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Suitability of Liquid Natural Gas Fuel for River Tender Recapitalization

REACT Report

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N O T I C E

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16. Abstract (MAXIMUM 200 WORDS)

The Inland Waterways and Western River Aids to Navigation Cutter (IWWRAC) project will recapitalize Coast Guard Inland Aids to Navigation (ATON) assets consisting of River Buoy Tenders (WLR), Inland Buoy Tenders (WLI) and Inland Construction Tenders (WLIC). In this REACT report, the Coast Guard Research and Development Center evaluates the suitability of using Liquefied Natural Gas (LNG) fuel on these new assets. Since formal requirements for the new assets are currently being developed, RDC moved forward assuming the new acquisitions would be similar to the existing WLR in manning, physical size, horsepower, and fuel usage. Based on these derived requirements RDC investigated the suitability of LNG from multiple perspectives including cost, availability, equipment availability, and regulation as applied to small vessels such as the WLR. This report contains the results of the investigation and recommendations for the use of LNG.

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EXECUTIVE SUMMARY

The Inland Waterways and Western Rivers Aids to Navigation Cutter (IWWRAC) Project will recapitalize Coast Guard Inland Aids to Navigation (ATON) assets consisting of River Buoy Tenders (WLR), Inland Buoy Tenders (WLI) and Inland Construction Tenders (WLIC). In this REACT Report, the Coast Guard Research and Development Center (CG RDC) evaluates the suitability of using Liquefied Natural Gas (LNG) fuel for these new assets.

Several assumptions were made by the team while developing this document. The most important was that the configuration, manning, and overall size of the new assets would be similar to existing WLRs and WLICs. The team assumed a push boat design with an approximate length of 100 ft and a beam of 25 ft. The estimated 1200 horsepower and 500 gallon of fuel per working day are also carried over to RDC's model.

This document addresses only the WLR and WLIC. It does not address the WLI. As indicated in this report, the bunkering demands for LNG do not easily fit within a 100 ft vessel let alone the smaller 65 ft vessel.

This study is limited to LNG. Compressed Natural Gas (CNG) is not considered viable as heavy thick walled high pressure tanks are required to withstand the 3000 plus PSI required to bunker the fuel. Also, the energy density of CNG is lower than LNG. CNG has less than 25% energy density when compared to diesel. For comparison, LNG has about 60% the energy density of diesel.

This report assumes a full 100% LNG fueled vessel. Dual fueled propulsion plants that burn diesel plus LNG are possible but not explored. The factors favoring or limiting LNG do not change appreciably with this assumption. The hazard zones, size, and complexity of the LNG equipment all remain. By comparison diesel fuel is easy to store in various compartments distributed throughout the vessel.

This document demonstrates that LNG is available today at a cost on par with diesel fuel. It shows that technology suitable for installation on the new assets is slightly ahead of the market's leading edge. Finally, this document shows that it is difficult to bunker appreciable amounts of LNG fuel on small vessels. Fuel storage is severely limited by regulations for gas fuelled vessels. Regulations limit the proximity of the LNG tanks from the hull to provide protection from external damage due to collision. Additional hazard zones designed to prevent vapor ignition place further restrictions on fuel placement.

The decision to use LNG comes down to an endurance requirement. A preliminary assessment suggests that a small vessel such as a CG river tender can bunker no more than 10,000 gallons of LNG. This is equivalent to bunkering 6,000 gallons of diesel. Note that this is considerably less than the WLICs that can take on over 20,000 gallons of diesel or the WLRs that can bunker over 40,000 gallon of diesel fuel.

The fuel endurance CONOP for the IWWRAC will determine if LNG is a viable fuel option. If the CONOP requires a fuel endurance of less than 10 days then the LNG options should be pursued further in the Alternatives of Analysis (AoA). If the CONOP requires more than 10 days endurance then diesel fuel is the recommended fuel. The Coast Guard should continue to track LNGs technology and price trends for possible inclusion in other platforms through the USCG Liquefied Natural Gas Carrier Center of Expertise (LGC NCOE).

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LIST OF ACRONYMS, ABBREVIATIONS, AND SYMBOLS

ABS	American Bureau of Shipping
AoA	Alternatives of Analysis
BTU	British Thermal Unit
CFR	Code of Federal Regulations
CG	Coast Guard
CH4	Methane (natural gas)
CO	Carbon Monoxide
CO2	Carbon Dioxide
CNG	Compressed Natural Gas (methane)
COTS	Commercial Off The Shelf
CYL	cylinder
DISP	displacement
ECA	Emission Control Areas
EPA	Environmental Protection Agency
ESD	Emergency Shut Down
F	Fahrenheit
ft	foot
g	grams
HC	Hydro Carbons
hp	horsepower - mechanical power or electrical equivalent
IMO	International Maritime Organization
ISO	International Organization for Standards
IWWRAC	Inland Waterways and Western Rivers Aids to Navigation Cutter
kt	Knot, nautical miles per hour
kW	Kilowatt - electrical power or mechanical equivalent
kWh	Kilowatt hour
L	Liter
lb	pound
LNG	Liquefied Natural Gas (methane)
MARPOL	International Convention for the Prevention of Pollution from Ships
MCS	Maritime Classification Society
MPa	MegaPascal (approximately equal to 145 psi)
NOx	Nitrous Oxides
PM	Particulate Matter
ppm	Parts Per Million
psi	Pounds per Square Inch
RDC	Coast Guard Research and Development Center
rpm	Revolutions Per minute
SOx	Sulfur Oxides
ULSD	Ultra-Low-Sulfur-Diesel
WLI	Coast Guard Inland Buoy Tenders
WLIC	Coast Guard Inland Construction tenders
WLR	Coast Guard River Buoy tenders

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1 BACKGROUND

The Inland Waterways and Western Rivers Aids to Navigation Cutter (IWWRAC) Project will recapitalize Coast Guard Inland Aids to Navigation (ATON) assets consisting of River Buoy Tenders (WLR), Inland Buoy Tenders (WLI) and Inland Construction Tenders (WLIC). Several of these vessels are approaching 75 year of age. In this REACT Report the Coast Guard Research and Development Center (CG RDC) evaluates the suitability of using Liquefied Natural Gas (LNG) fuel for these new assets.

1.1 LNG Physical Properties

This section presents a brief introduction to Liquefied Natural Gas (LNG). It describes its physical properties. It also serves to address a few of the common misconceptions and myths so that the reader may better understand the remainder of the report.

The terms LNG, methane, and natural gas will be used throughout this report. For clarity the term LNG is used to describe the liquefied form of the fuel. The fuel in its gaseous form will be called either natural gas or methane. In all cases the fuel is a mixture of simple hydrocarbons consisting primarily of methane (CH_4) with small additions of more complex hydrocarbons such as ethane (C_2H_6) and propane (C_3H_8).

A common misconception is that LNG is formed by compressing natural gas. Many people erroneously assume that compressing a methane will cause it to condense because they are familiar with the process for "making" propane and compressed air. Unfortunately, compression alone will not condense methane (CH_4), the largest component in LNG. Rather, CH_4 must be cooled to negative 261.5° F (-163C or 110k) to condense the fuel. This cooled liquid can then be stored in insulated tanks at lower pressures (< 145 psi). Unlike propane, LNG cannot be stored at room temperature.

Engines do not directly consume LNG. Instead, LNG must converted to a gaseous state. This is done by warming LNG which causes it to vaporize. The resulting natural gas increases the pressure inside the tank and provides a ready supply of natural gas for the engines. Heat must be carefully added to limit the storage tank's pressure or the fuel will be vented to the atmosphere. Likewise, the pressure in the LNG system must be high enough to supply the instantaneous gaseous fuel needs or the engines will be fuel starved. A computer control system is used to regulate this process.

LNG is considered a live fuel. Once methane is liquefied, it is a matter of time (many months) before it will vaporize. Energy in the form of heat is constantly flowing from the warm environment in which we live through the storage tank insulation and is absorbed by LNG. This warming causes the liquid to vaporize like a pot of boiling water. The speed at which the liquid LNG boils depends on the effectiveness of the tank's insulation. Like a pressure cooker, maritime LNG tanks are not designed to contain the tremendous pressure that would occur if all of the liquid vaporized. Instead, when the pressure reaches about 145 psi the tank's pressure relief valve will open and vent the methane gas to the atmosphere. Normally this does not occur as the engines consume the methane. Instead, this caution is more applicable to dock side periods that extend for perhaps a month or longer. This venting is undesirable as valuable fuel (money) is released to the atmosphere with potential environmental consequences as methane is a potent greenhouse gas. Repeated venting will negate any environmental benefits to using LNG.

One method of reversing LNG heating and the inevitable atmospheric venting is to install a cryogenic LNG chiller plant on the ship often found on larger commercial LNG tankers. This option is considered unfeasible for the IWWRAC Project due to the added expense, complexity, and space requirements of the chiller plant. Instead, the fuel on CG assets must either be consumed perhaps using a ship service generator or the vessel must be defueled during extended dock sides.

1.2 LNG Cost

The cost of fuel is the leading consideration for the investigation of LNG for river tender recapitalization. Patterns in commercial trucking provide the best predictors for cost since the majority of CG river tenders operate in remote locations.

RDC met with sales and technical representatives from several commercial fuel distributers. All suggested that small scale refueling operations in the often remote river tender locations would be conducted via a semi-tanker truck. For the foreseeable future, marine fueling terminals are not expected in the AOR of CG river tenders. Instead, LNG deliveries to CG river tenders are expected to be drawn from the closest economical source. This is expected to be the same network used to supply other inland consumers – primarily the trucking industry. This is an important factor in determining LNG feasibility as industry representatives ardently stated that the cost benefit of LNG erodes the further it is transported.

There has been an emergence of LNG in the commercial trucking markets. The driving factors include economics, improvements in technology that allow economical extraction of shale gas resources, and greenhouse gas initiatives. Figure 1 presents the location of commercial trucking stations that dispense LNG[1]. The placement of stations on the Interstate 40 corridor suggests a strong future for commercial LNG availability. Here a LNG fueled semi-trailer truck may travel from North Carolina to California with convenient refueling station less than 500 miles apart. Note the distribution across the lower USA is within close proximity to the continent's major sources of LNG.

One relevant source of pricing data is presented by the U.S. Department of Energy in their Clean Cities Alternative Fuel Price Report[2]. Figure 2 presents the "at the pump" pump price of LNG as compared to diesel fuel. In this figure, LNG has been converted to a diesel gallon equivalent. Note that this chart compares LNG to Ultra-Low-Sulfur-Diesel (ULSD, 15 parts per million) as ULSD was phased in for all on-road diesel fuel in the 2006 to 2010 timeframe under the Clean Air Act.

Unfortunately, the future price of LNG is unknown. On a national scale it is based on a complex interaction between supply, consumption, status of other fuels, policy, and exports. On a regional scale cost is further complicated by the distance to and operational state of the LNG production and delivery infrastructure. All things considered, the long term price is expected to equalize with liquid fuels. Price projections for LNG and other fuels may be found in the U.S. Energy Information Administration's Annual Energy Outlook with projections to 2040[3].

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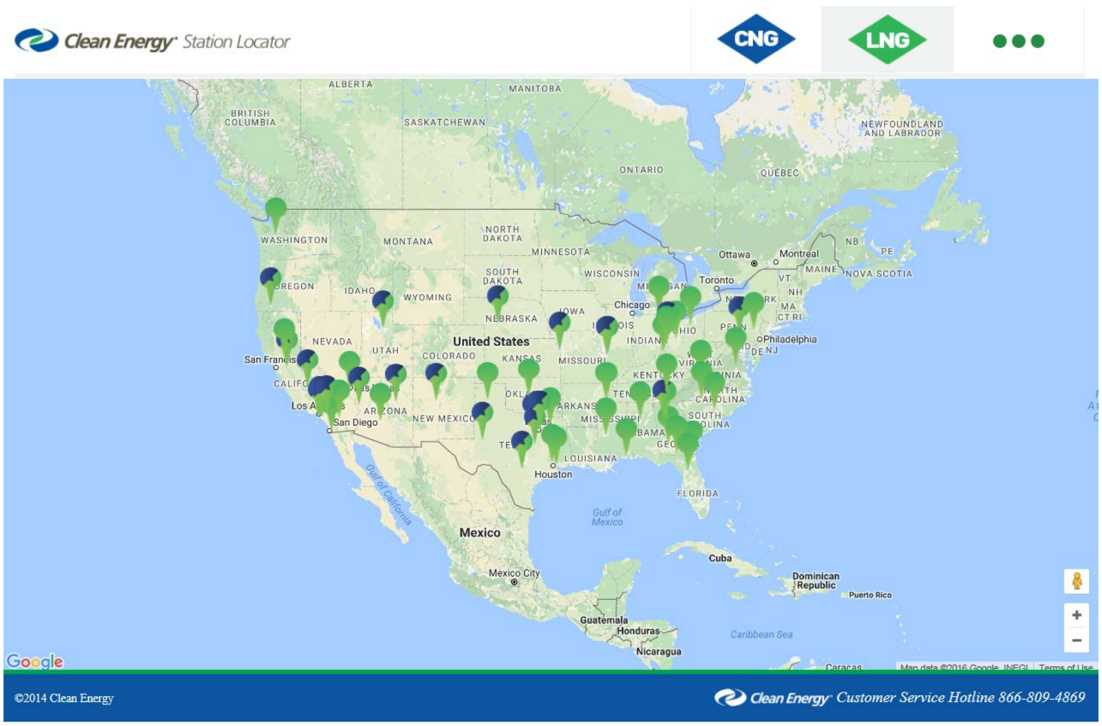
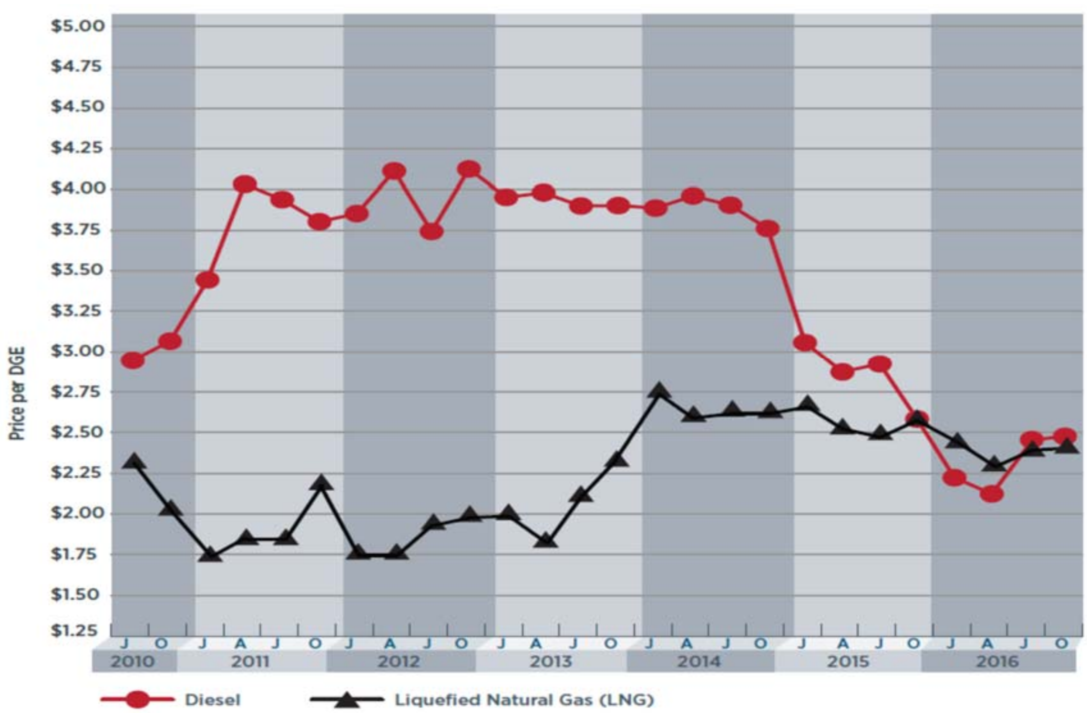
[1] https://www.cnglngstations.com/#1
[2] http://www.afdc.energy.gov/uploads/publication/alternative_fuel_price_report_oct_2016.pdf
[3] http://www.eia.gov/outlooks/aeo/



Source: https://www.cnglngstations.com/#1

Figure 1. Each green marker shows the location of a commercial LNG truck fueling station. The half blue markers show stations that dispense both LNG and CNG. Dedicated CNG stations are not shown.



Source: U.S. Department of Energy *Clean Cities Alternative Fuel Price Report*

Figure 2. At the pump cost comparison between Ultra-Low-Sulfur-Diesel and LNG with LNG cost adjusted to show diesel gallon energy equivalent. (October 2016).

1.3 LNG Storage and Vessel Design

Designing a vessel to safely use and bunker LNG is difficult. This is especially true for small vessels such as a river tender. There are several regulations to consider:

B/5: The International Maritime Organization (IMO) preliminary standards[4] include a "B/5 restriction" where B is the breadth of a ship. This is a measure designed to protect tanks from external damage due to collision. For example, a river tender with a 25 foot beam can have LNG storage tanks no closer than 5 feet from the edge of the ship.

B/15: The IMO standard establishes a lower boundary to prevent external damage due to grounding. For a river tender with a beam of 25 feet the LNG tanks must be at least 1.7 feet off the hull.

Zone 1: Hazard Zones are classifications to identify areas where explosive gas atmospheres may occur. Hazard Zone 1 is defined in the IMO preliminary standards as a 3 meter (≈10 feet) sphere around any fuel tank vapor outlet, bunker manifold valve, fuel pipe flange, etc. Machinery within this space must meet strict standards to limit the risk of ignition. As a rule, engines and people (hotel ventilation) shall not be in this zone.

Taken together, these regulations present a challenge for a small vessel designer. Especially for a ship that includes a living space for a relatively large crew. It is hard to separate the LNG fuel exclusion zones from the crew and machinery spaces. Appendix A provides a sketch of an LNG river tender that attempts to integrate all of these requirements. Contained within the appendix is an argument that suggests 10,000 gallon of LNG is near the maximum amount of LNG fuel that may be stored on a river tender. Note that the vessel described in Appendix A has not been evaluated for seaworthiness. The single location of LNG tanks high and aft is undesirable from a vessel stability standpoint. This stands in stark contrast with a diesel fueled vessel where diesel fuel may be distributed low throughout the vessel in multiple tanks with relatively relaxed requirements regarding placement.

The decision to use LNG comes down to an endurance requirement. How many days of fuel autonomy are required for a river tender? Appendix A suggests 12 working days are possible with zero reserve. To provide a safety margin, assume 10 days of autonomy. In contrast Appendix B which contains the historic fuel usage for the CG river tender fleet indicates between 30 and 90 working days between fueling are being bunkered.

A cursory review of industry literature reveals that LNG has been used successfully in tugs, ferries and large push boats. As previously stated, the river tender is expected to be smaller than the typical push boat and host a larger crew. This makes is difficult to keep the fuel separated from the people and machinery. The CG river tender also has a different mission profile. The tugs and ferries have minimal fuel storage requirements as they typically return to the dock each evening where they can refuel. The CG river tender is not expected to return to home port as often. Also, when the need arises, the CG may divert the tender outside the normal AOR where the extended fuel range will allow them to continue operations for several months.

[4] IMO annex 1 (Resolution MSC.391(95) – Adoption of the International Code of Safety for Ships Using Gases or other low-flashpoint fuels)

1.4 LNG Emissions

LNG is a relatively clean burning low emissions fuel. Commercial shipping companies and marine engine manufacturers are moving toward LNG solutions to meet emission standards as found in Code of Federal Regulations section titled *Control of Emissions from new and in-use marine compression-ignition engines and vessels* (40 CFR § 1042).

As part of a global effort to reduce emissions from maritime vessels, the US Environmental Protection Agency sent a delegation to the International Maritime Organization (IMO) to draft an agreement to reduce harmful emissions from ships world-wide. In October 2008, the IMO made amendments to the International Convention of the Prevention of Pollutions from ships (MARPOL). The amendment related to the emissions from marine engines is found in Annex VI of the amendment and establishes Emission Control Areas (ECAs) within 200 nm off the coast of North America. Other ECAs have been put in place around the world including Europe and the Caribbean further limiting the amount of certain harmful emissions (SOx, NOx, PM, etc) which may be produced by vessels. Figure 3 shows the ECAs for North America.

The ECAs established by MARPOL Annex VI establish a time phased response to reduce sulfur oxides (SOx) and nitrous oxides (NOx). According to Annex VI of MARPOL, the most stringent emissions limits, Tier III, went into effect 1 January 2016 for vessels operating within the ECAs. In 2010, the US Environmental Protection Agency (EPA) created a program in the US to enforce NOx and SOx agreed to in MARPOL Annex IV around North America. This federal program outlined in 40 CFR § 1042 was implemented in stages over several years. When this document was written the program had advanced through all stages and “Tier III” is applicable to small vessels such as river tenders.

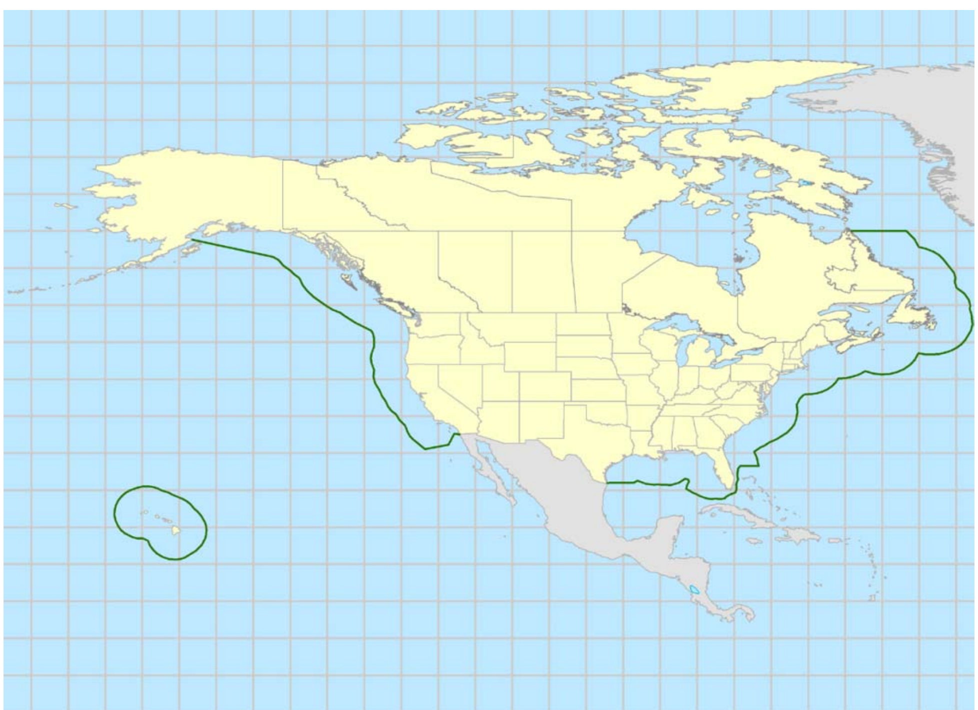


Figure 3. North American Emission Control Areas (EPA, 2010).

The Tier 4 standards come into effect in 2017 for engine with a capacity greater than 800 hp. The specific emissions limited by this Tier are particulate matter (PM), nitrous oxide (NOx), and hydrocarbons (HC). As seen in Table 1, the emissions limitations are listed by emissions mass (gram) over energy (kilowatt-hour). Based on past trends, the Coast Guard can extrapolate that the Tier 4 standards will be applied to smaller engines in the future.

Environmental regulations applicable to marine vessels are dynamic. There is a complex interplay between cost, improvements in technology, equipment availability, industry momentum, and politics on a national and international level. The CG should be alert to future changes and make a good faith attempt to define and then select the best technology available. For example, MARPOL Annex VI was recently released. Here the "global sulphur [sic] cap will be reduced from current 3.50% to 0.50%, effective from 1 January 2020."[5] This is an important consideration for the IWWRAC Alternatives of Analysis (AoA). The discussion of future regulations merges with discussions of fuel selection such as Ultra-Low-Sulfur-Diesel and other emission reduction technologies.

There are several different technologies which allow shipbuilders to be compliant with 40 CFR § 1042. The primary solutions include engine-internal solutions such as Exhaust Gas Recirculation (EGR) and fuel injection controls, off-engine solutions such as Selective Catalytic Reduction (SCR) or Oxidation Catalyst, and "Fuel Solutions" which include natural gas and bio-diesel. Figure 4 presents a summary of the technology solutions.

It is important to note that both engine-internal and off-engine solutions require additional auxiliary machinery which adds to engine complexity. One of the main benefits of using an LNG fuelled engine versus after treatment technology is that it does not require additional machinery / systems to bring the exhaust gas within Tier III limits other than a passive SCR treatment. This is not to say that an LNG engine is without emissions monitoring equipment as it may be necessary to monitor for "Methane Slip." This is an undesirable condition that occurs when the potent greenhouse methane gas escapes unburned from the combustion chamber.

Table 1. Tier 4 requirements for category 2 vessels from 40 CFR §1042.101.

Maximum Engine Power	Displacement (L/cyl)	Model Year	PM (g/kW-hr)	NO_x (g/kW-hr)	HC (g/kW-hr)
600 ≤kW <1400	all	2017 +	0.04	1.8	0.19
1400 ≤kW <2000	all	2016 +	0.04	1.8	0.19
2000 ≤kW <3700[a]	all	2014 +	0.04	1.8	0.19
kW ≥3700	disp. <15.0	2014-2015	0.12	1.8	0.19
	15.0 ≤disp.<30.0	2014-2015	0.25	1.8	0.19
	all	2016 +	0.06	1.8	0.19

[5] https://www.epa.gov/enforcement/marpol-annex-vi#marpol

Marine Tier 3 diesel engines in the 400 and 800 hp range are only starting to be produced. Natural gas fueled engines are available but are not marine certified. This makes side by side comparisons between Tier 4 natural gas and diesel fueled engines speculative. When conducting the Alternatives of Analysis (AoA) for the IWWRAC, the life cycle costs of these after treatment systems should be included in the cost comparison amongst the different propulsion systems. The AoA team should look at both the capital cost and the reoccurring maintenance costs.

Note that the primary audience of 40 CFR § 1042 is engine manufacturers. Even if the Coast Guard determined that the new Western River Tenders should be exempt from certain statutes it would still be difficult to find a US engine manufacturer that does not comply with the regulations since the rest of industry must comply with these regulations. The United States Coast Guard is able to apply for a “national security exemption” to the regulations found in §1042.635. Note that these exemptions are usually given to vessels “where the vessel in which it is installed has armor, permanently attached weaponry, specialized electronic warfare systems, unique stealth performance requirements, and/ or unique combat maneuverability requirements.” Even if the proposed IWWRAC does not meet any of the stipulations mentioned above it could still be exempt if a “request is endorsed by an agency of the federal government responsible for national defense.” Though possible to apply for an exemption, such a decision may appear hypocritical to commercial members of the maritime transportation system on the Western Rivers if the United States Coast Guard is enforcing the regulations outlined in 40 CFR § 1042 while not being compliant with its newly built fleet.

Exhaust Gas Components	Why Bad?	Primary: Engine-Internal Solutions	Secondary: Off-Engine Solutions	Fuel Solutions
Nitrogen Oxides NOx  NO NO_2	Ground ozone formation Respiratory issues Acid rain	Reduce temperature during the combustion process Exhaust Gas Recirculation (EGR)	Aftertreatment technology (e.g. SCR)	Natural Gas
Sulfur Oxides (SOx) 	Respiratory issues Acid rain	Fuel injection control	Aftertreatment technology (e.g. Scrubbers)	Natural Gas, Low Sulfur Fuels, Bio-Fuels
Particulate Matter (PM) 	Air pollution Respiratory and heart issues	Fuel injection control	Aftertreatment technology (e.g. DPF)	Natural Gas, Low Sulfur Fuels, Bio-Fuels
Hydrocarbons (HC)	Volatile Organic Compounds (VOCs)	Fuel injection control and engine maintenance	Oxidation Catalyst	Natural Gas
Carbon Monoxide (CO)	Toxic Ground ozone formation	Fuel injection control Low load avoidance	Oxidation Catalyst	Natural Gas
Carbon Dioxide (CO_2)	Greenhouse Gas/ Global warming	Various measures reducing total fuel consumption per ton-mile		

Source: http://www.marinelink.com/news/regulations-emission-tier360975

Figure 4. Pros & cons of different EPA compliance technology.

2 FUEL AVAILABILITY

RDC canvassed representatives from the LNG industry including Stabilis Energy, Pivotal LNG, Ferus/Eagle LNG, and REV LNG. LNG can be sourced today from at least three independent companies with national networks of LNG transportation and production facilities.

Bunkering directly from semi-tanker truck is the most likely fueling method for CG river tenders. Delivery by overland interstate trucking is a mature industry practice that has been in place for many years and has a reliable distribution model. An order placed 48 hours prior to delivery is a typical lead time requirement. Alternatively, it is possible for the CG to temporary store LNG in a temporary / permanent facility located at each port. The additional cost of the installed equipment, space requirements, security, and maintenance personnel may not be warranted.

A single semi-tanker truck carries 10,000 gallons of LNG. A cryogenic transfer pump assembly was recommended by all industry reps for fuel bunkering. This pump may be CG owned, leased as part of the delivery, or installed on the semi-tanker truck. This last option is problematic as it reduces the amount of LNG the semi-tanker truck can carry therefore adding additional cost. For reference, the pump, control system, and associated equipment would fit into the bed of a pickup truck and has an order of magnitude cost of $50,000. An alternative fuel transfer method is the “pressure transfer method.” Here the LNG is moved based on the pressure differential between the servicing and receiving tanks. This method is considerably slower than the pump method.

Delivery distance impacts cost. The bulk fuel delivery price is stated in term of dollars per gallon or dollars per unit energy. A typical mileage charge is approximately $0.06 per gallon per 100 miles. Additional fees apply for minimal distance traveled, multiple day travel, and “short load” if all of the fuel is not bunkered.

While LNG terminals are NOT built on the Western Rivers, nor are they likely to be in the future, the distribution system currently available (and projected to grow) will be sufficient to supply LNG to the USCG inland fleet of cutters.

3 EQUIPMENT AVAILABILITY

The machinery required to construct a LNG river tender appears to be available although key components such as engines lack marine certification. LNG should not be considered a turnkey solution as no single vendor offers a complete solution applicable to the CG river tender. For the purpose of this report, the technology is broken down into seven general categories. For each category, a description is given along with the work required to integrate the piece into a functional system.

3.1 LNG Storage Tanks

Tanks are available as both membrane and independent tanks. The membrane tank is built into the ship. The size and shape is defined by the hull compartmentalization as the various decks and bulkheads support the weight of the fuel. Each fuel compartment contains layers of insulation and an invar (nickel-iron alloy) or stainless steel “membrane” to contain the LNG. Recall that LNG is stored at a temperature of -259° F and each tank must withstand a maximum pressure of about 1.0 MPa (145 psi). Note that a secondary membrane is required since there is a risk of cracking the keel, frames, and hull due to metal embrittlement should the LNG escape the primary membrane.

The independent tank is self supporting and is not integral to the ship's hull. This tank could be installed within the skin of the ship in a dedicated compartment or it could be installed on the weather deck. One independent tank of interest is the ISO shipping container. Here a 20 ft cryogenic tank can store about 5000 gallons of LNG.

Note that the precaution about barriers still applies. Like the membrane tank, the independent tank is constructed with two shells. The internal membrane holds the LNG. It is surrounded by a layer of insulation. A vacuum is typically implemented between the shells for additional insulation. The external shell provides a layer of protection and is designed to contain the LNG should the internal shell fail. Cryogenic fluid must not be allowed to come into contact with a steel deck as it will crack. Areas that could potentially come into contact with a LNG leak such as tank connections, valves, and bunkering connections must contain an insulated drip pan.

3.2 Pipe and Valves

The cryogenic technology used for LNG is not new. It can be traced back to systems used during World War I to extract helium from natural gas. The requirements for pipe and valve are considered mature. Solutions appear to be readily available from multiple manufactures.

3.3 Vaporizer Unit

The engines used in a river tender will not run directly on LNG. Instead, LNG must be heated to its gaseous form and supplied to the engines at a pressure of approximately 75 psi. Regasification is typically done in a compartment known as a "cold box." The cold box is expected to be a custom designed system sized to fit the river tender's specific operational demand requirements. The cold box consists of an intermediate gaseous storage tank, heat exchanger(s), valves, solenoids, computer control systems, and failsafe devices. All of these items are readily available but not necessarily as a complete system.

In principle, regasification is an easy task. An automated system would add heat energy to the LNG causing it to boil. The liquid will change phase to a gas in a process similar to boiling water. By regulating the speed of this conversion, the pressure in the LNG tank may be regulated. Note that the tank and heat exchanger must be designed to accommodate the cryogenic temperatures.

In practice, this task is more difficult. The rate at which gaseous fuel is consumed is a function of throttle position which can go from a 1200 hp full throttle demand to miniscule 35 hp for hotel services. The regasification system must accommodate these demand changes ensuring that fuel is always available. It must also ensure that the intermediate storage tank do not over pressurize.

Appendix C further expands on this section by showing the equipment on the commercial vessel MK KORSFJORD - a ferry homeport in Trondheim Norway.

3.4 Engines

Gaseous fueled engines are currently found in a variety of applications. Some examples include propane fired standby generators, municipal supplied natural gas generators, landfill gas to energy applications, oil field on-location gas compression, and compression engines for natural gas pipelines.

Large maritime certified engines such as the 2000 hp CAT G3616 and the 1300 hp Wärtsilä 20DF are readily available today. Unfortunately, market research failed to find LNG marine rated engines appropriately sized for river tender operations. Here the desired rating is assumed to be between 400 and 800 hp. The actual power required is dependent on plant configuration which is assumed to be either 2 or 4 engines. Small methane fueled engines for use as ship service generators such as the 35 hp CAT 3404 are not available in marine packages.

On the other hand, there are many engines designed for generator, truck, pump, and industrial applications. For example, the CAT CG137-8 appears to meet the required power specifications. This 400 hp engine, similar to the diesel CAT 3408, is designed for oil field LNG fueled wellhead pumping application. Likewise, the 400 hp Cummins Westport ISX12G truck engine based on the lightweight X12 diesel could possibly be converted for maritime use.

Further work is required to determine if these smaller engines could be converted to maritime applications. The unique river tender operational, mechanical, and safety requirements will need to be determined. These will need to be analyzed against the standards defined by the American Bureau of Shipping (ABS), Maritime Classification Society (MCS), International Maritime Organization (IMO) standards, and Environmental Protection Agency standards. One manufacture (CAT) stated that this could certainly be done for engines such as the CAT CG137-8 but would cost a considerable amount of time and money.

It appears that the river tender LNG engine requirements are in front of the current state of the market. Should the maritime LNG market grow, these smaller engines are expected to be available. RDC recommends that the Coast Guard continue to track the development these engines as they may become a viable option for future cutter or small boat class designs.

One final comment regarding engines - Tier 4 diesel engines in the 400 and 800 hp range are only beginning to be developed and fielded. None appear to be marine ready. This makes side by side comparisons between LNG and diesel fueled engines speculative.

3.5 Propulsion Equipment

From a mechanical perspective there is nothing special about propulsion. Conventional mechanical, hydraulic, and electric propulsion systems are viable. There appears to be a trend where engine manufactures use the same block for both diesel and methane engines. From a mechanical perspective this allows drop in replacement of diesel with a methane engine.

This is still an area that requires attention. The engine room must be either gas safe or Emergency Shut Down (ESD) safe. In a gas safe machinery space, the equipment is designed so that no single failure can lead to the release of fuel. In an ESD safe machinery room, sources of ignition are automatically shut down in the event of a gas leak. The engine plus propulsion system must be analyzed against the gas safe / ESD safe criteria. Further analysis is also required to determine the impact this shutdown would have on vessel operations such as close-quarter maneuvering and damage control response. One mitigation is the inclusion of a battery assist. An outline of a hybrid hydraulic propulsion system is presented in Appendix A.

3.6 Hydrocarbon Detectors

Natural gas is tasteless and odorless. The mercaptan odor typically associated with municipal natural gas and propane is not present in LNG as it would freeze and contaminate the cryogenic fluid. Sensitive methane gas detection equipment is required for engine room, ventilation, and on deck gas detection.

Appropriate sensors are available from vendors such as RKI Instruments. These detectors are designed to operate at oil field wellheads as well as LNG tankers.

3.7 Command and Control

Sensors, actuators, and general automation are considered mature and available for use on a LNG river tender. Custom Programmable Logic Controller (PLC) code will be required to integrate the LNG specific system into the overall operation of the vessel.

4 RECOMMENDATIONS

Before presenting RDC's specific recommendation for an LNG fueled river tender, it is useful to summarize the benefits and problems associated with LNG.

LNG Benefits:

- LNG solution promises low pollution with minimal after treatment. This is a good solution to reduce NOx, SOx, and particulates.
- The Coast Guard gains notoriety among environmental advocates from the LNG solution.
- Shale gas accessed through hydraulic fracturing provides a readily available locally produced fuel. This may help stabilize the future price and stability of the maritime LNG. For comparison diesel is derived from crude oil whose price has been highly volatile over the past decade.
- A catastrophic LNG spill will evaporate or burn as a pool fire with no pollution remaining in the water. However, this is not entirely harmless as the liberated (unburned) methane is considered a potent greenhouse gas.

LNG Deficits:

- Tier 4 compliant diesel engines burning ultra low sulfur diesel fuel are not expected to be significantly different from a pollution control perspective than LNG engines.
- LNG leakage along the length of supply chain from wellhead to cylinder head can negate any pollution benefit.
- LNG Fuel is difficult to accommodate in a small vessel such as a river tender. It has a low energy density when compared to diesel. The collision zones and secondary containment areas limit the amount of fuel that may be bunkered. RDC estimates suggest that a LNG fueled vessel will have an endurance of about 10 working days. Any below deck LNG storage consumes excessive space due to secondary containment. Any above deck solution presents shipboard dynamics and stability problems.
- Fuel cannot be left unattended for more than perhaps a month. Recall heat leakage into the LNG tank is constantly causing the slow vaporization of LNG. This vaporization increases the pressure inside

the storage tank until 145 psi is reached at which time the pressure relief valve opens and vents methane directly to the atmosphere.

- LNG poses additional complications and hazards to the crew.

If we accept that modern Tier 4 diesel engines burning low sulfur fuel are nearly as good for the environment as a LNG fueled engine then most of the advantages associated with LNG are negated. Also, long term fuel prices are expected to equalize for LNG and diesel, as major consumers such as industrial, semi-trucking, rail, and power generation sectors all work to select the least expensive fuel alternative.

Diesel fuel is very close to the ideal maritime fuel. When compared to LNG, diesel is simple to use, easy to store and transport, provides improved energy density, can be bunkered nearly anywhere on the ship. It is also a proven fuel used on nearly every Coast Guard vessel. RDC estimates suggest that 10,000 gallons of LNG is near the limit for a 100 x 30 foot river tender.

The decision to use LNG comes down to an endurance requirement. A preliminary assessment suggests that a small vessel such as a CG river tender can bunker no more than 10,000 gallons of LNG. This is equivalent to bunkering 6000 gallons of diesel. This is considerably less than the WLICs that can take on over 20,000 gallons or the WLRs that can bunker over 40,000 gallon of diesel fuel as demonstrated in Appendix B.

The fuel endurance CONOP for the IWWRAC will determine if LNG is a viable fuel option. If the CONOP requires a fuel endurance of less than 10 days, then the LNG options should be pursued further. If the CONOP requires an endurance of 10 days or more then diesel fuel is the recommended fuel. Regardless, the CG should continue to track LNG technology and price trends for possible inclusion in other platforms.

APPENDIX A. PROTOTYPE LNG RIVER TENDER

As this REACT report was being developed, it was useful to sketch the outline of a prototype vessel. This allowed the team to visualize the LNG systems and better understand the requirements and regulations as they apply to the CG river tender. Most importantly, this exercise suggests an upper limit on the amount of fuel that may be bunkered. This appendix also captures some conceptual ideas that RDC gathered while researching river tender operations. They are included in the hope that they will be useful for the final river tender acquisition team for both LNG as well as diesel fueled options.

Figure A-1 is a sketch of RDC's prototype LNG fueled river tender. A simple push boat design was chosen as a common platform for both the WLICs and WLRs with the understanding that the barge (not shown) would be modified to meet the specific requirements of the vessel.

The design is an attempt to keep the fuel hazards as far away as possible from the living quarters and the machinery spaces. Observe that the stern of the boat is dominated by the LNG fuel. Engines are located amidships and living quarters pushed to the front of the vessel. This layout is necessary to accommodate the unique requirements of the LNG fuel. Note the large circles overlaid on the stern. These represent the explosive atmosphere hazard zones associated with the fuel. Recall that this hazard zone extends ≈10 feet from the LNG vent, fuel bunkering station, and any connection to the tanks. This includes the shore tie.

A.1 Fuel Storage

Bunkering and storage of the LNG fuel is the primary problem to be solved. There are two options to consider when deciding whether to include the LNG tank and cold box within the skin of the ship or on the weather deck. The B/5 and B/15 restriction for fuel placement limit compartment and system arrangement on the proposed river tenders. For a small push boat, these regulations stipulate that the LNG may be located no closer than approximately 5 feet from the skin of the ship and 2 feet from the bottom of the hull respectively. Recall that LNG is a cryogenic fuel with a temperature of −261.5° F. It is necessary to insulate the fuel from the steel frames and hull plating. Any direct spill of cryogenic fuel will embrittle the steel and crack frames and hull plating leading to loss of the compartment as well as endanger the crew. In addition to the primary membrane, secondary barriers must be added to protect the ship. All measures add cost and complexity plus consume below deck space. Given the explosive atmosphere hazard zones, B/5 plus B/15 restrictions, and additional space required for containment, any attempt to situate the LNG tank and cold box below deck was rejected.

The 20 foot ISO shipping container was identified as convenient freestanding LNG storage vessel. It should be mentioned that industry literature has featured larger vessels bunkering LNG in stacks of 40 ft ISO containers. The ISO LNG fuel container is expect to be ruggedized, readily available as a COTS product, and provide ease of maintenance by simply removing the tank form the river tender using a common ISO container crane. Since the ISO containers are transported via truck they are expected to include baffles to prevent sloshing loads.

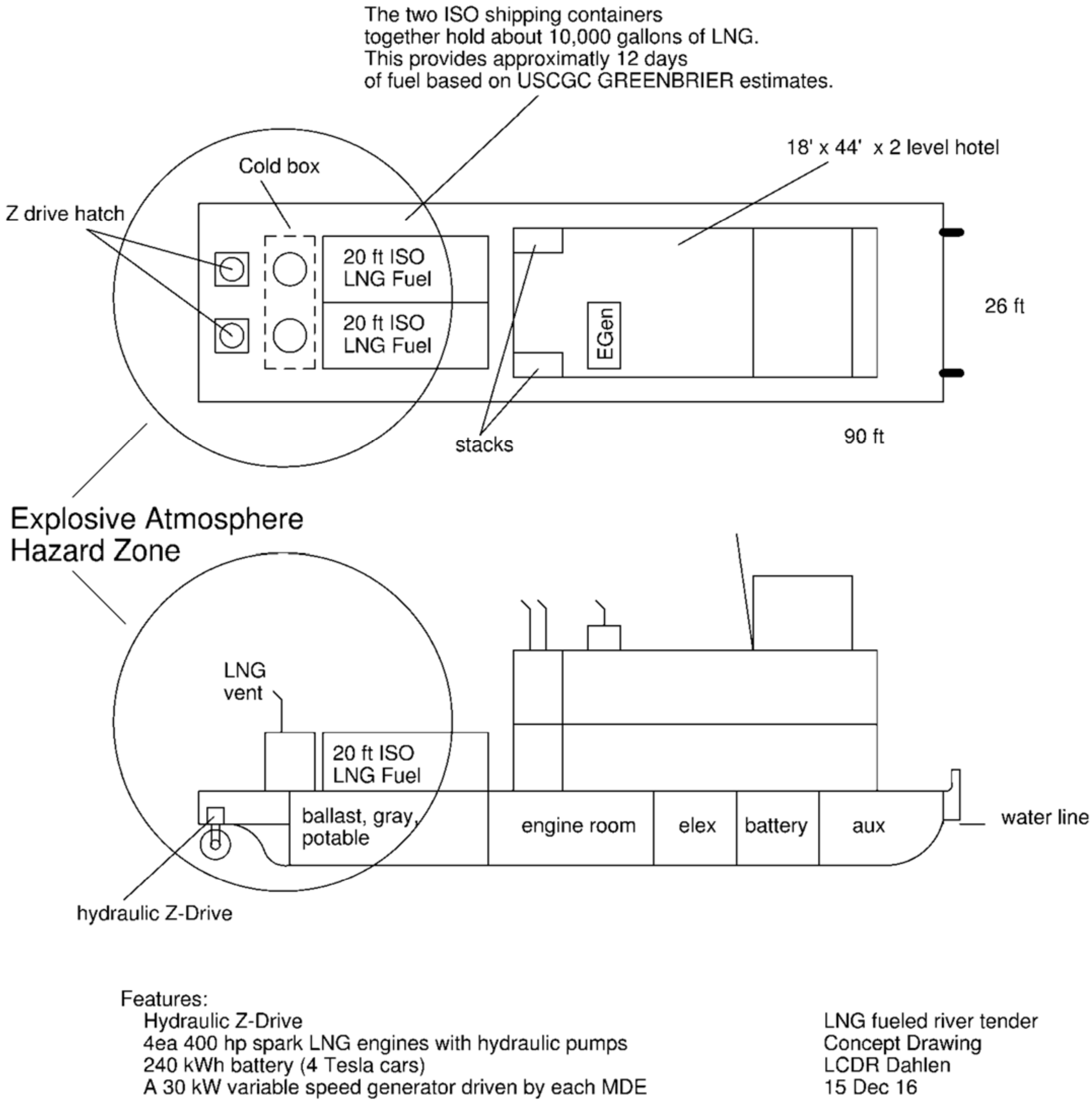


Figure A-1. Sketch of an LNG fueled river tender. The large circles at the stern of the ship are the explosive atmosphere hazard zones.

The ISO container provides three layers of protection including inner membrane, outer membrane (tank) and container wall. Each 20 ft container has a capacity of about 5,000 gallons of LNG. A single container weighs approximately 10 tons (empty) plus 8.7 tons of fuel. Two 20 ft shipping containers were chosen to fuel the vessel. They are installed on the aft part of the ship as show in Figure A-1. Based on fuel estimates provided by USCGC GREENBREIR this amount of LNG fuel equates to about 10 operational days.

USCGC GREENBREIR burns approximately 500 gallons of diesel fuel each day. This equates to about 800 gallons of LNG. A two day fuel reserve is assumed.

The beam of the ship is directly determined by the size of the ISO container based fuel storage tanks. A buffer zone must be maintained to minimize damage due to collision. The preliminary ISO standard implies that a ship with a 16 foot wide fuel tank (side by side ISO containers) will require a beam width of 26 feet – 5 feet on all sides of the tank to the edge of the ship. This meets the requirement that a LNG storage tank shall be located at a minimum distance of B/5 or 11.5 m." Where B is the beam width of the ship.

Note that the areas under the tanks must be provided with drip trays. These dams must be insulated to prevent cracking the deck plates should an LNG spill occur.

A.2 LNG Hazard Zones

The next step was to identify the explosive atmosphere hazard zones and work to keep people and machinery as far away as possible. **Accommodating this hazard zone dominates the design of the vessel.** Preliminary ISO standards define dangerous areas using a "Zone X" nomenclature where X is inversely proportional to danger. LNG hazard Zone 0 is the insides of the tanks. Zone 1 is a sphere surrounding any location where connections are made to the tanks and to where the tanks vent in the event of over pressurization. Zone 2 describes a physical distance from the weatherdeck mounted tank.

The prototype vessel was designed to minimize the ventilation, electrical and mechanical system located in Zone 1. Connections to the tanks, methane ventilation, and shore tie were made aft. The gasification (cold box) equipment is also placed aft. In Figure A-1, the methane vent pipes may be seen extending from the cold box structure aft of the tanks.

Zone 1[6] may be viewed as a 10 foot sphere that encompasses the entire aft section of the vessel extending forward to the middle of the fuel tanks. Electrical and other spark generating equipment in this section is minimized and must be explosion proof. This includes the rudder angle feedback mechanism located in a compartment aft and under the tanks, various methane sensors, LNG electronically actuated valves, navigation lights, and flood lights.

Zone 2[7] defines a safety zone surrounding the tank. Since the tank is contained within the skin of the ISO shipping container, zone 2 is interpreted to extend 5 feet. Consequently, there is a 5 foot gap between the front of the LNG tanks and the living quarters.

A.3 Propulsion

A river tender is a small vessel and it is difficult to meet the LNG hazard zones while keeping the vessel compact. Once the decision was made to install the fuel on the aft part of the ship it was necessary to move the engines forward. By installing the engines amidships they are out of zone 2 and the engine exhaust is outside of zone 1.

[6] IMO annex 1 (Resolution MSC.391(95) – Adoption of the International Code of Safety for Ships Using Gases or other low-flashpoint fuels)
[7] Enclosure (1) to CG-521 Policy Letter No. 01-12 – Design Criteria for natural gas fueled systems

The engines are now over 30 feet away from the propellers. A direct driveshaft could be used but would require support bearings and more importantly, access for personnel to inspect and replace the long drive shaft. This is undesirable as this lower part of the ship would be better used for ballast and potable water. This is especially important considering the heavy LNG fuel tanks are in a non ideal location high above the ship's center of gravity. With direct drive propulsion rejected there are two other options including electric and hydraulic.

Given the two options, hydraulic is preferred for multiple reasons. The first consideration is propulsion system efficiency. Table A-1 presents three different propulsion systems along with estimated efficiencies for each energy conversion. Propulsion efficiency is directly proportional to fuel consumption. The hydraulic system is not as efficient as the direct mechanical system but it is better than the electrical solution. Note, the efficiency numbers included in Table A-1 are estimates. Further study and analysis is required to refine these values. Still, the combined efficiency is expected to be within ± 3%.

Table A-1. Comparison of candidate propulsion systems.

Propulsion	Cost	Efficiency	Comments
Direct	least	best at ≈ 95%	• Requires long drive shaft to connect engines to "Z" drive plus additional support bearings. Service space consumes considerable below deck space. • Large spinning mass could be damaged by floating debris. • Requires large marine transmission with reduction gear, clutch, and reversing mechanism.
Hydraulic	moderate	moderate at ≈ 87%	• Flexible system - easy to parallel multiple methane fueled engines and/or electric driven hydraulic pumps. • Simple pumps repairable by ships force. • Best protection from floating debris.
Electric	highest	worst at ≈ 82%	• Disadvantage of electric motors in the hazard zone. • Complex electric system would require skilled EM2 or EM1 to service.

The hydraulic system promises to perform well in a river setting as it is tolerant of debris strikes. In the hydraulic system, the hydraulic motor is installed in the propeller hub resulting in a relatively small moving mass. Should a propeller blade strike a tree stump, the propeller would instantly stop and the hydraulic relief valves would open. This is preferable to a direct mechanical system where the large spinning mass of the propeller shafts, engine, and crankshaft would all experience a damaging torque. Likewise an all electric solution could suffer damage as the "L" drive gears and motor rotor would experience the damaging torque.

The hydraulic system is preferred from a LNG hazard zone perspective. As seen in Figure A-1 the propulsion pod compartment is located in the Zone 1 hazard area. Recall that the main hydraulic motor is located in the pod's underwater hub. The only items remaining in the pod compartment are the auxiliary hydraulic motors to steer the pod, rudder angle indicators, flooding sensors, and explosion proof lighting. This compartment could be constructed as a simple void with minimal or on demand ventilation as no cooling is required. Note that the all electric solution would feature a large electric motor mounted directly on top of the pods is an "L" or possible "Z" drive configuration. This electric motor complicates the design as the thruster space must be forcefully ventilated to cool the motor. Also, all components must be built to methane Emergency Shut Down (ESD) safe specification to prevent the risk of explosion.

Before closing the discussion on hydraulic drive it should be mentioned that an auxiliary retractable and 360° rotatable drive could be added to the barge. This could act as a bow thruster and even allow the barge to maneuver unattached from the push boat should the need arise.

The model's propulsion system also includes a large battery capable of powering the propulsion, auxiliary, and hotel electrical loads. For reference, this battery has the energy equivalent to 4 Tesla roadsters. For an LNG fuelled system the battery provides continued steerageway in the event of cold box freeze which would starve the engines of fuel. The vessel can also continue to operate in an emergency situation. Should a gas leak be detected, the engines and other hot sources of ignition can immediately be shut down. The battery along with explosion proof motors connected to the hydraulic propulsion can continue to provide propulsion for a limited time.

There are additional benefits to using a battery such as allowing the crew to sleep at night without any running engine. Recall that CG river tender operations are only carried out during the day. The crew spuds down for the night or ties off to a convenient structure such as a tree. Finally, the vessel is capable of operating in 100% electric mode to pass through zero emissions zones. Such zones exist in California cities. None are identified on the western rivers but this may change over the lifetime of the river tender. Station keeping and other low power operations such as docking can be performed under all electric propulsion.

Further discussion of the battery system is outside the scope of this REACT report.

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APPENDIX B. HISTORIC FUEL USAGE

This chart shows the historical diesel fuel bunkering for the CG river tender fleet. The final column shows the amount of LNG required to bunker based on the maximum amount of diesel fuel taken aboard.

Platform	Hull Num	Name	Homeport	State	Diesel Fuel per bunker (6 yr avg)	Diesel Fuel Bunker (low)	Diesel Fuel Bunker (High)	High Usage Diesel to LNG Equivalent (gal)
75' WLIC	75301	*Anvil*	Charleston	SC	4211	435	13405	22288
75' WLIC	75302	*Hammer*	Atlantic Beach	FL	5266	550	18435	30651
75' WLIC	75303	*Sledge*	Curtis Bay	MD	5269	1180	15117	25134
75' WLIC	75304	*Mallet*	Corpus Christi	TX	14032	1091	23232	38627
75' WLIC	75305	*Vise*	St Petersburg	FL	9434	2472	16843	28004
75' WLIC	75306	*Clamp*	Galveston	TX	8719	2000	13615	22637
75' WLIC	75309	*Hatchet*	Galveston	TX	7334	1147	14725	24483
75' WLIC	75310	*Axe*	Morgan City	LA	4230	1041	11509	19135
100' WLIC	315	*Smilax*	Atlantic Beach	NC	11452	2250	26760	44493
160' WLIC	800	*Pamlico*	New Orleans	LA	6688	1600	20063	33358
160' WLIC	801	*Hudson*	Miami Beach	FL	11149	2098	18790	31241
160' WLIC	802	*Kennebec*	Portsmouth	VA	16856	3000	26534	44117
160' WLIC	803	*Saginaw*	Mobile	AL	8999	3141	15975	26561
65' WLR	65501	*Ouachita*	E. Chattanooga	TN	14833	5787	31042	51612
65' WLR	65502	*Cimarron*	Buchanan	TN	12755	3000	32313	53725
65' WLR	65503	*Obion*	Owensboro	KY	20317	7999	35675	59315
65' WLR	65504	*Scioto*	Keokuk	IA	12867	6000	24139	40135
65' WLR	65505	*Osage*	Sewickley	PA	11813	1200	29081	48352
65' WLR	65506	*Sangamon*	E. Peoria	IL	12154	4000	29004	48224
75' WLR	75307	*Wedge*	Demopolis	AL	13020	3622	22066	36688
75' WLR	75401	*Gasconade*	Omaha	NE	12943	2000	43212	71846
75' WLR	75402	*Muskingum*	Sallisaw	OK	11559	600	33577	55827
75' WLR	75403	*Wyaconda*	Dubuque	IA	13906	3400	27130	45108
75' WLR	75404	*Chippewa*	Buchanan	TN	25177	4482	37561	62451
75' WLR	75405	*Cheyenne*	St. Louis	MO	11781	2734	34816	57887
75' WLR	75406	*Kickapoo*	Vicksburg	MS	20602	3000	46599	77478
75' WLR	75407	*Kanawha*	Pine Bluff	AR	18945	4390	35537	59086
75' WLR	75408	*Patoka*	Greenville	MS	18768	1550	49634	82524
75' WLR	75409	*Chena*	Hickman	KY	19568	6000	35028	58239
75' WLR	75500	*Kankakee*	Memphis	TN	25396	5925	38875	64636

Figure B-1. Historic fuel usage.

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APPENDIX C. LNG BUNKERING PRIMER

This appendix presents an example LNG system as installed on the MK KORSFJORD a ferry homeport in Trondheim Norway. It includes pictures of the installed LNG system plus associated equipment such as the cold box and fueling equipment. It then presents a general procedure for taking on fuel.

C.1 LNG Tank

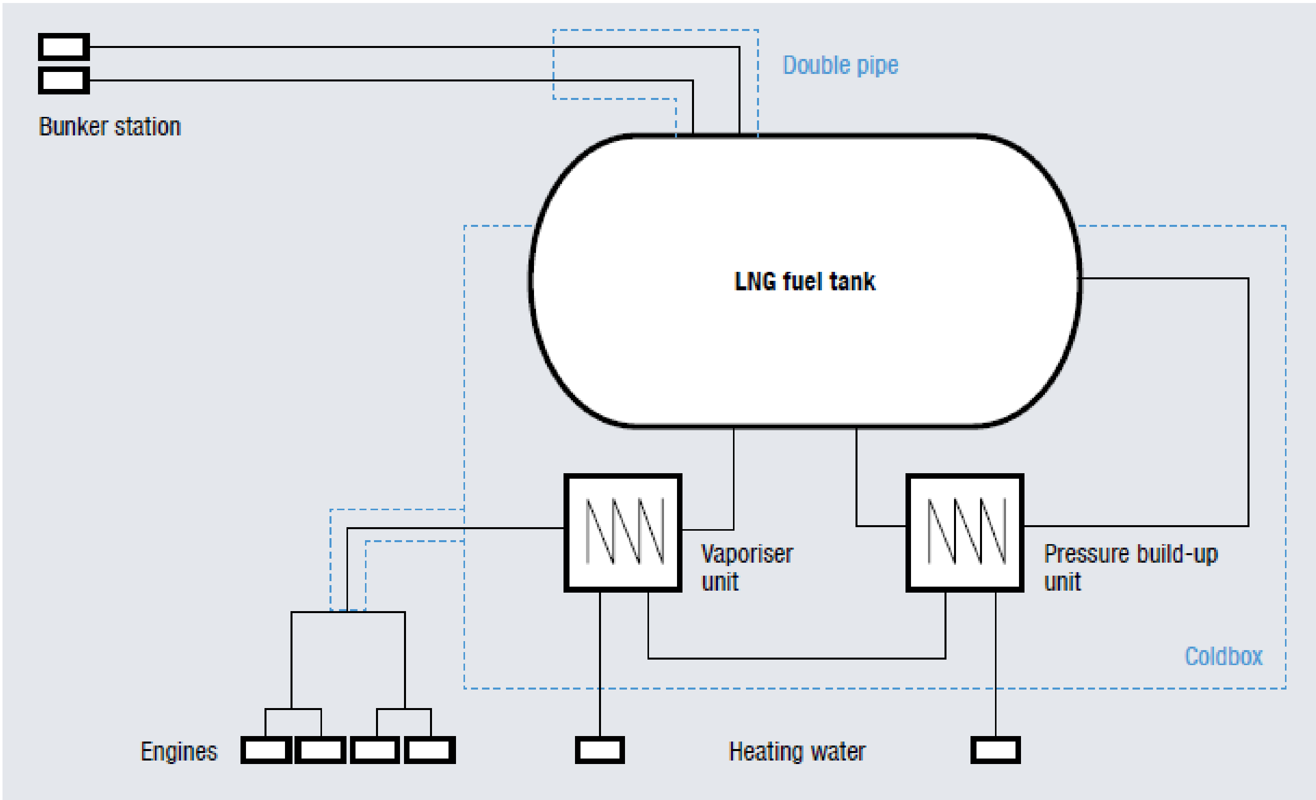
The standard Class C ISO tanks associated with the transportation of LNG are generally composed of two shells. According to the manual produced by Cryo AB for the Norwegian Coast Guard vessels "The suspension of the inner vessel to the outer vessel is designed such that it gives a slow heat transfer to the liquid in the inner vessel at the same time as it's capable of transmitting large acceleration forces between the vessels even when the inner vessel is filled with liquid". To slow heat transfer, the space between the two tank shells are vacuum insulated and includes a layer of perlite, which provides additional insulation in the event the vacuum is lost between the two shells.

C.2 Cold Box

The Cold Box is a compartment located adjacent to the LNG tank which stores many of the cryogenic components associated with the LNG system onboard a vessel. Major components located in the cold box include the water heated vaporizer unit and vacuum insulated pipes. The water heated vaporizer unit may be further broken into sub-components including the product vapor circuit, pressure build up circuit, and water circuit. Figure C-1 shows the interconnections between the major components associated with the LNG system.

The vaporizer unit and pressure build up unit are generally contained within the same heater exchangers as shown in the Figure C-2. Within the product vaporizer circuit, fluid / LNG is draw from the LNG tank through a dip pipe which penetrates the upper part of the inner vessel, to the evaporator (top part of the heat exchanger) where it is heated to gas. Liquid is moved through the system by the pressure in the tank and on-going evaporation. The phenomenon pushing liquid and gas through the circuit is known as the thermosypon effect and is regulated by the evaporation occurring in the product vaporizer circuit.

The lower heat exchanger is known as the pressure build up circuit which allows the LNG system to regulate pressure in the LNG tank. Liquid / LNG is circulated through the PBU because of the difference in liquid height within the tank and difference in liquid and vapor density.



Source : Cryo AB.

Figure C-1. LNG tank and cold box.

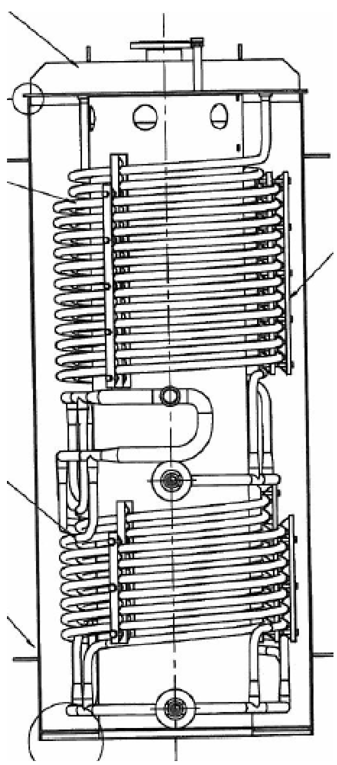


Figure C-2. LNG vaporizer unit (upper circuit) and pressure build-up unit (lower circuit) are housed together.

A "water circuit" is led through the top of the heat exchanger which is composed of a heated water / glycol mixture. The water / glycol mixture absorbs waste heat from the engines / prime movers and transfers the absorbed heat to the LNG during vaporization. A pump system circulates the water / glycol mixture through the entire vaporizer unit. According to the manual produced by Cryo AB, "icing can develop in the vaporizer if the heating of the water for some reason ceases. For this reason there is a temperature sensor in the circuit, which measures the water temperature in the vaporizer". This sensor will automatically close the valve leading LNG to the vaporizer if the temperature falls below a certain temperature or the water / glycol mixture running through the vaporizer drops below a certain amount.

Throughout the Cold Box, pipes carrying LNG are double walled and vacuum insulated similar to the LNG tank. Special cryogenic valves are also utilized within the Cold Box. Vacuum insulated pipes are also used during bunkering to reduce heat transfer between the ambient atmosphere and the LNG traveling through the bunker lines.

A final major element of the LNG system (besides the natural gas engines) located outside of the Cold Box is the Gas Ramp Unit (GRU). This component is usually located in the "valve room". The purpose of the GRU is to govern and regulate the gas supply and pressure being led to the engines. Normally, the GRU is associated which an electronic control system which is monitored by the engineering watch.

C.3 LNG Bunkering

In addition to the LNG system onboard the LNG fuelled vessel, an equally important process is "bunkering" which is the transfer of LNG from a cryogenic truck, barge, or bunkering station. Below is a description of a normal bunkering process from an LNG truck to a LNG fuelled vessel.

1. The vessel receiving LNG is placed in "Normal Standby (NSD) – gas system shut down". This means that the LNG system on the ship is secured including the gas engines and pressure build up unit.
2. The bunkering line is connected between bunkering truck and ship. Figure C-3 shows the bunkering connection point located on a LNG fuelled vessel. Figure C-4 shows the cryogenic bunkering lines used during the process. Note that a pump is required to transfer the LNG from the truck to the ship. This pump may be installed on the truck or located on the pier.
3. The bunkering line is prepared for use by displacing the atmospheric air with a dry inert nitrogen gas. This nitrogen flows from bottles stored on the ship through the bunkering line and is vented through the gas mast located on the truck. This process takes approximately 5 minutes.
4. During this process, the tank pressure in the bunkering truck is increased using an internal PBU.
5. After inerting the bunkering line with nitrogen, gas is purged from the top of the LNG tank on the ship to the gas vent on the bunkering truck. The natural gas purging from the tank on the ship occurs for approximately 4 minutes.
6. After the line is inerted and the top of the ship's LNG tank is purged, cold tank bunkering commences. Bunkering may occur from either the top of the ship's tank to decrease the overall pressure in the tank or from both the top and bottom or the ship's tank to regulate the pressure in the tank during the entire bunkering process.
7. Once bunkering has concluded, liquid line stripping occurs in which residual liquid inside the bunkering line evaporates and is pushed to the ship's tank. In this stage the LNG in the hose absorbs heat from the environment and evaporates. This is done for approximately 3 minutes.

8. After liquid line stripping is finished, the bunkering valves closest to the LNG tank are shut and any gas that is trapped within the bunkering line is released from the ship's gas mast for approximately 2 minutes.
9. After releasing the trapped gas from the bunkering line, the bunkering line is inerted and purged using nitrogen. The nitrogen and any remaining trapped gas are released from the ship's gas mast. This is done for approximately 3 minutes.
10. After the line has been inerted, the bunkering hose is disconnected and the bunkering process is secured.

Figure C-3. Shipboard LNG bunkering connection point.

Figure C-4. On deck stowage of LNG bunkering hoses.