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The Future of LNG as a Fuel for U.S. Vessels

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I. Overview

Worldwide there are about 30 LNG powered vessels in service and another 30 or so are in design or construction. Roughly half of those in design or construction are U.S. vessels. (6)

We believe that LNG is now emerging as the fuel of choice for the propulsion of U.S. vessels in many marine applications due to its inherent benefits:

- Safe Proven by years of demonstrated safe marine operations.
- Clean Meets and exceeds new North American Emission Control Area (ECA) standards.
- Available Estimates show almost unlimited North American supply.
- Cost Effective Significantly less than diesel fuel options on an energy equivalent basis.

LNG powered vessels can meet and exceed these new ECA emission standards and in many applications can cut expenses despite the required initial investment needed for natural gas engine and fuel systems.

Essential to the operation of LNG powered vessels is the infrastructure required to support refueling. Primary elements consist of waterfront liquefaction facilities, LNG transport barges that enable remote waterfront LNG refueling facilities and bunker barges that facilitate LNG refueling simultaneously with cargo loading or unloading operations.

With available financing and continued regulatory cooperation, the potential for LNG powered vessels (both in the U.S. and worldwide) is enormous.

Over recent years, we at Bristol Harbor Group, Inc. (BHGI) and our sister company, The Shearer Group, Inc. (TSGI) have taken a leadership role in this field by engaging in four separate LNG vessel projects:

- Two LNG Powered Ships:
 - A 4,200 horsepower LNG towboat.
 - A U.S. Army debris collection vessel.
- Two LNG barges essential to required infrastructure:
 - \circ A 232 foot, 2,000m³ LNG transport/bunker barge with a membrane tank.
 - A 300 foot, 3,000m³ double hull LNG transport barge with Type C pressure tanks.

This work has provided BHGI with considerable experience not only in the design of LNG vessels but also in the integration of sophisticated LNG systems, and in the analysis of associated risks needed to ensure safety. It has also provided us with experience in working with the U.S. Coast Guard (USCG) and the American Bureau of Shipping (ABS) through the design approval process.

II. The Case for LNG as A Fuel for U.S. Vessels

Safe: Proven by Years of Demonstrated Safe Marine Operations.

LNG has been transported and used safely in the U.S. and worldwide for roughly 40 years. The LNG industry has an excellent safety record. This is the result of several factors:

- The industry has technically and operationally evolved to ensure safe and secure operations.
- The physical and chemical properties of LNG are understood such that risks and hazards are mitigated by continuously improving technology and operating systems.
- The standards, codes and regulations that apply to the LNG industry have evolved to further ensue safety. (2)

In the marine field, there are more than 30 LNG powered vessels in service today. That is not counting the almost 400 LNG carriers, most of which are dual fuel, and routinely use boil off natural gas as fuel. (6) To date these vessels have maintained an excellent safety record. (2)

A comprehensive study of LNG safety was completed by the Center for Energy Economics in June of 2012. That study showed that in the 47 year period from 1965 to 2012 a total of only 20 incidents of consequence were reported involving vessels powered by or carrying LNG.

- None of these resulted serious injuries or fatalities.
- None resulted in the loss of a vessel.
- Only seven resulted in damage to hull structure. (2)

We are not aware of any serious LNG marine related incidents since 2012.

<u>Clean:</u> LNG Dual Fuel Diesel Propulsion Systems Meet and Exceed Demanding North American ECA Air Quality Standards.

Emission control requirements are one factor that drives the emergence of LNG as a fuel of choice. For many years the United States Environmental Protection Agency (EPA) has been advancing a strategy to control air pollution from large ships. The designation of the North American Emission Control Area (ECA) with significant engine emission reduction requirements is a key element of that strategy. This includes waters extending 200 miles off North American coasts (including the U.S. and Canada) as an area in which stringent international emission standards will apply for ships. (9)



Figure 1. North American Emission Controlled Areas (9)

The Environmental Protection Agency (EPA) has expanded this to include waters off Puerto Rico and the U.S. Virgin Islands and is considering whether other areas of the United States and its territories such as Alaska, Pacific U.S. Territories, and smaller Hawaiian Islands will be included as well. (9)

Standards imposed for marine diesel engines operating in these ECA's require very significant emission reductions which include the following:

- The ECA fuel sulfur dioxide (SOx) engine emission standard is 1,000 ppm (1/10th of 1%) starting January 2015. (10)
- The ECA nitrous oxide (NOx) engine emission standard, which varies with rated engine speed, amounts to an 80% reduction below Tier 1 starting in 2016. (10)

Vessels that choose to continue using conventional bunker fuels must use costly cleanup technologies when traveling in ECA zones. This requires a substantial capital investment in a scrubber retrofit for sulfur dioxide (SOx), and selective catalytic reduction technology to remove nitrous oxide (NOx). Another compliance option is to fuel ships with low-sulfur distillate fuel which can double annual fueling costs. All of these permanently add substantial annual operations costs in a competitive market. (1)

Natural gas is an alternative fuel that offers what many consider a better option to ensure compliance to these strict ECA standards:

- Inherent sulfur dioxide (SOx) emission reduction of 98%.
- Greater than 80% nitrous oxide (NOx) emission reduction below Tier 1 as shown in Figure 2. (12)



Figure 2. NOx Emission Reductions of LNG Powered Wartsila Marine Diesels as A Function of Engine RPM (11)

In addition, LNG can also provide ongoing compliance for a range of potential future legislation as compared to high sulfur fuel:

- It emits 99% less harmful particulates.
- It provides a 20% reduction in greenhouse gasses. (12)(23)

Available: Projections Show Long Term Availability of U.S. Natural Gas.

The momentum behind natural gas development in high horsepower industries is being driven by shifts in the long term supply of low cost natural gas. Rapid technology advances in new drilling techniques have unlocked vast U.S. resources of natural gas that were previously too expensive to extract. Since the beginning of 2005, natural gas production in the U.S. has increased 30%. The most recent Energy Information Administration (EIA) figures predict a 56% increase from 2012 to 2040. (1)

Substantial increases in natural gas demand are predicted in the energy marketplace, including utility, industry, and transportation users. Accounting for this increase in demand, the EIA, MIT and the Potential Gas Committee all project ample long term domestic supplies of natural gas. This is helping companies project stable long-term cost saving benefits when investing in a switch to natural gas. (1)

Cost Effective: Projections Show Sustained Low Costs of U.S. Natural Gas.

As a result of significantly increased natural gas availability in the U.S., natural gas prices have proven to be lower and more stable than diesel fuel as illustrated in Figure 3. This is projected to continue for generations into the future. (25)



Figure 3. Relative Costs of Natural Gas vs. Wholesale Diesel (13)

This increased, stable, long term supply of low cost natural gas has led to a fundamental change in the energy market place as utility, industrial, and transportation users are increasingly turning toward natural gas powered technologies. (1)

In today's upside down oil markets, the financial model for LNG propulsion has changed somewhat. Conventional wisdom is that LNG loses viability if the cost for the LNG delivered is more than 80% of diesel on a diesel gallon equivalent (DGE) basis. Diesel is approaching that price now, but Ultra Low Sulfur Diesel (ULSD) is 15% to 25% more, still making LNG an attractive option. (1)

Right now it is difficult to accurately predict the cost of LNG bunker fuel delivered to vessels in US ports. Estimates indicate that the cost of shore-side liquefaction alone will double the delivered price of the fuel relative to the price of delivered pipeline natural gas. However, experts still predict that even accounting for these added costs, it is relatively certain that marine LNG bunker fuel costs will be substantially lower than ECA regulated low sulfur diesel fuel costs as shown in Figure 4. (4)



Figure 4. Projected Relative Costs of LNG vs. Residual and Distillate Diesel (4)

These projections demonstrate that in the long run, marine LNG fuel costs will be less than half of ECA compliant low sulfur distillate diesel fuel.

In order for LNG propulsion to make economic sense, these projected savings in fuel costs must offset the substantial cost of conversion for existing vessels or the incremental cost of LNG propulsion for new ship construction.

Representative conversion costs (4)(7):

- Tug with 2 X 1,500 HP : \$7.2 million
- Ferry with 2 X 3,000 HP: \$10.8 million
- Bulk Carrier with 2 X 5,000 HP: \$24.0 million

New construction incremental costs are projected to be somewhat less than conversion costs.

The economics of any specific project is thus dependent on several factors:

- Annual fuel usage.
- Availability of LNG bunkering infrastructure.
- Reliable projections of delivered LNG and alternative diesel fuel costs.
- Vessel conversion cost (or new construction incremental cost). (4)

The best fit vessels are typically those that have a higher fuel consumption and fixed routes with available LNG refueling infrastructure. It is important to note that LNG is not economically beneficial for all applications.

III. The Required Infrastructure

One of the problems for U. S. ship owners considering LNG propulsion is that there is currently a lack of LNG bunkering infrastructure. DNV GL has recommended that the U.S. Maritime Administration conduct an analysis of vessel types that use U.S. ports to determine what bunkering methods will be necessary and where. This would also include assessing which ports would be best suited to LNG bunkering based on practical and security reasons. (7)

As shown in Figure 5, there are four options available for bunkering U.S. LNG powered vessel:

- Waterfront LNG Storage Tank
- Bunker Barge or Ship
- Bunkering Truck
- Portable Tank Transfer



Figure 5. Bunkering Options Available (3)

Also shown in Figure 5 are the three options available to fuel LNG Waterfront Storage Tanks:

- Waterfront Liquefaction Plant
- LNG Transport Barge or Ship
- Supply Truck

Waterfront Liquefaction Plants:

Even before completion of the recommended MARAD analysis, marine LNG infrastructure has been progressing well. Three waterfront liquefaction facilities are already planned and progressing:

- Atlantic: WesPac Midstream LLC recently signed a long term agreement with Pivotal LNG to construct a new LNG facility in Jacksonville, FL. That combined with Pivotal's other assets positions them to serve customers in Puerto Rico and the U.S. Virgin Islands as well. (15)
- Gulf of Mexico: LNG America in conjunction with Buffalo Marine is developing a hub and spoke bunker fuel delivery system for LNG as fuel for the marine market in the Gulf Coast region. Buffalo Marine is one of the premiere bunkering companies in the Gulf of Mexico with over 50 bunkering vessels. (7)
- Pacific Northwest: Puget Sound Energy (PSE) is building an LNG plant in Tacoma, WA which will produce 8 million gallons of LNG per day for the marine, trucking and rail markets. (14)

Transport Barges:

As illustrated in Figure 5, LNG transport barges enable the economic use of waterfront LNG fueling tanks that are remote from LNG liquefaction plants. One U.S. LNG transport barge project is underway:

• Bristol Harbor Group, Inc. has designed a 300 foot double hull LNG transport barge for Conrad Shipyard, LLC. It has already received ABS approval in principle and is intended for blue water costal transport of LNG. The design utilizes four (4) Type C pressure tanks, each with a capacity of 750 cubic meters.

Bunker Barges:

Also as illustrated in Figure 5, LNG bunker barges enhance the infrastructure significantly because they enable LNG ship refueling at locations distant from waterfront liquefaction plants and from waterfront LNG storage tanks. LNG bunker barges also potentially facilitate LNG refueling simultaneously with cargo loading or unloading operations. Additionally, LNG bunker barges potentially have the capability to refuel a vessel not in a port, such as mid-streaming on the rivers. Two U.S. LNG bunker barge projects are underway:

- Bristol Harbor Group, Inc. has designed a 232 foot membrane tank LNG bunker barge for Conrad Shipyard, LLC. This is the first dedicated North American LNG bunker barge. It has already received design basis approval from the United States Coast Guard (USCG) and is scheduled for delivery to WesPac Midstream LLC in early 2016.
- LNG America is currently designing two classes of bunker barges. (16)

IV. Financing

Clean Marine Energy (CME) is a global facilitator of finance mechanisms for LNG conversion and ECA compliance. WesPac Midstream LLC is a leading provider of energy infrastructurre and LNG solutions. (7)(8)

The recent strategic partnership between these two companies enables CME to offer shipowners interested in LNG propulsion a complete solution:

- Financing for ship conversion to LNG power.
- Assured supply and delivery of LNG fuel.

This is accomplished through CME's Emissions Compliance Service Agreement (ECSA). Under this agreement the cost of conversion (which can range from \$5M to \$25M or more) is financed by CME's fund. This fund is managed by Oaktree Capital Management, a leading global Investment Manager. CME subsequently shares in the cost savings offered by cheaper LNG fuel for a period of years after which ownership of the propulsion equipment transfers to the ship owner. (7)

This type of financing greatly simplifies the decision to convert. An ECSA is a capital efficiency solution that leverages third party capital to fund capex investments without adding to the ship owner's cost basis by transitioning capex to opex. The ship owner pays no upfront capital for ECA compliance, and the company that pays for the ship fuel continues to pay what they would have paid anyway, with some immediate shared savings during the ECA (1) implementation.

V. The Status of US LNG Powered Vessels

The deep draft U.S. Jones Act fleet has suffered from years of decline. Since 2000 the fleet has declined from 200 vessels to less than half of that size. The average age of the fleet is 22 years with many vessels beyond the typical operating life of ocean going vessels.

A combination of vessel age, pending ECA emission regulations and new market demand is resulting in a significant increase in both newer vessel conversions and new-builds, many of which are LNG powered or LNG ready. As illustrated in the following, our sources indicate that a total of 28 U.S. LNG powered vessels are already planned or under construction and that the total number of U.S. LNG powered vessels could exceed 376 by 2029. (1, 13)

To date virtually all of these planned and under construction vessels are dual fuel with the capability to operate on 100% diesel if required. (1)

| Area of Operation | Operator | Number of Vessels | Conversion or Newbuild | Fuel | Expected Delivery |
|-----------------------------------|------------------------|----------------------------------|---------------------------|------|----------------------|
| Atlantic (Florida To Puerto | Crowley Maritime | 2 | Newbuild | Dual | 2017 |
| Rico) | | Con-Ro Vessels | (VT Halter) | | |
| Atlantic (Florida | Sea Star Line | 2 | Newbuild | Dual | 2015 – 2016 |
| To Puerto Rico) | (TOTE) | Marlin Container Ships | (NASSCO) | | |
| Atlantic | Crowley Maritime | 4 | Newbuild | Dual | 2015 - |
| | | Tankers | (Aker S.Y.) | | |
| Atlantic (New York Harbor) | U.S. Army | 1 Debris Collection Vessel | Conversion | Dual | TBD |
| | | | | | 2014 |
| Gulf of Mexico | Harvey Gulf | 6 | Newbuild | Dual | 2014 – 2016 |
| | | OSV | (Gulf Coast) | | |
| Pacific | TOTE | 2 | Conversion | Dual | 2016 |
| | | Orca Container Ships | (NASSCO) | | |
| Pacific | Matson | 2 | Newbuild | Dual | 2018 |
| (To Hawaii) | | Container Ships | (Aker S.Y.) | | |
| Great Lakes | Interlake Steamship | 1 | Conversion | Dual | |
| | · | Ore Carrier | | | |
| Great Lakes | VanEnkevort | 1 | Conversion | Dual | |
| | | Tug & Barge | | | |
| Inland | TBD | 1 | Newbuild | Dual | |
| Waterways | | Towboat | (Conrad) | | |
| Inland | Washington | 6 | Conversion | Dual | |
| Waterways | St. Ferries | Ferry Boats | | | |

U.S. LNG Powered Vessels Planned & Under Construction (1) (13):

Total

Atlantic:



Crowley Two RoRo (ConRo)



TOTE Shipholdings Two Marlin Containerships



U.S. Army Crowley Debris Collector Four Tankers





Harvey Gulf Six Offshore Supply Vessels

Gulf of Mexico:

Pacific:





TOTE Shipholdings Two Containerships

Matson Navigation Company Two Containerships

Great Lakes:



Interlake SS Co. One Ore Carrier



<u>VanEnkevort</u>Tug & Barge One Bulk Carrier

Inland Waterways:



The Shearer Group, Inc. 4,200 HP Towboat



Washington St. Ferries Six Ferry Boats

U.S. LNG Powered Vessels Projected for the Gulf of Mexico, Great Lakes and Inland Waterways Over the 15 Year Period from 2014 to 2029. (1)

Gulf of Mexico:

•

| Vessel Type | Number of Vessels |
|-------------------|----------------------|
| Cargo, Carrier & | 9 New-builds |
| Container | 15 Conversions |
| Towboat & Tugboat | 68 New-builds |
| Offshore Support | 112 New-builds |
| Tanker | 15 New-builds |
| | 44 Conversions |
| Total | 204 New-builds |
| | 59 Conversions |
| Great Lakes: | |
| Vessel Type | Number of Vessels |
| Dry Bulk Carrier | 6 Conversions |
| Cargo & Container | 3 Conversions |
| Passenger | 1 New-build |
| | 1 Conversion |
| Towboat & Tugboat | 3 New-builds |
| Total | 4 New-builds |
| | 10 Conversions |
| Inland Waterways: | |
| Vessel Type | Number of Vessels |
| Towboat & Tugboat | 66 New-builds |
| Cargo | 1 Conversion |
| Offshore Support | 14 New-builds |
| Tanker | 1 New-Build |
| | 4 Conversions |
| Total: | 81 New-builds |
| | 5 conversions |

This amounts to an impressive grand total of 363 vessels in these three areas alone over this 15 year period ending in 2029. 80% of these are new-builds.

We have not yet identified long term U.S. LNG powered vessel projections for the Atlantic and Pacific areas. However as identified above, 13 additional vessels are already planned or under construction in these two additional areas:

Atlantic:

| Vessel Type | Number of Vessels |
|------------------------|------------------------------|
| Cargo & Container | 4 New-builds |
| Tanker | 4 New-builds |
| Army Debris Collection | 1 Conversion |
| Total | 8 New-builds 1 Conversion |
| Pacific: | |
| Vessel Type | Number of Vessels |
| Cargo & Container | 2 New-builds |
| | 2 Conversion |
| Total | 2 New-builds 2 Conversion |

This brings the total projected number of U.S. LNG powered vessels for all five areas by 2029 to at least 376.

VI. BHGI / TSGI Leadership

Five years ago Bristol Harbor Group, Inc. (BHGI) joined forces with The Shearer Group, Inc. (TSGI) through common ownership. Each company is a full service naval architecture and marine engineering firm specializing in commercial vessel design and consulting. As sister companies they are able to offer their clients enhanced capabilities through shared resources and expertise.

Over the past 22 years BHGI has produced more than 50 unique designs, to which more than 100 vessels have been built. They include barges, tugs, ATB/articulated tug-barges, passenger vessels, dredges, and yachts.

Over the past 27 years The Shearer Group, Inc. has evolved into a global leader in the design of inland towboats and barges. It has designed thousands of inland barges along with a myriad of towboat, dry dock and other specialty designs. In addition, the company is one of the only naval architecture and marine engineering members of The American Waterways Operators, Inc.

Bristol Harbor Group, Inc., and The Shearer Group, Inc., have been involved in LNG projects since 2009. Through our combined efforts, we are currently designing two of the twenty-eight LNG powered vessel designs listed on page 14 and two of the three active LNG bunker and transport barge projects that are essential to the LNG refueling infrastructure.

The BHGI / TSGI Design Process

Quality is an important part of engineering, and at Bristol Harbor Group, Inc. and The Shearer Group, Inc. our naval architects and marine engineers are experienced and trained not only in the applicable codes and regulations but also in the engineering fundamentals upon which they were developed.

Our engineering team follows strict document checking procedures. All drawings and calculations that leave either office. are checked by a senior or principal naval architect and marine engineer prior to release. This checking process ensures that all documents have at least "two sets of eyes" on them, and fosters a team approach for almost all of our projects.

Further, regular design review meetings are held to ensure that our naval architects and marine engineers are not working in a vacuum. With a core purpose "To Create," it is important to make sure that we are constantly innovating and pushing our work product to the limits. That said, our engineers also have much real world experience, enabling us to make sure that our designs are innovative, yet practical.

At BHGI and TSGI, we endeavor to over deliver to our clients. This does not mean that we over think issues, but rather that we deliver drawings with more detail than the client might be expecting, and calculation packages with more depth than the client has seen in the past. We do this because we have discovered that this is our preferred work method, i.e., this is what "floats our boat." We are not happy when drawings leave the shop with less detail than we think necessary. Therefore, we look for clients for whom this too is a priority, and those clients tend to make up our large repeat client base.

Our engineers are degreed naval architects and marine engineers with a passion for creating simple, efficient designs. Our team is client focused and we pride ourselves on our ability to communicate with clients. Simple, practical solutions to complex problems are our specialty.

Precautions for Safe LNG Vessel Design

As pointed out in Section II, LNG has been transported and used safely in the U.S. and worldwide for roughly 40 years. The LNG industry has an excellent safety record which is largely the result of three essential principles:

- The industry has technically and operationally evolved to ensure safe and secure operations.
- The physical and chemical properties of LNG are understood such that risks and hazards are mitigated by continuously improving technology and operating systems.
- The standards, codes and regulations that apply to the LNG industry have evolved to further ensue safety. (2)

During our six years of our leadership role in the design of U.S. LNG vessels, these principles have formed the basis of our design philosophy:

- Our LNG designs have technically evolved to ensure safe operations.
- Our engineers have been trained to understand the risks and hazards associated with LNG and continuously improve our technology and operating systems to mitigate them.
- Our engineers have gained not only an understanding of LNG codes and regulations, they also work with the regulatory bodies to provide improvements and clear interpretations.

We have embraced these principles because they are proven over 40 years of industry experience and they are consistent with our BHGI / TSGI design process.

In addition, we perform a Preliminary Risk Analysis for each LNG vessel design to examine LNG related components and systems to identify associated risks and risk controls. It is our intention that risks are eliminated whenever possible and that those that cannot be eliminated are mitigated. Our overall approach includes five steps:

- Configure each system specifically.
- Analyze each system independently taking into account system interactions.
- Identify associated risks or concerns.
- Examine risk mitigation controls already in place.
- Recommend appropriate additional controls.

The risk assessment methodology used is the same as that used by ABS. It systematically evaluates the following for each risk item:

- The Likelihood (On a scale from A to E)
- The Consequences (On a scale from 1-5)
- The Risk Level (On a scale from Low to High) (Based on Likelihood and Consequences)

Particular attention is paid to risks that could result in:

- Serious Injury to Personnel from Direct Contact with LNG.
- Serious Injury to Personnel from Asphyxiation.
- Formation of a Flammable Vapor Cloud Potentially Leading to Fire or Explosion.
- Brittle Fracture Damage to Steel Structures Exposed to LNG.

The Regulatory Process

Current waterfront regulations focus on import or export of large quantities of LNG as cargo. Further, current vessel regulations focus on gas fueled ships and are derived from LNG cargo ships with gas fueled plants. That said, a policy letter for LNG barges was released last month, CG-ENG Policy Letter 02-15, Design Guidance for Non Self-Propelled Vessels Carrying Liquefied Natural Gas in Bulk.

BHGI and TSGI are actively involved in shaping the regulations for LNG barges. Ed Shearer of TSGI sits on the Chemical Transportation Advisory Committee (CTAC) and BHGI has secured a design basis letter for their LNG Bunker Barge from the USCG prior to the release of the aforementioned policy letter. BHGI has been holding biweekly teleconferences with the USCG regarding the design of their bunker barge for the past six months, having delivered their initial design basis presentation to the USCG in November 2014. More recently, BHGI was involved in a HAZID / HAZOP workshop for their LNG Bunker Barge design, which is the first step towards USCG approval of the design, and involved subject matter experts from around the globe.

A brief sample of some of the codes, standards and guidelines for LNG vessels are as follows:

- CG-ENG Policy Letter 02-15 Design Guidance for Non Self-Propelled Vessels Carrying Liquefied Natural Gas in Bulk
- Interim Guidelines on Safety for Natural Gas-Fuelled Engine Installations in Ships (MSC.285(86))
- International Code of Safety for Ships Using Gases or Other Low Flashpoint Fuels (IGF Code) in development
- CG-521 Policy Letter 01-12 Equivalency Determination: Design Criteria for Natural Gas Fuel Systems
- CG-OES Policy Letter 01-15 Guidelines for Liquefied Natural Gas Fuel Transfer Operations and Training of Personnel on Vessels Using Natural Gas as a Fuel
- 46 CFR Parts 10, 11, 12, 13, and 15
 - o Crew Certification and Training Requirements
- ABS Guide for Propulsion and Auxiliary Systems for Gas Fueled Ships (ABS Guide)

Notes:

- Det Norske Veritas (DNV) published Rules for Gas Fuelled Engine Installations Aboard Vessels in January, 2010.
- The International Maritime Organization (IMO) is also currently developing International Standards. Interim Guidelines were published June, 2009.

 American Bureau of Shipping (ABS) recently released a report "Bunkering of Liquefied Natural Gas-Fueled Marine Vessels in North America" to provide guidance to potential owners and operators of gas-fueled vessels as well as LNG bunkering vessels and facilities.

Our LNG Powered Vessel Designs

As discussed earlier we are presently engaged in the design of two LNG powered vessels. The first is the design of a new 4,200 horsepower LNG towboat which is being powered by dual fuel diesel engines. The second is the repowering of a U.S. Army debris collection vessel which, due to the smaller size of its engines, is being powered by typical diesel engines coupled with natural gas-air fumigation systems. Although these vessels differ significantly, they both have similar integrated gas handling systems.

Our Integrated Gas Handling Systems

Both of our LNG powered vessel designs utilize Integrated Gas Handling Systems to safely store LNG and to manage critical LNG and gas related operations. Components of each of these systems include:

- Type C LNG Storage Tank
- Stainless Steel Tank Room Containing
 - o Bunkering System
 - o Tank Pressure Build-up System
 - Gas Supply System
 - o All Related Piping, Sensors and Safety Systems
- Electronic Control System

In both of our designs, the storage systems are located above deck, aft on the vessel. Our U.S. Army Corps of Engineers LNG repower design requires one integrated gas handling system and our LNG powered towboat requires two. An illustration of a representative integrated gas handling system is shown in Figure 6.



Figure 6. Typical Integrated Gas Handling System

The Type C tank is a double wall vacuum insulated pressure tank with a design pressure of approximatelly 8-9 bar. It is a proven design configuration and is supplied by an experienced tank manufacturer. The design of the tank's structure and supports account for marine related operational load requirements in accordance with IMO and ABS regulations. The inner tank is austentic stainless steel and the outer tank is carbon steel. It is equipped with boil off gas and thermal relief gas valves. This tank provides primary and secondary containment of the LNG.

The tank room is stainless steel and functions as a secondary barrier for the critical systems that it contains. It is structurally integral with the LNG tank and has a dedicated forced vantillation system and an automatic fail safe fire damper. A drain overboard is fitted that will open during bunkering to drain any potential bunkering related spill overboard.

Attached to the Tank Room is a cabinet containing the Gas Handling System and Electronic Control System. This system controls and helps manage every aspect of the Integrated Gas Handling system inclucing:

- The Bunkering System
- The Tank Pressures Maintenance System
- The Gas Supply System

The Bunkering System

As shown in Figure 7, our vessels can be refueled from:

- A Shore Based LNG Tank
- A Fuel Truck
- A Bunker Barge or Vessel



Figure 7. Bunkering Options (3)

Bunkering takes place directly to the bunkering manifold located in the Tank Room which is equipped with spill protection and an overboard drain. This eliminates the need for a separate bunkering station.

The bunkering process will be overseen by a properly trained operator. The control panel will be located in a safe location from the bunkering station. Independent high level and system failure alarms and effective ship to shore or ship to ship communications are in place.

The process is continuously controlled by the Tank Room Electronic Control System where tank level and pressure are monitored to prevent overfilling or over-pressurization. This system also monitors a variety of gas leak and other detection equipment in the Tank Room and other areas throughout the process.

Vapor Recovery

For clarity, the Bunkering System is illustrated schematically in Figure 8.

Figure 8. Tank Room Fuel Bunkering System

The bunkering process consists of seven basic steps:

- 1. Connect shore based piping to the bunkering manifold.
- 2. Inert the connected lines with nitrogen.

- 3. Cool the system tanks by introducing LNG through the spray fill manifold.
- 4. Initiate the LNG fuel transfer process.
- 5. Drain the lines once transfer is complete.
- 6. Purge remaining natural gas from pipes with nitrogen.
- 7. Disconnect shore based lines from bunkering manifold.

During bunkering operations, the system is arranged so that no gas is discharged to the air. Most of the LNG is received through the bottom fill pipe: however, some can be received through the spray header which serves to cool gas at the top of the tank and thus reduce tank pressure. The vapor return line returns evaporated gas to the bunker supplier and if needed can also be used to balance pressure between the delivering and receiving tanks.

The Tank Pressure Maintenance System

The Pressure Maintenance System maintains pressure in the LNG tank. During times when the vessel is idle, natural gas is not being consumed by the engines and pressure in the LNG tank can gradually build as heat from the atmosphere warms the LNG. If this happens, relief valves in the top of the tank vent natural gas to the atmosphere through the vent mast to maintain pressure within safe limits.

During times when the engines are consuming natural gas, pressure in the tank is generally reduced. For this reason, prior to initiating gas flow into the Gas Supply System, the Pressure Build-Up Evaporator is started to bring the pressure in the LNG tank to the required level. The Pressure Build-Up System then maintains LNG Tank at that pressure as natural gas is consumed by the engines. Tank pressure maintenance is also controlled by Tank Room Electronic Control System.

For clarity, the system is illustrated schematically in Figure 9.



Figure 9. Tank Pressure Build-Up And Relief System

The function of each component of the Tank Room Pressure Build-Up System follows:

- The Pressure Build-Up System **Isolating Valve** is shown directly to the right of the Pressure Build-Up Evaporator. It is a pneumatically remote controlled shut-off device.
- A **Pressure Activated Valve** just upstream of the Pressure Build-Up Evaporator initiates and maintains flow into the system whenever the LNG Tank Pressure is below the preset level.
- **The Pressure Build-Up Evaporator** builds up and maintains a preset pressure in the LNG Tank when activated. It accomplishes this by evaporating LNG and returning the resultant natural gas to the top of the LNG Tank.
- A **Pressure Relief Valve** vents outgoing natural gas to the Vent Mast when the pressure of the outgoing natural gas exceeds a preset limit.

The Gas Supply System

The Gas Supply System is a very critical component of this overall system. Its function is to provide a reliable supply of gas at the appropriate pressure needed by the propulsion system. This process is

continuously controlled by the Tank Room Electronic Control System. For clarity, a representative arrangement of this system is illustrated schematically in Figure 10.



Figure 10. Gas Supply Systems

The function of each component of the Tank Room Gas Supply System follows.

- The **Master Isolation Valve** is shown directly to the right of the Evaporator. It is located as close as possible to the LNG Tank and is a pneumatically remote controlled shut-off device. It is activated automatically in the event of abnormal situations including leakage anywhere in the system, etc.
- The **Main Gas Evaporator** evaporates the LNG liquid to natural gas. It is designed to ensure a stable gas pressure during all phases of intense evaporation.
- A **Back Pressure Valve** is positioned just after the evaporator to allow natural gas from the LNG tank to enter the gas stream just before it enters the heater.
- The **Safety Relief Valve** is positioned just after the Gas heater and opens to vent gas to the Vent Mast if the pressure is above a preset level.
- The **Gas Heater** heats the gas to the temperature range required.
- A **Pressure Gauge** and a **Temperature Gauge** are located just after the Gas Heater and provide input to the Control System.

- The **Master Fuel Gas Valve** is directly after the Gas Heater. It is a pneumatically remote controlled shutoff device that can be activated as needed by the control system.
- A **Slam Shut Regulator** regulates pressure and slam shuts off gas flow if the pressure its upper limit.

There are multiple third party vendors capable of providing Integrated Gas Handling Systems. These include TGE and Wartsila. Such systems already are approved for and have proven reliability on shipboard installations. Additional advantages offered by such systems include:

- Separate Construction and Easy Installation.
- No Additional Secondary Barrier Required.



Our LNG Powered 4,200 HP Towboat Design

Figure 11. TSGI LNG Towboat ELLEN G.

The Shearer Group, Inc. (TSGI), has developed the design of a Liquefied Natural Gas (LNG) powered 4,200 horsepower towboat in collaboration with Conrad Shipyard, LLC. This design has already been awarded an "Approval in Principle" (AIP) by the American Bureau of Shipping (ABS). The potential for the concept to blossom in this largely fixed, point-to-point market is very real with over 130 U.S. LNG powered towboats and tugs projected by 2029. (1)

The towboat is based on TSGI's proven azimuth drive (z-drive) towboat design that debuted in 2008. Eight of these towboats, which also pioneered the use of z-drives for inland with towing operations, have been built for Southern Towing Company, where significant fuel savings relative to conventional towboats have been well documented.

The Integrated Gas Handling System

As described above, LNG for this vessel will be stored and supplied by two integrated gas handling systems located on the main deck aft. Components of these systems include:

- Type C LNG Storage Tanks
- Stainless Steel Tank Rooms Containing:
 - o A Bunkering System
 - o A Tank Pressure Build-up System
 - A Gas Supply System
 - o All Related Piping, Sensors and Safety Systems
 - o An Electronic Control System

The Dual Fuel Diesel Engines

Our LNG powered towboat design capitalizes on Wärtsilä's proven dual fuel technology. A primary benefit of this technology is that conventional marine diesel fuels can also be used if required. The switch between fuel types is made seamless without a loss of power or speed.

While Wärtsilä's existing dual fuel engines are medium speed diesels, it is anticipated that future engine developments will result in lighter and smaller high speed units. Our design is flexible enough to allow for the use of either of these engine options as well as options available from other manufacturers.

The Wärtsilä system specified is a smaller version of the system currently installed on the Harvey Gulf Offshore Support Vessels (OSV). It is important to note that a conventional towboat is not diesel-electric like an OSV. Diesel-electric applications are perfect for LNG adoption because they allow the prime movers to run at constant speed. We have mitigated this with our towboat design by using dual fuel engines which reduce the throttle lag, and z-dives which allow for more control at a given throttle setting. In fact to go from full forward to full reverse with a z-drive, you do not adjust the throttle setting at all, you simply rotate the thruster 140 to 150 degrees.

Perhaps the biggest selling point for the new concept is that the new design removes the risk from early adopters because this design is based totally on proven technologies. Moving to a z-drive design would be a risk for many operators on its own. However, using our proven z-drive design as the basis for our LNG towboat design, we have mitigated that risk. Further, Wärtsilä's dual fuel engines and their LNG storage and delivery system have been proven (or are being proven) domestically by Harvey Gulf and in numerous cases internationally. Our towboat employs the same basic system architecture, which has been accepted by U.S. regulators. By combining these two proven technologies, we are able to remove the design risk.

With Approval in Principle in hand, we know that the basic design is acceptable to ABS. Further, we know that ABS and USCG work hand in hand on many of these projects, and thus we infer that the major design issues are also acceptable to USCG. That said: the next step is to submit class drawings to ABS and USCG for review and approval. We expect that USCG will limit their review to the LNG storage and supply systems, as well as fire and safety plans. ABS on the other hand will review all structure and systems.

One of the variables that has been a sticking point for LNG propulsion – especially for smaller hulls – is the proximity of the LNG bunker tanks to the accommodations. In the case of an inland towboat, this is especially evident. The design team worked around this issue by locating the tanks in open air above the machinery space and sufficiently aft of the accommodations space. Structural fire protection is provided along with adequate buffer zones to meet Class requirements for the storage tank location.

This kind of forward-thinking design effort simply can't be done in a vacuum. Collaboration was important in the design of the new towboat. Conrad Shipyard, LLC established in 1948 and headquartered in Morgan City, LA, had a big hand in moving the LNG towboat concept forward applying its many years of experience to arrive at a buildable, efficient design. In addition, the development team included a series of piping, valve, and tank manufacturing companies with vast experience in the design, development and installation of their products.

U.S. Army LNG Repower Design

Figure 12. U.S. Army *Driftmaster*



Figure 13. Driftmaster Engine Room

Bristol Harbor Group, Inc. has a design contract with the U.S. Army Corps of Engineers to develop a design to convert one of its vessels to LNG power. The Corps have narrowed their search to the *Driftmaster*, a drift or debris collection vessel, because it has room for additional fuel tanks and its duty cycle allows for flexibility in fueling. When (and if) converted, the *Driftmaster* will serve as an R&D vessel to study the suitability of LNG as a fuel for other U.S. Army Corps vessels.

The diesel engines required to power the *Driftmaster* are smaller than any presently available dual fuel diesel engines. As a result, the solution selected for dual fuel conversion of the *Driftmaster* is to add an Air Fumigation System to each main propulsion diesel engine. Such fumigation systems enable the diesels to run on a combination of diesel fuel and natural gas with over half of the power from natural gas.

The Integrated Gas Handling System

As described above, LNG for this vessel will be stored and supplied by an integrated gas handling system located on the main deck aft. Components of this system include:

- A Type C LNG Storage Tank
- A Stainless Steel Tank Room Containing
 - o A Bunkering System

- o A Tank Pressure Build-up System
- o A Gas Supply System
- o All Related Piping, Sensors and Safety Systems
- An Electronic Control System

The Air Fumigation System

Simply stated, an air fumigation system meters a small amount of natural gas into the induction system of a diesel engine. This dual fuel configuration does not change any of the original equipment manufacturer (OEM) diesel engine components and monitors diesel engine compliance with OEM system parameters. The OEM diesel engine control system and controller governor remain unaltered and in control of the engine and automatically act to reduce diesel fuel flow as natural gas is introduced. The result is a diesel fuel substitution of 40% to 60% natural gas for significant reductions in diesel fuel costs. With input data from sensors throughout the system, the air fumigation system automatically delivers the correct mix of air to natural gas to the engine air intake system for all throttle settings.

The air to fuel ratio maintained by these systems is maintained at a maximum of approximately 2% which is well below the 5% lower explosive limit of methane gas.

Figure 14 provides a schematic illustration of a representative Air Fumigation System as may be configured for the *Driftmaster* engine room.



Figure 14. Fumigation System (20)(22)

The function of each component follows:

- The Manual Shutoff Valve provides a manual means for turning off the flow of natural gas.
- The Filter eliminates particulate infiltration over 50 microns.
- The Vapor Draw Regulator maintains the gas pressure supply at very near atmospheric.
- The **Dual Shutoff Solenoid valve** allows for gas flow to be smoothly increased over a short period of time while transitioning from diesel to dual fuel and for automatic gas flow shutdown when required.
- The **Electronic Throttle Body** fine tunes gas flow to the system.

There are multiple third party vendors capable of supplying air fumigation systems for diesel engines. These include GFS, Altronic, and American Power Group. Such systems have proven reliability in land based installations (particularly in oil field and Frac installations) yet none has yet been adapted to and approved for shipboard installations.

As we considered the application of air fumigation systems to a marine environment, five modifications were made to mitigate the risk of possible gas leaks in the engine room:

- Engine room piping is of double wall construction with a nitrogen purge.
- Gas train components are enclosed in a gas tight enclosure.
- The slam shut regulator is relocated to the tank room to minimize the number of gas train components in the engine room.
- Enhanced engine room ventilation has been added.
- Gas detectors have been added.

Our LNG Bunker and Transport Barge Designs



LNG Bunker Barge Design (Membrane Tank)

Figure 15. BHGI LNG Bunker Barge

WesPac Midstream LLC (WesPac), a provider of energy infrastructure and liquefied natural gas (LNG) solutions, and its affiliate Clean Marine Energy LLC (CME), the global facilitator of tailored solutions for Emission Control Area (ECA) compliance, announced a construction contract with Conrad Orange Shipyard, Inc., a division of Conrad Shipyard, LLC, to build the first dedicated LNG bunker barge for the marine market in North America. This barge will be a critical supply chain component in ongoing efforts around the world to reduce the environmental impact of maritime activity through the conversion of ships to LNG.

The first 2,200 cubic meter (cbm) barge is expected to be delivered in early 2016 and planned to initially be deployed in Tacoma, Washington, to service ship owner Totem Ocean Trailer Express's Orca class RO/RO vessels, in addition to other LNG-powered vessels. Subsequently the barge will be relocated to Jacksonville, Florida to serve TOTE's (parent company to Totem Ocean) new build Marlin class container vessels and other LNG-powered vessels in the Port of Jacksonville.



Figure 16. Contract Signing

The LNG barge will feature one tank equipped with MARK III Flex cargo containment technology, from the French engineering and technology company GTT (Gaztransport & Technigaz), to be constructed by Conrad Orange Shipyard, Inc. under GTT license. Bristol Harbor Group, Inc. will be responsible for the vessel's design, with the American Bureau for Shipping (ABS) acting as the classification society.

This initial bunker barge for TOTE is part of the WesPac/CME plan to provide an integrated LNG solution for engine conversion, infrastructure, supply, and delivery logistics to the shipping industry. As more U.S. Jones Act shipowners and operators seek to meet stringent 0.1 percent sulfur limits within ECAs by converting to LNG as a cleaner bunker fuel, WesPac/CME plans to exercise its options with Conrad to construct additional LNG fueling barges to serve other North American ports.

GTT Mark III System



Figure 17. GTT Mark III System (18)

MARK III Membrane System is a cryogenic liner directly supported by the barge's inner hull. This liner is composed of a primary metallic membrane positioned on top of a prefabricated insulation panel including a complete secondary membrane:

Primary stainless steel

The primary membrane is made of corrugated stainless steel 304 L, 1.2 mm thick. It contains the LNG cargo and is directly supported by and fixed to the insulation system. Standard size of the corrugated sheets is 3m x 1m.

Secondary triplex

The secondary membrane is made of a composite laminated material: a thin sheet of aluminum between two layers of glass cloth and resin. It is positioned inside the prefabricated insulation panels between the two insulation layers.

Insulation

The insulation consists of a load-bearing system made of prefabricated panels in reinforced polyurethane foam including both primary and secondary insulation layers and the secondary membrane. The standard size of the panels is 3 m x 1 m. The thickness of the insulation is adjustable from 250 mm to 350 mm to fulfill any boil off gas requirement. The panels are bonded to the inner hull by means of resin ropes which serve a double purpose: anchoring the insulation and spreading evenly the loads. (18)

Reliability

The corrugated membrane technology continuously improved since 1967 is approved by all the major classification societies. It benefits from more than 30 years of experience at sea.

Safety

The two independent insulation spaces are continuously flushed with nitrogen gas. The integrity of both membranes is permanently monitored by detection of hydrocarbon in the nitrogen.

Zero stress concept

The orthogonal corrugation pattern enables the membrane to accommodate any thermal or hull deflection stresses and to work under the fatigue limit thus providing outstanding lifetime.

Negligible edge loads

Because of low stress on the primary membrane, prefabricated foam corner panels can be used to anchor the membrane to the hull thus minimizing thermal flux.

High resistance

An insertion of fiberglass in the thick of the polyurethane foam gives high mechanical properties to the panels. The high density of the foam and the plywood covering both sides of the panels – for an even load distribution – allow the insulation to withstand high impact pressures and absorb the energy resulting from liquid motion.

Compactness

The low thermal conductivity of the foam and of the corners results in a thin insulation; thus maximizing the cargo capacity for any ship external constraints.

Modular concept

This modular system calls for standard prefabricated components that can accommodate any shape and capacity of tanks and are designed for mass production techniques and easy assembly. (18)

LNG Transportation Barge Design (Type C Tank)



Figure 18. BHGI LNG Transportation Barge

BHGI has developed a 3,000 cubic meter Liquefied Natural Gas (LNG) transport barge for Conrad Shipyard, LLC. This design utilizes one of BHGI's proven oil barge hull designs. Bristol Harbor Group has been awarded an "Approval in Principle" (AIP) by the American Bureau of Shipping (ABS) for the design.

BHGI has a decade long relationship with Conrad Shipyard, LLC which has constructed many coastal liquid cargo barges from 26,000 BBL to 80,000 BBL to BHGI designs. It is the 300' version of these successful double hull oil barges that serves as the basis for this LNG Transport Barge, which can easily be scaled to 4,000 cubic meters as needed.

This new design will serve the purpose of primarily transporting LNG in blue water along the United States coastline. Storage containment consists of four Type C pressure tanks, all equally sized at 750 cubic meters. The tank design offers suitable hold times for cargo transport without the need for reliquefaction. The design is focused on constructability and ensuring cargo safety.

VII. Conclusions

BHGI and TSGI believe that LNG is likely to be the choice for many ships operating in and around the United States ECA because of its advantages versus diesel:

- Safe Proven by years of demonstrated safe marine operations.
- Clean Meets and exceeding new North American ECA standards.
- Available Estimates show almost unlimited North American Supply.
- Cost Effective Significantly less than diesel fuel options.

Positing that this is true and that LNG or dual fuel vessels are adopted by U.S. operators, significant investment in infrastructure will be required in order to support said vessels. Primary elements consist of waterfront liquefaction facilities, LNG transport barges that enable remote waterfront LNG refueling facilities and bunker barges that facilitate LNG refueling simultaneously with cargo loading or unloading operations.

As noted herein, BHGI and TSGI have taken a leadership role in this field by engaging in several different LNG projects, including one that is currently under construction at Conrad Shipyard, LLC's Orange facility in Orange, Texas.

For more information please visit our websites at, bristolharborgroup.com and shearer-group.com, or contact Greg Beers, P.E. at (401) 253-4318.

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- Wartsila Corporation
- American Power Group, Inc.
- Altronic LLC

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Note that vessel photos included in this document are from publically released documents of respective vessel owners, shipping lines or builders.