping and marine transportation. Specific study topics will be directed by MARAD that benefit not only maritime commerce in the Great Lakes region, but other transportation modes along with ports and vessels operating on the inland rivers and coastal waters.

With stricter emission standards forthcoming from the Environmental Protection Agency (EPA) and the International Convention for the Prevention of Pollution from Ships (MARPOL), some companies are interested in converting existing main steam and diesel propulsion systems from using heavy fuel oil (HFO), Intermediate fuel oil (IFO) or even coal as a primary fuel to NG. However, the technology is new in the U.S. with only a few marine operators who have engaged in preliminary NG conversion research. Regulations for vessels using NG as a fuel are uncertain and the supply chain is undeveloped. MARAD requested that during the first year, GLMRI research the feasibility of converting the existing steam propelled vessels to using natural gas, either CNG or LNG, as their primary fuel source. The conversion of these vessels would entail repowering to new diesel engines and replacing the existing fuel oil bunker tanks with NG storage tanks. Initial efforts are depicted in this report.

Project Overview

The initial focus for the study was a preliminary examination on converting the existing fleet of approximately 10 U.S. flag commercial Great Lakes steamships to using NG as their principal fuel source. While these vessels are legally exempt from the new emission requirements, the owners recognize that the best environmental solution would be to replace the steam engines that have poor thermal efficiency resulting in significant emissions. They believe that the recent abundance of domestic NG may provide a new cost effective opportunity for conversion to using NG as a primary fuel source.

NG would be a clean burning fuel that would make the U.S. flag fleet a world leader in reducing harmful air emissions including greenhouse gases. The looming issue of a probable shortage of low sulfur marine diesel fuel would be mitigated. Knowledge gained through the conversion of the steam ships may be adaptable to converting existing diesel powered vessels to NG, where practicable.

The Great Lakes vessels, so essential to our national steel supply chain, would be using a reliable, relatively low cost domestic fuel source. In theory, the long service life of the hulls for Great Lakes vessels enables the owners to spread the conversion costs over a longer period of time than for an ocean carrier. The repowering and fuel conversion process may provide opportunities for carriers to gain fuel efficiency, increased productivity, and operational improvements.

Vessel conversion and operations would create and keep employment in the Great Lakes region not only for vessels but all along the supply chain. A significant number of vessel conversions may result in lowering the incremental costs for NG and related engines and may precipitate new shipbuilding. Advances in engineering, technology, training, and operations of Great Lakes vessels adapted for using NG fuel could be transferred to U.S. flag coastwise and inland vessels. The use of NG as the primary fuel for Great Lakes vessels has the potential to benefit the carriers, shippers, and public, along with the natural environment.

Challenges: Conversion of a vessel's main power plant or fuel type is expensive, complex, and engineered for that specific vessel. The existing market and regulations do not reward carriers and their shippers for the substantial additional cost of moving beyond minimum compliance, no matter how much the environment is improved. Carriers who adopt using cleaner fuel such as NG early may be penalized for being environmentally pro-active. The capital costs of conversion will have to be recovered through improved performance, lower operating costs, and possible increases in freight rates. Carriers will have difficulty obtaining private financing for conversions if there are not clear monetary benefits that translate into income for debt repayment.

Shippers select carriers based on freight rates and reliability. A marine carrier who elects to move beyond compliance by incurring high capital costs in converting to NG as a fuel vs. another carrier who is meeting minimum standards with less expensive technology may be penalized in the market when a shipper selects the lower cost operator meeting minimum standards. Economic and market incentives, such as the EPA Smartway Partnership, may be needed for shippers to support carriers who are early adopters of the cleaner gas system. Currently there are no NG fueling ports on the Great Lakes and the fuel distribution system would have to be developed. The Great Lakes shipyards would have to embrace the new technology, add equipment, and train their workforce for NG conversion. NG has a lower British Thermal Unit (BTU) rating than petroleum based fuels on a per gallon basis. This means that vessels must not only have cryogenic LNG tanks but also have adequate storage space for intended voyages.

Industry's Opinion: Researchers from the GLMRI met with leaders from the carriers, shipbuilding, and government agencies and informally discussed NG conversion. These groups see clear long term advantages to NG conversion and have already embarked on vessel conversion studies and to a very limited extent, fuel sourcing. However, there is guarded optimism about the opportunity because of the scope of change, availability of capital, the lack of cohesive and cooperative federal state and local government backing, and the potential to lose market share to unconverted ships.

Industry Interest and Involvement

GLMRI with the assistance of the Lake Carriers' Association (LCA) coordinated a meeting with key shipping company representatives from five companies sailing on the Lakes representing over 60 percent of the U.S. Flag (Great Lakes) fleet, MARAD members, and the GLMRI research team. The meeting was held in Cleveland, Ohio, on 23 August 2011. The purpose of the meeting was to explore the interest level on possible conversion of the Great Lakes vessels to use NG as a primary fuel source. Based upon comments from the Lake Carriers' representatives present and other stakeholder discussions, it appeared that the best study target for using NG would be the existing steamships. Although CNG had been considered by some operators, their initial studies indicated that the stowage advantages of LNG would make it the most practical type of gas for most Great Lake carriers' operating parameters. There are still many concerns that must be addressed before moving to LNG such as safety measures with cryogenic pressure tanks, and the BTU equivalencies between diesel and LNG. The GLMRI research team was given access to information and resources to prepare engineering conversion studies on three AAA steam vessels operated by the Great Lakes Fleet. Although the initial focus was on the AAA the experience gained would provide critical information that could be transferred to other vessels in the fleet.

In addition, GLMRI embarked on a smaller scale demonstration project utilizing the *S.S. Badger* along with other projects. The *S.S. Badger*/Lake Michigan Carferry Service (LCMS) is seeking to transition its fueling from coal to another energy source as soon as practicable. LCMS is considering the use of CNG as an alternative. The GLMRI research focused on engineering design and using the *S.S. Badger* model as a case study to apply specific information to evaluate the preliminary impact of utilizing CNG/LNG as a primary fuel, while providing information technology to transfer to other industry platforms or other modes for CNG/LNG usage.

Based upon stakeholder input, it was also decided that research should be done on the supply of NG and also the regulations pertaining to using NG as vessel fuel. An educational and outreach program was recommended so that the results of GLMRI's research be shared with as large an audience as possible.

Study Focus

GLMRI worked with MARAD to build a work plan on what could be achieved within the first phase of the study, within the available funding resources and time.

Once the final plan was confirmed, GLMRI program managers developed sub-agreements within GLMRI affiliate universities and Great Lakes' experts to address the specific topics. A key component of the study was the cooperation provided by the LCA membership and representatives from the NG industry. Access to vessels, plans and experts was made available to the GLMRI research team. GLMRI teamed with engineering faculty and firms. Also, GLMRI personnel met with the USCG District 9 senior representatives, so that they were aware and, where appropriate, could support the studies.

A conceptual study to analyze the engineering, financial, environmental, and energy issues associated with steamship conversion was led by Dr. Michael Parsons, Professor Emeritus from the University of Michigan's Naval Architecture and Marine Engineering Department.

A sub-contract was awarded to Bay Engineering, Inc. (BEI) out of Sturgeon Bay, Wisconsin to address the engineering and design, and to identify the issues impacting converting the *S.S. Badger* to NG fuel while retaining the existing steam engines. Another sub-project was awarded to GLMRI Affiliate Rochester Institute of Technology to apply their emissions comparison model against multiple fuel alternatives for the *S.S. Badger* and do a truck modal comparison.

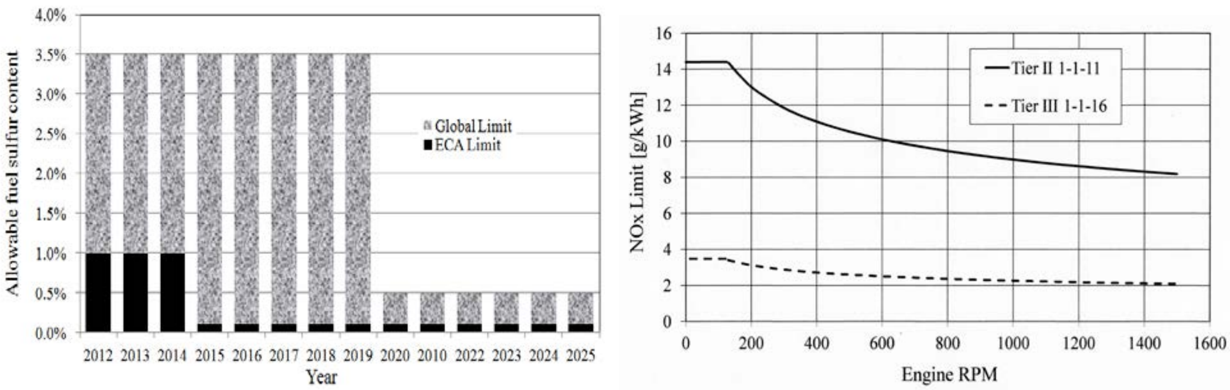
GLMRI employed a retired career USCG officer with extensive background both in regulatory issues and the Great Lakes to research federal, state, and local issues impacting the maritime use of LNG. Dr. Stewart, GLMRI Co-director, led a team of students at the University of Wisconsin-Superior to research gas suppliers and pipeline companies to explore the LNG supply chain needed to support the fuel demand for the fleet with the potential for this fuel to be used by other modes of transportation. In addition, GLMRI staff met with USCG members in Washington, D.C. to cooperatively review the study progress and share information.

Plans were developed to execute venues for education and outreach of the materials gathered and outcomes of the study. For material dissemination, GLMRI consolidated the literature review, reports, presentations, articles and videos/links on the Institute's web page www.glmri.org for public access. In addition, in the GLMRI Quarterly Updates, study progress highlights have been included and sent to over 600 national and international offices for awareness and engagement of governmental agencies, industry and political offices.

Study Outcomes:
Engineering and Design: AAA Steamships

Early discussions ensued on which vessels were suitable for conversion. Some of the smaller vessels may not have the stowage space for an adequate supply of LNG. Conversions specifications need to be considered of the various power alternatives, along with the useful life of the converted vessels.

The design focus investigated the feasibility of conversion of the approximately 10 remaining steam powered U.S. Great Lakes bulk carriers to LNG fueled propulsion. These vessels have the worst air emissions within the U.S. bulk carrier fleet and are currently grandfathered from having to meet EPA requirements. The goal of this research was to develop conceptual designs for the conversion of these vessels to LNG fuel using gas engines to achieve very low emissions and significantly reduced fuel consumption and cost.   They would then meet the more stringent ECA air emissions requirements (Fig. 1) that will come into effect on the Great Lakes in 2015/2016 without the need for exhaust gas scrubbers or Selective Catalytic Reduction (SCR) that would be required in a diesel conversion. The LNG fueled bulk carrier air emissions would go from worst to best among the U.S. Great Lakes fleet.



(a) ECA Marine Fuel Sulfur Content Limits in 2015 (b) ECA Tier III NOx Emissions Limits in 2016

Figure1: More stringent Emissions Control Area Requirements for the Great Lakes in 2015 and 2016

The use of LNG would also result in a significant fuel cost savings that could provide added justification for the vessel conversion and further economic life. Reduced manning may also be feasible with the move away from steam propulsion. The study considers arrangements, effects on cargo capacity at constant draft, fuel usage, air emissions, maintenance requirements, manning, and remaining ship life-cycle economics. The conceptual designs are in accordance with the requirements of the American Bureau of Shipping (ABS) Guide "Propulsion and Auxiliary Systems for Gas Fueled Ships," May, 2011.

A detailed assessment of the fuel costs associated with use of LNG fuel for AAA Class vessels considered four options: the existing steam plants burning Bunker C; single fuel LNG gas engines burning LNG with Marine Diesel Oil (MDO) electric generators; dual fuel LNG gas engines burning LNG and a small amount of MDO pilot fuel with MDO electric generators; a diesel conversion burning either MDO or Intermediate Fuel Oil (IFO). The conversions are based upon using one Rolls-Royce Bergen B35:40V12PG spark ignited single fuel LNG engine, a Wärtsilä 12V34DF dual fuel MDO pilot ignited LNG engine, or a MaK 6M43C diesel engine for propulsion, respectively. The annual fuel cost comparison for these options is shown in Table 1. The LNG conversions offer about a 2 million USD, 30 percent annual fuel cost savings compared to the current steam plants, which is comparable to that provided by a diesel conversion that is equipped with an exhaust gas scrubber which would allow burning IFO after 2015.

Table 1: Annual Fuel Cost Comparison for AAA Class Bulk Carriers

	Existing Steam	Single Fuel LNG	Dual Fuel LNG	Diesel	Diesel
main engine fuel	Bunker C	LNG	LNG & MDO	MDO	IFO
generator set fuel	Bunker C,MDO	MDO	MDO	MDO	MDO
main engine fuel price	$675/t	$690/t	$690/t,$1025/t	$1025/t	$682/t
generator fuel price	$675/t,$1025/t	$1025/t	$1025/t	$1025/t	$1025/t
fuel cost per voyage	$123,038	$83,261	$86,535	$110,035	$82,520
voyages in 300 day season	53	53	53	53	53
annual fuel cost	$6,521,014	$4,412,833	$4,586,355	$5,831,855	$4,373,560
annual fuel savings rel. to current steam plant		$2,108,181 32.3%	$1,934,659 29.7%	$689,159 10.6%	$2,147,454 32.9%

Air emissions associated with use of LNG fuel for AAA Class vessels were also evaluated for the four options: the existing steam plants burning Bunker C; single fuel LNG gas engines burning LNG with MDO electric generators; dual fuel LNG gas engines burning LNG and a small amount of MDO pilot fuel with MDO electric generators; and a diesel conversion burning MDO. This was based upon operations after January 1, 2015, when the 0.1% sulfur marine fuel requirement would be in effect. The results of this study are summarized in Table 2 with the same three engines were considered. The LNG conversions offer major improvements in the nitrogen oxide (NOx) emissions compared to a diesel conversion. All of the conversions offer major improvements in particulate matter sulfur oxide (SOx), particulate matter (PM) and carbon dioxide (CO_2) emissions. The LNG conversions, particularly the single fuel option, offer significant advantages over the diesel conversion in terms of the particulate and SOx emissions.

Table 2: Annual Air Emissions Comparison [metric tonnes/300 day operating year]

	Existing Steam	Single Fuel LNG	Dual Fuel LNG	Diesel
main engine fuel	2% S Bunker C	LNG	LNG/0.1% S MDO	0.1% S MDO
generator fuel	0.45% S MDO	0.1% S MDO	0.1% S MDO	0.1% S MDO
notes	turbogenerators			no SCR
HC w/o CH4	4.26	64.52	91.05	14.52
CH4	n.a.	93.59	152.15	n.a.
NOx	76.71	70.19	73.44	307.76
CO	8.38	36.67	64.44	15.73
PM	36.28	0.64	2.54	3.97
PM-10	36.28	0.64	2.54	3.97
PM-25	35.19	0.62	2.46	3.85
SOx	371.05	1.60	1.65	11.45
CO2	30722.7	15091.0	15540.1	18156.6
CO2 equivalent GHGs	30722.7	17056.3	18735.2	18156.6

Conceptual designs were developed for both the single fuel and dual fuel conversions. The most challenging naval architectural issue is to obtain enough volume within the vessel to store the LNG since it requires 3 to 4 times as much gross hull volume as an equivalent amount of petroleum fuel. The AAA vessels are particularly good candidates for an LNG conversion, however, because the portion of the vessel between web frame (FR)183 and (FR)195 currently occupied by the boilers, deaerating feed tank, and fuel bunkers can become available for two vertical LNG fuel tanks. An LNG storage tank design for the AAA vessels was developed for the project by Chart Ferrox, a.s. of Decin, Czech Republic. These 17.5 ft. outer diameter, 43 ft. tall double wall, vacuum and pearlite insulated cryogenic tanks have the equipment for tank pressure control and LNG re-gasification installed in a cold box within the tank support skirt below the tanks. These 199 gross cubic meter tanks would have enough capacity to allow the AAA vessels to fuel once per typical round trip (Duluth, MN, to Gary, IN) with a fuel margin of about 60 percent. The inboard profile of the aft part the conversion using the single fuel Rolls-Royce Bergen B35:40V12PG engine is shown in Figure 2. The main deck aft plan view of the single fuel LNG conversion of AAA class vessels is shown in Figure 3. The dual fuel LNG conversion is similar with only minor variations needed to accommodate a slightly (0.6 m) longer engine and the needed MDO fuel bunker. Although slightly inferior in terms of fuel savings and emissions, the dual fuel option would offer a potentially major advantage since it can operate on MDO only if LNG is not available when and where needed in the initial years of the development of a LNG infrastructure with the Great Lakes. The project is continuing to develop overall remaining life-cycle economic tradeoff comparison of the LNG and diesel conversions.

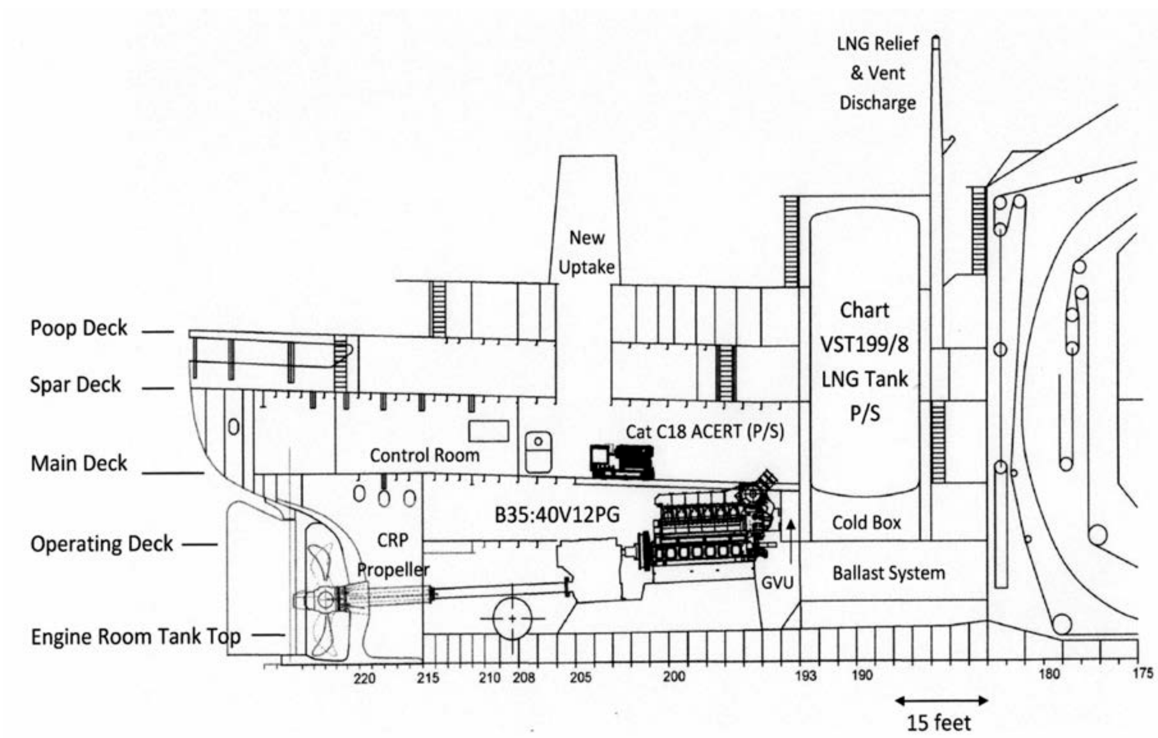


Figure 2: Inboard Profile Aft of AAA Class Vessel Single Fuel LNG Conversion

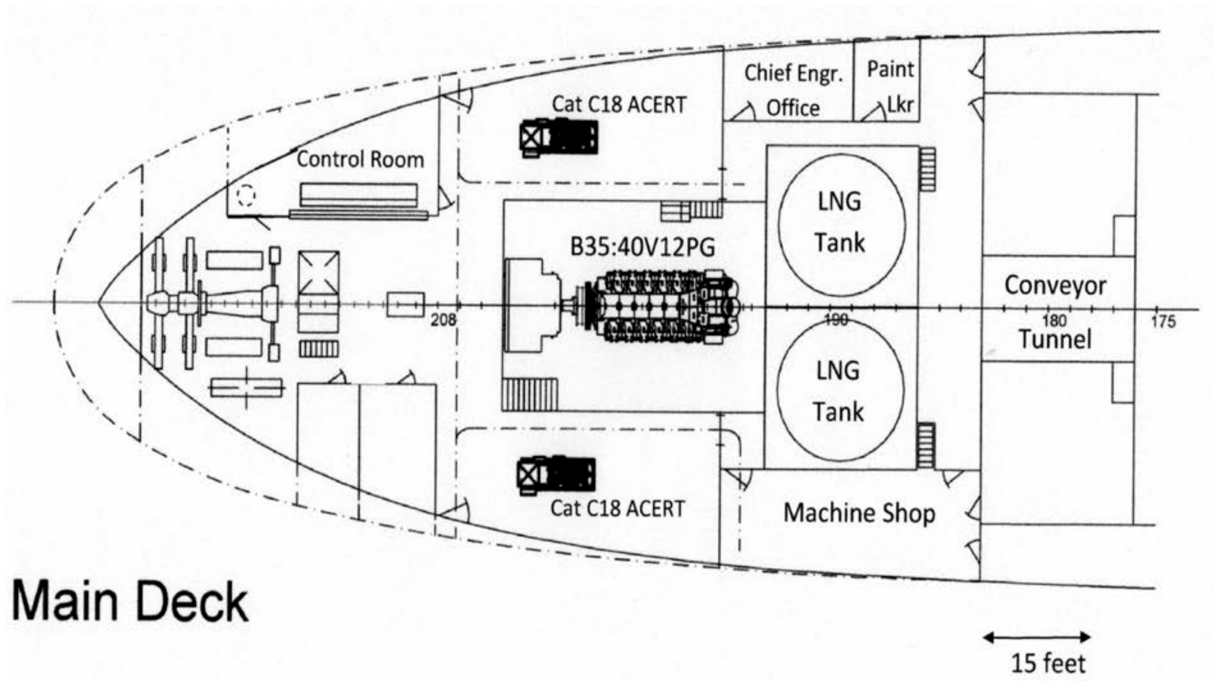


Figure 3: Main Deck Aft of AAA Class Vessel Single Fuel LNG Conversion

Demonstration Project Model: *S.S. Badger*

GLMRI worked closely with the LCMS and marine engineering experts in exploring the feasibility of converting the *S.S. Badger* to operate its engines on NG. The focus of this effort was to perform an assessment of the tradeoff between a CNG and a LNG conversion for the *S.S. Badger*, assuming that the current boilers and main engines will be maintained. A sub-contract was awarded to BEI to address the engineering and design, and to identify the issues impacting converting the *S.S. Badger* to NG. Another sub-project was awarded to GLMRI Affiliate Rochester Institute of Technology to run their developed emissions comparison model against multiple fuel alternatives for the *S.S. Badger* and a modal comparison. GLMRI hired a retired career USCG officer with extensive background both in regulatory issues and the Great Lakes to address federal, state and local issues impacting the maritime use of LNG. The study also looked at fuel availability and options for the current Ludington, Michigan to Manitowoc, Wisconsin route, considering the possible purchase of LNG from a Wisconsin peak shaving plant with trucking the LNG to Manitowoc. The engineering team also considered the arrangements for fuel storage and bunkering (to include stock pile requirements) along with the inherent safety of the fuel storage options for a passenger vessel and the shore side support. A conceptual design was developed for installation on the *S.S. Badger*.

rior to the study, the *S.S. Badger*/LMCS was considering the use of CNG as an alternative fuel to the coal currently in use. The GLMRI project focused on engineering design and using the *S.S. Badger* model as a case study to apply specific information to evaluate the operational impact of utilizing CNG/LNG as a primary fuel, while providing information technology to transfer to other industry platforms, such as other ships or even other modes for CNG/LNG usage.

BEI applied the ABS criteria for the arrangements and construction of machinery, equipment, and systems for vessels operating with natural gas as fuel, in order to minimize risks to the vessel, crew, and environment in their design analysis for the *S.S. Badger* (The BEI full report with references and citations is included at Tab 5). The system will be configured to use NG to power the existing boilers with new NG burners instead of coal. The boilers in turn will provide steam energy to power the propulsion and auxiliary systems.

There are several locations that can be used for the gas storage. Both LNG and CNG gas storage tanks could be located on the open deck; at least B/5 (11.9 ft or 3.627 m for *S.S. Badger*) from the ship's side. Stainless steel drip trays will be fitted below the LNG tank connections and be away from the entrance, air inlets and openings to accommodation spaces, services spaces, cargo spaces, machinery spaces, and control stations. The gas storage tanks and equipment should be located so as to facilitate sufficient natural ventilation, in order to prevent accumulation of escaped gas.

The tank type will be double-wall Type C cryogenic tanks for LNG or high pressure gas tanks for CNG. The Type C tanks have a double wall design, which consists of an inner cryogenic cylindrical vessel with an outer jacket. This design creates a double barrier required by ABS safety regulations, so that no additional structural secondary barrier is required for a Type C tank. The inner vessel is made of stainless steel and outer jacket is made of mild steel. The space in between the inner vessel and outer jacket is filled with perlite insulation and held under a vacuum. The insulation method maintains the temperature of the LNG and prevents stress cracks forming due to high temperature differential. These tanks and accessory system can be expensive to construct and install onboard a ship. The cryogenic tanks typically come with a cold box attached to one end, which acts as a secondary barrier to hold the LNG leakage temporary for no less than 15 days. The cold box contains the control equipment needed for the tank operation, connection fittings, and other fuel gas preparation equipment such as the vaporizers. ABS indicates that the outlet from the pressure relief valves of the LNG storage tank is normally to be located at least B/3 (6.045 m/19.833 ft. for *S.S. Badger*) or 6 m (19.685 ft.), whichever is greater, above the weather deck and 6 m (19.685 ft.) above the working area and gangways, where B is the greatest molded breadth of the ship in meters. The outlets are normally to be located at least 10 m (32.808 ft.) from the nearest air intake, air outlet or opening to accommodation, service or control spaces, or other nonhazardous spaces; and also the exhaust outlet from machinery or from furnace installation.

Storage tanks for LNG are not to be filled to more than 98% full at the reference temperature. In order to maintain the cryogenic environment in the LNG tanks, the tanks will have at least 10 percent LNG left upon arrival. Gas storage tank monitoring equipment will have to be installed to prevent overfilling, monitor pressure and temperature and conduct safety shutdown if leakage is detected.

For the current Ludington-Manitowoc route, the most convenient fuel source of LNG is the SE Wisconsin LNG peak shaving plant in Milwaukee. However, the decision is left to the fuel supplier to determine the fuel source location. The ideal transportation method would be a truck with tank trailer from the fuel source (i.e. a shaving plant) or a distribution point (i.e. a gas refill station) to ship dock in Manitowoc. According to the information collected, LNG can be supplied by one LNG supplier from several plants within 500 miles via cryogenic tanker truck. The cryogenic tanks on the truck are similar to the tanks onboard the ship. A typical truck can carry about 12,250 gallons (46 m^3) of LNG and unload at a rate up to 300 gallons per minute (GPM).

CNG can be transported to the dock using trucks with CNG containers/tube trailers from a Manitowoc pipeline gas station owned by one of the CNG suppliers. The fuel will be transferred from the tanker truck directly to the onboard gas storage tank(s). A storage bunker at the ferry berth is not necessary, which reduces the initial investment cost and would make it possible to relocate the ferry to serve other routes.

Based on the engineering study, it is feasible to convert the *S.S. Badger* to use NG as the primary fuel. There may be schedule issues in fueling the vessels if loading and discharging of passengers is not allowed during fueling. LNG may be available from the peak shaving plant in Wisconsin but contract negotiations by the vessel operator would be needed to ensure supply. A separate study would need to be completed to determine capital costs and operating costs with a LNG powered *Badger* to assess if the conversion would be economically feasible.

Regulatory Jurisdiction

There are many federal, state, and local government agencies in the U.S. that have jurisdiction over some aspect of LNG. There are agencies that have jurisdiction over the vessel (ship) and agencies that have jurisdiction over the facility that stores and/or transfers LNG to the vessel. Facility types are further broken down into fixed facilities (storage tanks or liquefaction plant) and mobile facilities (LNG tank truck).

The international standards that address LNG fueled engines on ships are found in the International Maritime Organization Interim Guidelines For Gas-Fuelled Engine on Ships (IMO Resolution MSC 285(86)). Most of the classification societies around the world have adopted the IMO standards. Domestically, the U.S. National Fire Protection Association Code (NFPA 59A: Standard for the Production, Storage, and Handling of Liquefied Natural Gas) is the standard that had been adopted by fire departments around the country.

There are a myriad of federal, state, and local government regulations that address LNG safety and security requirements at facilities. The U.S. Army Corps of Engineers requires a permit for construction of LNG facilities (tanks and liquefaction plants) that complies with the Rivers and Harbors Act. Other federal agencies regulate production facilities that handle large quantities of LNG. The smaller amounts of LNG for refueling vessels do not currently meet production regulatory requirements. Those agencies that have regulations for LNG but do not include the smaller amounts for bunkering include: the Federal Energy Regulatory Commission (FERC) and the Department of Energy (DOE). FERC has jurisdiction over import and export of LNG however there is a provision in the regulations that provide an exemption for companies that use LNG for transportation. Similarly, DOE has jurisdiction over import and export of

LNG, but they do not have regulations that address small amounts of LNG being transported via an intermodal system (i.e. truck or rail). The EPA has authority over marine engine emissions, facility emissions and discharges.

The USCG exercises regulatory authority over LNG facilities that affect the safety and security of port areas and navigable waterways. Additionally, the USCG is responsible for navigation safety, vessel engineering, training and safety standards, and all matters pertaining to the safety of facilities or equipment located in or adjacent to navigable waters up to the last valve immediately before the receiving tanks. The USCG authority also includes LNG facility security plan review, approval, and compliance verification as provided in 33 CFR Part 105, and siting as it pertains to the management of marine traffic in and around the LNG facility.

USCG regulations in 33 CFR Part 127 (Waterfront facilities handling liquefied natural gas and liquefied hazardous gas) only apply to facilities that handle large quantities of LNG. Similarly, Coast Guard Navigation and Vessel Inspection Circular 01-2011 (Guidance Related to Waterfront LNG Facilities) and Commandant Instruction (COMDTINST 16010.3 Risk Based Decision-Making Guidelines) only apply to LNG facilities and tank ships that transport LNG as cargo. The USCG is working on policy that will apply to the transfer from a fixed or mobile facility to the vessel.

While the USCG has been working on policies that address training requirements for LNG bunkering, the Merchant Marine Personnel Advisory Committee (MERPAC) recently formed a working group to advise the USCG on Standards of Training Certification and Watchkeeping (STCW) qualifications and licensing requirements. Similar to facilities, vessels need to comply with the Maritime Transportation Security Act (MTSA) and the accompanying regulations in 33 CFR 104 (Maritime Security: Vessels). Compliance with these requirements will be to the satisfaction of the cognizant USCG Captain of the Port.

There are state and local requirements pertaining to LNG fixed and mobile facilities. These requirements include permits for fixed facilities and compliance with the applicable NFPA Code for mobile facilities. See Tables 3, 4 and 5.

Table 3: Facility Requirements

Agency/Organization	NFPA	Regulations	Policy	IMO
USCG	YES	NO*	YES	NO
Federal Energy Regulatory Commission	NO	NO	NO	NO
Environmental Protection Agency	NO	YES	YES	NO
State of Michigan	YES	NO	NO	NO
State of Wisconsin	YES	NO	NO	NO
Army Corps Of Engineers	NO	YES	NO	NO
Federal Motor Carrier Administration	NO	NO	NO	NO
City of Ludington	YES	YES	NO	NO
City of Manitowoc	YES	YES	NO	NO
Pipeline and Hazardous Material Safety Admin	NO	YES	NO	NO
Federal Railroad Administration	NO	NO	NO	NO
Department Of Energy	NO	NO	NO	NO

Table 4: Mobile (Tank Truck) Facility Requirements

Agency/Organization	NFPA	Regulations	Policy	IMO
USCG	YES	NO	YES	NO
Federal Energy Regulatory Commission	NO	NO	NO	NO
Environmental Protection Agency	NO	NO	NO	NO
State of Michigan	NO	NO**	NO	NO
State of Wisconsin	NO	NO**	NO	NO
Army Corps Of Engineers	NO	NO	NO	NO
Federal Motor Carrier Administration	NO	YES	NO	NO
City of Ludington	YES	NO	NO	NO
City of Manitowoc	YES	NO	NO	YES
Pipeline and Hazardous Material Safety Admin	NO	NO	NO	NO
Federal Railroad Admin	NO	NO	NO	NO
Department Of Energy	NO	NO	NO	NO

Table 5: Vessel Requirements

Agency/Organization	NFPA	Regulations	Policy	IMO
USCG	YES	NO***	YES	YES
Federal Energy Regulatory Commission	NO	NO	NO	NO
Environmental Protection Agency	NO	YES	YES	NO
State of Michigan	NO	NO	NO	NO
State of Wisconsin	NO	NO	NO	NO
Army Corps Of Engineers	NO	NO	NO	NO
Federal Motor Carrier Administration	NO	NO	NO	NO
City of Ludington	YES	NO	NO	NO
City of Manitowoc	YES	NO	NO	NO
Pipeline and Hazardous Material Safety Admin	NO	NO	NO	NO
Federal Railroad Administration	NO	NO	NO	NO
Department Of Energy	NO	NO	NO	NO

*The USCG does not have regulations that apply to the transfer of small quantities of LNG from a storage facility to a vessel. The USCG applies NFPA standards to their policy and regulatory efforts. The regulations in 33 CFR Part 127 applies to facilities that handle large quantities of LNG.

**The States of Michigan and Wisconsin have no regulations that apply to the transfer of LNG from a tank truck to a vessel or facility. They do regulate the transportation of LNG over the roads of their respective states.

*** The USCG does apply NFPA and IMO to their policy and regulatory efforts.

Because the use of LNG as maritime fuel is new in the U.S., it was important to learn from countries that have successfully implemented this technology. Over the past decade, Norway has built NG powered ferries and are currently building additional NG powered vessels to support the North Sea oil and gas industry. This initiative was undertaken in part because of the strict emission standards in Europe and the establishment of ECAs. The primary government agency that has jurisdiction over commercial shipping is the Norwegian Maritime Authority (NMA). NMA has similar authorities to the USCG in that they are responsible for ensuring that Norwegian vessels meet the highest level of safety and environmental standards, that mariners are properly qualified (licensing), and that foreign ships that enter Norwegian ports and territories meet applicable international rules. Norway adopted IMO Resolution MSC 285(86), Interim Guidelines For Gas-Fuelled Engine on Ships and all Norwegian flagged ships must comply with those standards

The future of LNG fueled vessels on the Great Lakes is extremely positive. The U.S regulatory and policy framework is being developed, and there is an opportunity for the maritime industry to provide input in the development of governmental regulations and policy.

Emissions Analysis:

Great Lakes shipping is unique considering the range of marine fuels used among fleet vessels. Current Great Lakes marine propulsion systems use fuels ranging from solid fuel (coal) to modern distillate fuels (diesel fuel). A number of studies have considered the environmental performance of alternative fuels in modern shipping, but suffer from several limitations such as: (a) focusing on new-vessel technologies without consideration of remaining working life for the majority of the fleet; (b) focusing on direct-fit applications such as LNG tankers using LNG fuel in main engines, ignoring the potential or limitations when applied to broader vessel types; and, (c) focusing broadly on infrastructure issues at ports and along supply lines with an assumption that all vessels may feasibly adopt advanced fuels.

Currently the LMCS operates the *S.S. Badger* across Lake Michigan, traveling between Manitowoc, WI and Ludington, MI, avoiding the alternative, land-based route through Chicago. The 4-hour, 62-mile cruise carries passengers, autos, recreation vehicles, tour buses, motorcycles, bicycles, commercial trucks, and over-size cargo. In its current configuration, the *S.S. Badger* typically reserves space for 12 heavy-duty vehicles (HDVs) with 53 ft. trailers, with space for additional vehicles (typically passenger cars). The full capacity of the *S.S. Badger* is 180 “vehicle units,” a proprietary measure developed by LMCS. For comparison, one tractor trailer is equal to 4 vehicle units. For the baseline analysis, the researchers assumed the *S.S. Badger* could carry a full load of 45 tractor trailers, which corresponds to 180 vehicle units; we consider more typical (e.g., smaller) cargo volumes in a sensitivity analysis.

The *S.S. Badger* propulsion system is powered by two Skinner Unaflow four-cylinder steam engines each rated at 3,500 horsepower (hp). The engines use high-pressure steam generated by coal-burning watertube boilers. Documents in support of a petition under section 5.3 of the EPA's *2008 National Pollutant Discharge Elimination System Vessel General Permit*, in effect until 19 December 2012, have been filed on behalf of LMCS in a public docket; these documents include much of the fuel consumption and engine-boiler plant details needed for this work.

To estimate the current coal-fired emissions by the *S.S. Badger*, the researchers used information provided by LMCS to perform a calculation using fuel-based emissions methods. However, to develop emissions estimates under alternative fuels, the researchers needed to make energy conversions from coal to each of the fuel alternatives and consider whether other systems changes may also be made. The project scope specified that alternative fuels would be used to fire the boiler-steam-engine system – as opposed to a retrofit scenario replacing the steam engine(s) with internal combustion or diesel engines. This is important for two reasons affecting this case study.

1. By converting the boiler-steam-engine system from coal to alternative fuels, the emissions under each fuel alternative are derived from watertube steam boiler combustion factors rather than emissions from high-pressure/high-temperature internal combustion power plants.
2. By applying the conversion to the boiler combustion, the amount of energy consumed represents the total energy delivered to service the vessel (i.e., including auxiliary servicers) rather than the energy associated with the propulsion steam engines alone. Truck fuel consumption also powers auxiliaries, and while the proportion may be insignificant compared to propulsion, this is included in the fuel consumption rates for trucking; importantly, almost 50 percent of consumption goes to auxiliaries on the *S.S. Badger*. Most analyses of marine propulsion emissions consider the main engines (dedicated to propeller thrust) separate from auxiliary engines (powered by independent internal combustion generators). For the *S.S. Badger* and some other older vessel designs, the use of boiler steam to power all main and auxiliary power needs required a more holistic calculus, similar to trucking.

To determine energy consumed by the *S.S. Badger* engines, the analysts first determined how much fuel the engines currently consume per trip. They then converted fuel consumption to BTUs based on fuel energy content. The current consumption of coal is based on the reported fuel consumption in a year and normalized by the number of trips taken in a year.

Table 6: Total trip emissions for the two alternative routes using conventional and alternative fuels. Emissions values are measured on a per Twenty Foot Equivalent (TEU) container basis for the entire trip

	Total Trip Emissions (kg per TEU-trip)					
	CO_2	**SOx**	**NOx**	**PM_{10}**	**CH_4**	**CO**
All Truck Route (Full)	400	0.004	0.17	0.0084	0.0012	1.0
Car Ferry route using Coal	590	3.6	91	110	0.50	42
Car Ferry route using IFO	530	630	81	41	1.5	7.9
Car Ferry route using MDO	520	130	27	3.0	0.081	7.9
Car Ferry route using LNG	410	0.003	0.26	0.018	0.0081	0.65
Car Ferry route using CNG	410	0.003	0.26	0.018	0.0081	0.65
Car Ferry route using Bio-Diesel	500	11	3.9	0.44	0.053	1.6

Existing Maritime Usage of LNG

NORWAY: A look at recent LNG marine fuel developments

From August 12-18, 2012, a GLMRI research team visited Norway to observe the use of LNG as a marine fuel in non-LNG cargo vessels which Norway has been using for over 12 years and to meet with industry and government experts. The goals of the visit were to observe the propulsions plants of vessels with both single fuel LNG and dual fuel LNG and MDO gas engines and discuss LNG marine fuel developments with representatives of the building shipyards, operating companies, engine manufacturers, classification society and national regulators. The focus area of the trip was in Bergen, Norway, and included side visits to Halhjem, Alesund, Ulsteinvik, Haugesund, and Oslo. Members of the team were able to accomplish the following:

- Tour the Rolls-Royce factory building and testing single fuel LNG gas engines in Bergen, Norway
- Tour the single fuel LNG engine propulsion plant onboard the operating Fjord1 ferry *MV Raunefjord*
- Observe refueling of the LNG supply tanks at the Halhjem, Norway ferry terminal from truck
- Observe the LNG bunkering of the *MV Raunefjord* at the Halhjem, Norway ferry terminal
- Tour the dual fuel LNG engine plant onboard the nearly completed Eidesvik platform supply vessel *Viking Princess*
- Meet with NMA personnel who regulate Norwegian LNG vessels in Haugesund, Norway
- Visit the Kleven Verft shipyard, Ulsteinvik, Norway, during the final weeks of building the *Viking Princess*
- Visit the Fiskerstrand shipyard, near Alesund, Norway, builder of the latest Fjord1 single fuel LNG ferry *MV Boknafjord*
- Meet with Det Norske Veritas classification personnel involved in LNG vessel development and approval in Oslo, Norway.

The team was also able to ride and tour the propulsion plant of the ferry *MV Raunefjord* operated by Fjord1during transits between Halhjem and Sandvikvag, Norway. Three LNG fueled ferries delivered in 2006 and 2007 now operate on this critical link along Norwegian highway E39 between Bergen and Stavanger. These double-ended ferries are 129.8 m long with a capacity of 212 cars, 22 trailers, and 587 passengers. They are equipped with integrated electric plants with a dual propeller (pusher and puller) rotating thruster located at each corner of the hull. They can make 21 knots operating three of four thrusters and 23 knots maximum using all four. The ferries have Rolls Royce Bergen single fuel LNG gas engine generator sets with a total capacity of 6180 ekW. They are built using the Det Norske Veritas emergency shut-down safety design concept because these early engines did not have double-wall piping up to the cylinder heads.

Photo 1: Single fuel LNG ferry *MV Fanafjord*, sister ship of the *MV Raunefjord*, underway

Photo 2: Dual fuel LNG Platform Supply Vessel *MV Viking Princess* at Kleven Verft shipyard

Team members were able to observe the transfer of LNG from a road truck to the two 500 m^3 dedicated shore storage tanks at the Halhjem ferry terminal. It was noteworthy that these tanks were located only a few feet behind a resort marina and the transfer was accomplished during normal daytime hours. They were also able to observe the bunkering of the *MV Raunefjord* from these tanks later that night. Bunkering was undertaken at night so that no vehicles or passengers would be onboard at the time.

Photo 3: Dedicated 500 m^3 LNG storage tanks at ferry terminal in Halhjem, Norway

Photo 4: Resupply of LNG storage tanks from a road truck

The steam conversion project team members were also able to tour the propulsion plant of the nearly completed Eidesvik Platform Supply Vessel *Viking Princess* in the Kleven Verft shipyard. The vessel is 89.6 m long with an integrated electric plant supplied by two Wärtsilä dual fuel 6L34DF generator sets and two Wärtsilä dual fuel 6L20DF generator sets. These generators produce a total output of 7332 ekW. The ship is equipped with two rotating dual propeller thrusters aft and two bow thrusters and an azimuthing thruster forward for use in dynamic positioning. The *Viking Princess* was built using the Det Norske Veritas inherently safe engine room design concept since these engines did not have double-wall piping up to the cylinder heads. The vessel already had LNG onboard and was operating one of its smaller dual fuel generators on MDO for shipboard power at the time of the visit.

Photo 5: Wärtsilä dual fuel 6L20DF generator set onboard the PSV *Viking Princess* with double-walled gas supply line in yellow

While the use of LNG fuel involves new, higher technology and additional safety considerations, the use of LNG as a marine fuel for non-LNG cargo vessels is now part of normal marine practice in Norway following the introduction of the ferry *MV Glutra* 12 years ago.

Developing a Great Lakes Marine Supply Chain for NG

Currently vessels on the Great Lakes either fuel at USCG approved fuel terminals such as Calumet in Duluth, MN, at loading docks such as CN ore docks in Two Harbors, Minnesota or at unloading locations such as Burns Harbor, Indiana. All of these facilities have met USCG and local safety regulations and are approved locations. The location of the facilities is driven by the range of the vessels fuel tanks and the trade routes on the Lakes.

Converting to NG as a fuel will not alter the marine trade routes on the Lakes, but the lower BTU content of NG means that range of the vessels will change, based on the fuel tank capacity.

Converted vessels will require increased fueling. The availability of the fuel may be an issue along with regulatory approval of fueling locations. These factors may necessitate new fueling locations and will certainly require existing locations to install approved NG fueling facilities.

Industry has been evaluating existing locations and also new sites such as Point Detour in the St. Mary's River in Michigan for supplying NG. The engineering studies on the AAA vessels indicated that the denser LNG would be a preferable fuel more than CNG for most Great Lakes cargo vessels because of the longer range with fewer fuel stops and minimal cargo capacity being lost for tankage. There may be exceptions for dedicated ferry routes that may prove more cost-effective using CNG.

Models of NG supply chains are described in Figure 4. In order to establish a NG fueling location there needs to be an adequate supply of NG within a cost-effective distance. For LNG the cost-effective trucking range from the liquefaction plant to the fueling location is 250 to 300 miles.

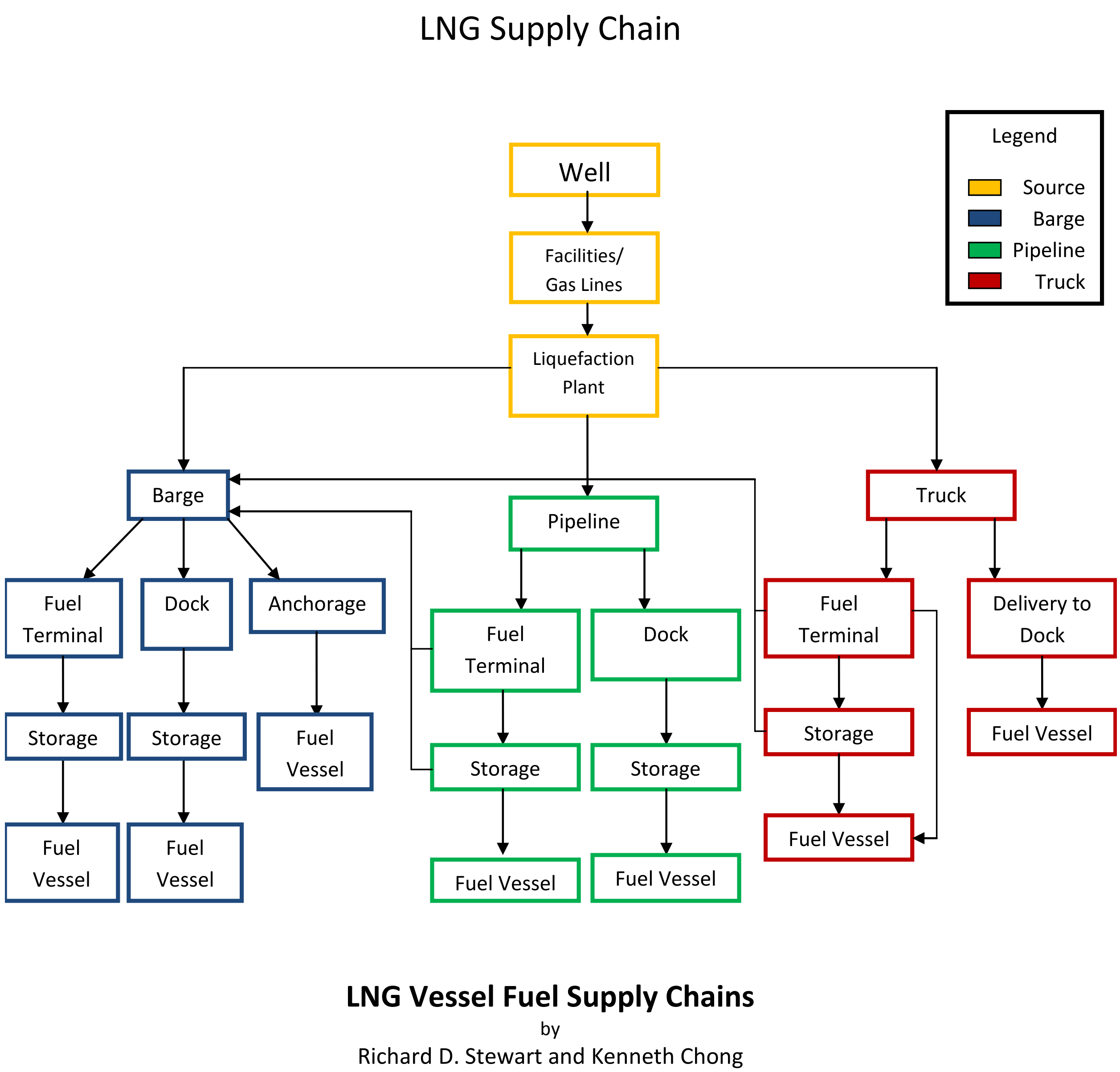
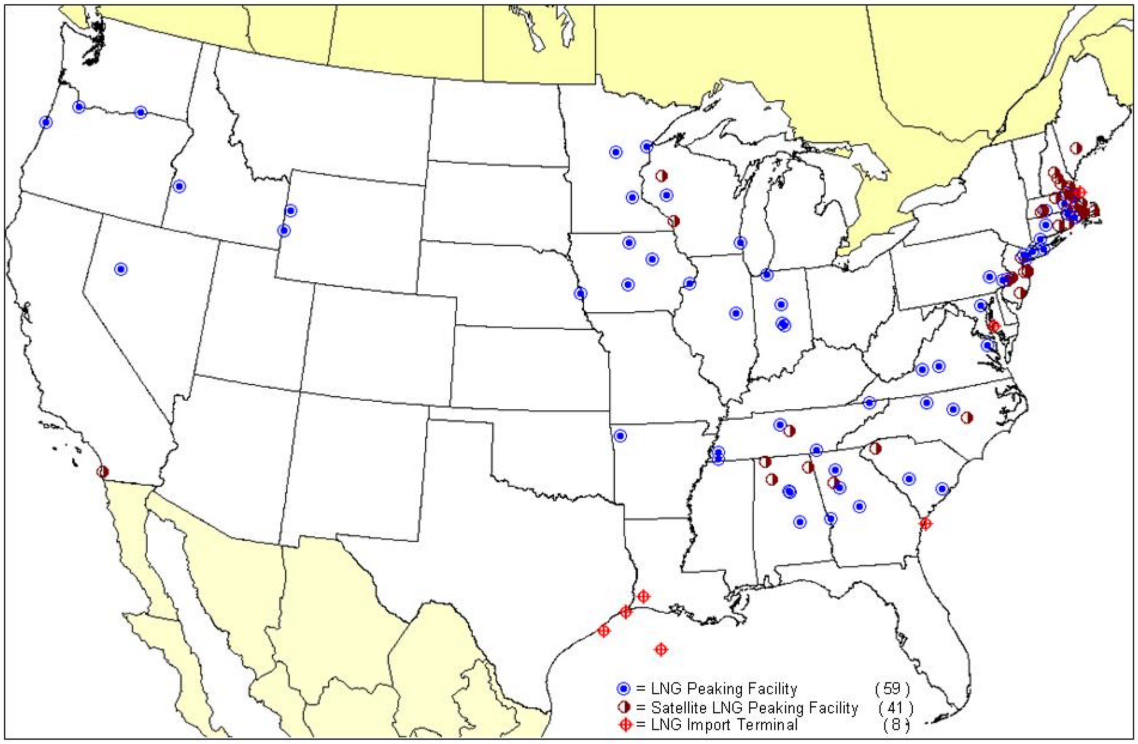


Figure 4: LNG Vessel Fuel Supply Chains

The existing liquefaction plants in the Great Lakes region are peaking plants (see Figure 5). These plants are designed to provide a reservoir of LNG for utility company's when demand for NG peaks such as during an intense subzero cold spell. These plants principal purpose is for utilities, and their ability to sell excess LNG is governed by Public Utility Commissions. Peaking plants have been supplying LNG to Clean Energy and other non-utility users. The Peaking plant in Wrenshall, MN contacted the research team and indicated that it may be willing to explore LNG contracts with ship operators. This information was passed onto the LCA.



Note: Satellite LNG facilities have no liquefaction facilities. All supplies are transported to the site via tanker truck.
Source: Energy Information Administration, Office of Oil & Gas, Natural Gas Division Gas, Gas Transportation Information System, December 2008.

Figure 5: LNG Peaking Plants in the U.S.

As the demand for LNG as a fuel increases the supply and location of the existing peak shaving plants will likely not be sufficient to meet the growing demand. The research team determined that in the Duluth/Superior location there is significant potential demand from the following user groups within 150 miles that have all been exploring the conversion of their assets to NG:

1. The maritime industry
2. Trucking
3. Class 1 railroads
4. Mining
5. Transit
6. Agriculture

Models that have been discussed to increase the NG supply in the Great Lakes include:

1. Construction of new small and medium sized liquefaction and/or compression plants in key locations that would cost effectively serve multiple markets by realizing economies of scale. In most cases they would serve markets up to 300 miles away with the potential for longer hauls where it was cost effective. The LNG/CNG could travel to a final

destination on multiple modes if the locations were well served by truck, rail and marine.

a. This model can provide competitive pricing from multiple sources.
b. This model lowers the risk of a loss of supply due to a very large plant being shut down.
c. The model may not realize the lowest possible prices as the maximum economies of scale for liquefaction will not be achieved.
d. This model fits into the cost-effective truck drayage limits.
e. This model can provide year round transportation when the Great Lakes are closed due to ice and lock maintenance.

2. A European model where LNG is moved from a central waterfront terminal that is connected to a very large liquefaction plant to multiple fueling locations. The conceptualized supply chains for this model include LNG supply vessels, containerized LNG transported by multiple modes of transportation moving LNG from the central terminal to other locations. This supply chain that could stretch for hundreds of miles would require significant volumes to be cost effective.
    a. This model limits competitive pricing from multiple sources.
    b. This model increases the risk of a loss of supply due to a very large plant being shut down.
    c. The model will realize the lowest possible prices as the maximum economies of scale for liquefaction will be achieved.
    d. This model may fit into the cost-effective truck drayage limits for some users.
    e. If this model relies on marine transportation for moving product to key markets it will be unable to provide year round marine transportation when the Great Lakes are closed due to ice and lock maintenance.
    f. The facility may be able to move product by rail during the ice season but history has indicated that railroads charge premium rates for service that switches between rail and marine when the product is captive to the railroads during winter.

Both of these models are best served with pipelines from the wells to the liquefaction/compressing facilities of a sufficient size to meet demand. These models will require significant capital investments, long term contracts with users, and public acceptance of the liquefaction/compressing facilities and supply chain. Because the marine use of LNG/CNG is new in the U.S., the regulations governing fueling are in the developmental stage. The supply chain models will be impacted by regulatory changes.

Education and Outreach:

As a resource for public use, GLMRI gathered and reviewed literature, reports, articles, publications, blogs and other media venues on the utilization of natural gas and specifically LNG. The GLMRI Program Office has compiled the material and cataloged it for use and reference by the research team and other interested parties. An on-line directory of information on LNG and information is publicly accessible on the GLMRI web page. http://www.glmri.org/research/lngMisc.php In addition to articles, presentations and reports, information on LNG in trucking and rail, along with sections on liquefaction and processing gas are compiled. Also included is a separate category for video links. http://www.glmri.org/research/lngVid.php GLMRI continues to update the on-line materials. Separate sections have been set up with the informational presentations from the GLMRI education and outreach venues.

GLMRI has sponsored several meetings and venues to support the LNG Study, and also Dr. Stewart, Ms. Wolosz, and GLMRI researchers have presented their findings at conferences, meetings, and educational events. A detailed list is included at Tab 8 of this report. These venues have included meetings with federal, state and local agencies, political representatives, international government agencies, professional societies, non-profit associations, industry partnerships, environmental interest groups, and other public entities. Estimated outreach in conjunction with this study has been extended to over 4,000 people.

Conclusions

During the 1940s and 1950s, the U.S. Great Lakes commercial fleet of almost 200 vessels transitioned from using coal as a primary fuel to using oil. The change was a major undertaking that impacted all segments of the maritime industry. Some vessels elected to not only change fuel but repowered from steam to diesel engines. The new fuel that was adopted by other modes of transportation and for home heating fuel altered trade on the Lakes as the east to west coal shipments diminished to a small fraction of their former volume. The entire supply chain of trains, coaling docks and barges virtually disappeared and tankers started carrying crude and refined products from the head of the Lakes to other ports. Crew requirements aboard vessels were transformed along with operating procedures. There were some in the industry who adopted the change early and those who resistant to change. New coal fired vessels such as the *S.S. Badger*, were being launched in the 1950s even as other vessels in adjacent Great Lakes yards were being converted to oil.

This major transformation of the Great Lakes maritime industry occurred for several key reasons that parallel the current situation with NG. Oil had become abundant as new fields in the Middle East were discovered. The oil supply chain serving multiple markets of the economy was being rapidly developed. New marine engineering and shipyard technology for oil fired ships had been developed that improved operations and lowered costs. During the shift from coal to oil the U.S. Maritime Commission, the forerunner of MARAD, took a leadership role. The Commission supported relevant research and development, transferred technology from the coasts and even entire vessels to the Great Lakes. The Commission worked with other agencies to ensure that new regulations and training of mariners promoted a safety culture with the new fuel. The transition was expensive, time consuming and created new dangers such as oil spills along with petroleum health and safety hazards. Entire industries, such as coal tippling docks ceased to operate and their employees were released. The high capital costs for conversion and development of the supply chain resulted in winners and losers in the market place. The transformation 60 years ago took place because of changing market forces, active government support and the vision by both the private and public sector to seek the long range benefits.

This preliminary public/private research by GLMRI has occurred because of cooperative leadership from MARAD. The research team has concluded that:

- The peer reviewed engineering study determined that the conversion of the AAA class of steamships on the Great Lakes from oil fired steam ships to diesels engines running on NG can, from an engineering perspective, be accomplished.
  - The general research findings are transferable to the other steam and diesel powered vessels on the Great Lakes. However, vessel specific conversion plans would be necessary.
  - The majority of the Great Lakes fleet would have the greatest operating flexibility and cargo carrying capacity using LNG as their primary fuel.
  - The business case for conversion was beyond the scope of this study.
- The peer reviewed engineering study determined that the conversion of the *S.S. Badger's* historic Skinner steam engine to using NG as a fuel can, from an engineering standpoint, be accomplished.
  - The repowering of the *S.S. Badger* to diesel engines would increase energy efficiency but at the loss of the national historic register steam engines.
  - CNG as well as LNG may be viable options for this vessel on its fixed route.
  - The operating schedule of the vessel may be adversely impacted if fueling is not allowed during loading and unloading.
  - The business case for conversion was beyond the scope of this study.
- The conversion of Great Lakes' vessels from oil or coal to NG will significantly reduce their environmental impact.
  - The referenced converted vessels move beyond compliance with ECA regulations and eliminate the need to dispose of the hazardous waste from stack scrubbers.
  - Operating the *S.S. Badger* on NG would result in not only meeting air emission regulations but would also eliminate the need to dispose of coal ash.
  - Trucks transiting on cross lake ferries burning NG while using the latest diesel engine technology may realize environmental advantages compared to all highway movements.

- Safe and economically viable regulations specific to vessels using NG as a fuel needs to be fully developed.
- The NG supply chain for all modes of transportation is in its infancy and currently could not supply a major fleet transition of the vessels to NG.
    - At present there are no approved fueling docks for transferring NG.
    - The existing supply of LNG in the Great Lakes to serve vessels is limited but there is industry interest and potential for new liquefaction plants in key locations. The marine industry was the focus of this study but rail, highway, mining, agriculture and transit are all interested in expanding the use of NG as a transportation fuel.
    - The adoption of NG by multiple modes can reduce cost by realizing economies of scale and the transfer of diesel technology between modes.
- European countries such as Norway are significantly more advanced in all areas of using NG as a marine fuel and tapping into their expertise can reduce costs and time.
    - The shipyard, supply chain, training and regulations that have evolved over a decade of use provide extremely useful insight and possible adoption in the U.S.
- A program of public outreach and education is essential for stakeholder understanding of the potential benefits and issues related to conversion of marine vessels to NG.
    - Many stakeholders have misconceptions of NG or lack any detailed knowledge to make informed decisions.
    - Most stakeholders are unaware that U.S. flag NG carriers have used NG as a marine fuel for over four decades with an exemplary safety record, or that it is being used in Europe for passenger and car/truck ferries and Coast Guard Cutters.

Recommendations:

- MARAD's continued leadership role in this public/private partnership is essential to moving forward with the transition. MARAD is able to interact cooperatively with other key government agencies and can engage foreign agencies who are also involved with developing NG as a marine fuel.
- Research needs to done to see how the findings of this Great Lakes study can be utilized and expanded for inland rivers and coastwise trades.
- Studies need to be accomplished on the feasibility of converting existing Great Lakes diesel powered ships to using NG.
- Shipyards need to be supported in order to gain the expertise and technology needed to build, maintain and repair natural gas fueled vessels.
- A comparative environmental study should be done to assess the total fuel cycle, i.e., from well to stack, for diesel fuel and NG.
- The research into the development of the NG supply chain for marine use needs to continue. Through MARAD's leadership other modal agencies as well as private enterprise can be part of a collaborative process that looks at supply chain synergies.

- The USCG is seeking input from all concerned parties and MARAD's LNG Task Force can to continue to be a resource on regulatory issues concerning NG fueling, operations and training in the maritime industry.
- Public outreach and education should continue and where appropriate expanded. Efforts need to be made to cooperate with NG suppliers to other modal markets to ensure efficient broad coverage that embraces all modes.
- There is a need to support those interested in adopting improved technology early since they are taking the greatest risk. Support could be financial and/or institutional. (An example of a successful MARAD program for the Great Lakes was the Merchant Marine Act of 1970 that provided incentives for companies converting to diesel and building 1000 foot ships.)
- Shippers will be a key factor in companies adopting NG. Studies need to be done to assess how to improve the environmental footprint of the marine segment of a supply chain improves the shipper's supply chain and their green image. Environmental agencies and classification societies enhance shipper support of environmental improvement from adopting NG. This is accomplished through the formal recognition to marine carriers such as ABS Energy Management Certification and the Clean Excellence Award from the EPA in Transportation Efficiency Innovations. MARAD can be proactive in this process.
- Repowering the existing Great Lakes steam ships to diesels fueled by NG appears to have significant environmental and economic benefits. Alternatively, given the age of the vessels, a public-private partnership could pursue visionary research efforts to design the Great Lakes fleet of the future. Designs that utilize not only NG as a fuel but also integrated diesel electric technology, the latest safety features, integrated bridge navigation systems and designs addressing emerging climate change issues on the Lakes. Those vessel designs should take advantage of lower unit costs by adopting series production and state of the art shipbuilding technology. The designs would not only encompass the existing Great Lakes trades but be adaptable for new Lakes markets with technology transferable to the rivers and coastal markets.