NATURAL GAS TOWBOAT DEMONSTRATION PROJECT

FINAL REPORT

Submitted to: Maritime Administration
1200 New Jersey Avenue, SE
Washington, DC 20590

Prepared by: Pittsburgh Region Clean Cities
1436 Royal Park Blvd
South Park, PA 15129

The Shearer Group
3118 Harrisburg Blvd, Suite 100
Houston, TX 77003

“O”Ring CNG
5349 Route 36
Coolspring, PA 15730

Clipper Enterprises, LLC
P.O. Box 10668
Pittsburgh, PA 15235-9998

Life Cycle Engineering, Inc.
859 Missionary Drive, Suite 210
Pittsburgh, PA 15236

Date: December 13, 2019

TABLE OF CONTENTS

1 Executive Summary 1

1.1 Overview 1
1.2 Project Proposal/Objectives 2
1.3 Summary of Results and Findings 5

2 Oceangoing/Inland Introduction 6

2.1 Background 7
2.2 Objective 7
2.3 Historical Perspective 7
2.4 Terminology 8
2.5 Prior Work 9
2.6 Proposed Effort 9

3 Natural Gas Conversion 10
4 Technology Options 11

4.1 Engine Technology 11
4.2 Fuel Storage Technology 13
4.3 Environmental Impact 13
4.4 U.S. Coast Guard (USCG) 14

4.4.1 Natural Gas Code 15
4.4.2 Subchapter M 15

4.5 Environmental Protection Agency (EPA) 16
4.6 International Maritime Organization (IMO) 17
4.7 National Fire Protection Association (NFPA) 17

5 Classification Societies 17

5.1 American Bureau of Shipping (ABS) 18
5.2 Det Norske Veritas – Germanischer Lloyd (DNV-GL) 18

6 Project Evolution 18

6.1 Kick-Off/Initial Plan of Attack 19
6.2 Project Timeline Discussion 19
6.3 *M/V RON-CHRIS* & *M/V PRINCIPIO* Design 21

6.3.1 *M/V RON-CHRIS* As-Is 21
6.3.2 *M/V PRINCIPIO* As-Is 22
6.3.3 Design Concept 23
6.3.4 Design Challenges 23
6.3.5 Technology Insertion Discussion – CNG Tank Gap Analysis 25
6.3.6 Equipment Quotes 26

6.4 USCG Interaction 26
6.5 Hybrid Design Concept 27
6.6 Catastrophe 28
6.7 Replacement Boat/s 28

6.7.1 Gulf Materials - *M/V TIMMY* and *M/V OKAN* 29
6.7.2 Survey 30
6.8 Port of Pittsburgh 30
6.9 Barge Operator Perspective 30
7 Summary, Conclusions and Recommendations 32
7.1 Summary of Drivers for Natural Gas Conversion – Oceangoing vs. Inland 32
7.2 Inland Waterway Market Changes 32
7.3 Natural Gas Regulation Discussion 33
7.4 Regulatory Challenges 33
7.5 Recommendations 35
Appendices A-1
Appendix A Dual Fuel Inland Towboat, Basis of Design A-1
Appendix B Dual Fuel Inland Towboat, Preliminary Risk Analysis B-1
Appendix C (TSGI Letter to USCG) Equivalency Considerations for Storage Tank and Bunkering Connections C-1
Appendix D (TSGI Letter to USCG) Equivalency Considerations for Dry Chemical Fire Protection D-1
Appendix E (TSGI Letter to USCG) Equivalency Considerations for Class1/Div.2 Rating of Solenoid Valves. E-1
Appendix F (TSGI Letter to USCG) Equivalency Considerations for Double Block and Bleed Valve Configuration F-1
Appendix G (TSGI Submission to USCG) *M/V RON-CHRIS*, Basis of Design & Preliminary Risk Assessment G-1
Appendix H (TSGI Submission to USCG) *M/V PRINCIPIO*, Basis of Design & Preliminary Risk Assessment H-1
Appendix I (TSGI Submission to USCG) *M/V PRINCIPIO*, Drawing Package and Equivalency Letters (1 of 3) I-1
Appendix J (TSGI Submission to USCG) *M/V PRINCIPIO*, Drawing Package and Equivalency Letters (2 of 3) J-1
Appendix K (TSGI Submission to USCG) *M/V PRINCIPIO*, Drawing Package and Equivalency Letters (3 of 3) K-1
Appendix L (TSGI Submission to USCG) *M/V PRINCIPIO*, Altronic GTI Bi-Fuel System: FMEA and PSTP L-1
Appendix M (USCG Response to TSGI) *M/V RON-CHRIS*, LNG Conversion Project Regulatory Assessment M-1
Appendix N (USCG Response to TSGI) *M/V PRINCIPIO*, LNG Fuel System N-1
Appendix O (USCG Response to TSGI) *M/V PRINCIPIO*, LNG Piping Systems O-1
Appendix P (USCG Response to TSGI) *M/V PRINCIPIO*, Hazardous Area Plan, Gas Detection System, Alarm and Monitoring System P-1
Appendix Q (USCG Response to TSGI) *M/V PRINCIPIO*, General Arrangement, Structural Fire Protection and Structures Q-1
Appendix R (USCG Response to LCE) *M/V PRINCIPIO*, LNG Tank Equivalency R-1
Appendix S (USCG Response to TSGI) *M/V PRINCIPIO*, Fire Suppression and Water Spray Systems S-1

Appendix T	(USCG Response to TSGI) *M/V PRINCIPIO*, Natural Gas Fuel Piping and Ventilation Systems T-1
Appendix U	(USCG Response to TSGI) *M/V PRINCIPIO*, Failure Modes and Effects Analysis, Periodic Safety Test Procedures U-1
Appendix V	Design Concept Details....... V-1
Appendix W	Technology Insertion Discussion – CNG Tank Gap Analysis W-1
Appendix X	M/V RON-CHRIS Conversion Equipment Quotes X-1
Appendix Y	Hybrid Design Concept....... Y-1
Appendix Z	Replacement Boat Surveys Z-1

LIST OF FIGURES

Figure 1: Port-side view of M/V RON-CHRIS 21
Figure 2: Starboard-side view of MPDE on board M/V RON-CHRIS 22
Figure 3: Starboard-side view of M/V PRINCIPIO 22
Figure 4: Port and Starboard Engines on M/V PRINCIPIO 23
Figure 5: Reintjes Hybrid Drive System....... 27
Figure 6: M/V PRINCIPIO on Dry-dock 28
Figure 7: Bow View of the M/V OKAN 29
Figure 8: View of M/V TIMMY during Barge Operations 30

LIST OF ACRONYMS

ABS	American Bureau of Shipping
AIP	Approval in Principle
ASME	American Society of Mechanical Engineers
C	Celsius
CARB	California Air Resources Board
CBA	Cost-Benefit Analysis
CFCR	Clean Fuels/Clean Rivers
CFR	Code of Federal Regulations
CNG	Compressed Natural Gas
CO_2	Carbon Dioxide
DNV	Det Norske Veritas
DOC	Diesel Oxidation Catalysts
DOT	Department of Transportation
ECA	Emission Control Area
EPA	Environmental Protection Agency
ESD	Emergency Shutdown
GHG	Greenhouse Gas
GL	Germanischer Lloyd
HSFO	High Sulfur Fuel Oil
HP	Horsepower

HPDI	High Pressure Direct Injection
IGF	International Code of Safety for Ships using Gases or other Low-flashpoint Fuels
ICG	International Code of the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk
IMO	International Maritime Organization
LCE	Life Cycle Engineering
LNG	Liquefied Natural Gas
LPDI	Low Pressure Direct Injection
MARAD	Maritime Administration
MARPOL	The International Convention for the Prevention of Pollution from Ships
MGO	Marine Gas Oil
M/V	Motor Vessel
NFPA	National Fire Protection Association
NG	Natural Gas
NO_X	Nitrogen Oxide
OCMI	Officer in Charge, Marine Inspection
OSHA	Occupational Health and Safety Administration
PM	Particulate Matter
PNG	Peoples Natural Gas
POP	Port of Pittsburgh Commission
PRCC	Pittsburgh Region Clean Cities
PSI	Pounds per Square Inch
ROI	Return on Investment
SAE	Society of Automotive Engineers
SME	Subject Matter Expert
SO_X	Sulfur Oxide
TOTE	Totem Ocean Trailer Express
TSGI	The Shearer Group, Inc.
TSMS	Towing Safety Management System
ULSD	Ultra Low Sulfur Diesel
USCG	U.S. Coast Guard
VLSFO	Very Low Sulfur Fuel Oil

1 EXECUTIVE SUMMARY

1.1 Overview

Natural gas has been proposed as an alternative fuel for marine transportation for the past 10 to 15 years. As the marine industry seeks alternatives to burning diesel, there has been increased attention on over-the-highway fuels as cleaner burning fuel alternatives. The inland towing industry is no exception. One of the earliest documents evaluating the opportunity for use of natural gas was a 2012 study published by American Clean Skies Foundation[1]. This study provides details and challenges with converting U.S. inland marine vessels (workboats) to natural gas, specifically liquefied natural gas (LNG).

In early 2012, Pittsburgh Region Clean Cities (PRCC) partnered with People Natural Gas (PNG) to explore the effectiveness of using natural gas as a fuel for Pittsburgh region workboats. The exploration evaluated natural gas fuel storage choices, engine types, and operator preferences for a small, 98-foot single engine propelled towboat that was built in 1934. Workboats, such as the one detailed in the study, are prevalent within the Pittsburgh region, operating between locks on the inland waterway network that included the Allegheny, Monongahela and Ohio rivers. Several conclusions emerged from this effort:

- LNG was the clear choice for storage because of energy density and fueling complexity;
- Dual fuel operations was essential to ensure that the operator could switch back to diesel in case LNG was not available;
- Marine engine availability in this horsepower range for either dedicated or dual fuel technologies was limited; and
- Regulations were evolving and requirements would be stringent to ensure that natural gas was as safe as diesel fuel.

In June 2015, this exploratory work was followed up by a study published by the Port of Pittsburgh Commission[2] (POP) that evaluated the Pittsburgh Marine Corridor to assess the feasibility of converting the regional inland waterways fleet to natural gas. The project was funded by local foundations with an interest in determining whether there were opportunities for economic development and cleaner fuels. The goals of the study were to:

- Explore the creation of a natural gas marine corridor in the Pittsburgh region;
- Increase awareness of natural gas as a marine fuel;
- Expand the potential of natural gas to the inland waterways;
- Evaluate natural gas as an alternative fuel for towboat operators reducing reliance on expensive diesel fuel; and
- Determine whether sufficient natural gas fueling infrastructure exists.

The study resulted in a comprehensive evaluation of natural gas as a fuel for the inland waterways including defining applicable technologies, business drivers, safety and regulatory analyses, and

[1] Natural Gas for Marine Vessels, U.S. Market Opportunities, American Clean Skies Foundation, April 2012
[2] Pittsburgh Marine Corridor Natural Gas Conversion Feasibility Assessment, Port of Pittsburgh, June 2015

fueling requirements and nexus point opportunities for other transportation modes to benefit from shared fueling infrastructure. Six key recommendations resulted from the study:

1. Create a more appropriate ruleset for smaller vessels, vessels with smaller fuel capacity, or vessels operating within a restricted geographical region (i.e. the inland waterways)
2. Allow for the acceptance of cross-industry standards for similar designs and applications.
3. Revisit the classification of "Major Modifications", especially for older vessels.
4. As the price differential between diesel and natural gas increases, use the efforts of this project as a baseline from which future companies or research teams can start again.
5. Revisit the project should additional/stricter changes in emissions regulations come into effect.
6. Revisit the project should improvements in onboard technology (storage or use of natural gas) have the potential to prevent major design and vessel operational changes.

The study concluded that to make an impact in the Pittsburgh region and in the inland waterways, conversion of these older and smaller vessels would need to be demonstrated to make any impact on the inland waterways in the areas of emissions and/or fuel economics. The Clean Skies study used cost scaling of larger project costs to estimate the work. This study concluded that as with many current inland towboat technologies, adaptation of shore side technologies may make these projects affordable.

During this same timeframe, the U.S. Maritime Administration (MARAD) advertised funding opportunities for vessel demonstration projects focused on a conversion to natural and vessel energy conservation. The objective of the funding opportunities was to gather data on potential emissions reductions and the effectiveness of technologies. PRCC submitted proposals under the funding opportunities and was awarded for a natural gas pilot demonstration project on the inland waterway. A cooperative agreement between MARAD and PRCC was executed in September 2015.

This report captures the activities and associated lessons learned with the demonstration project. Unfortunately, due to emergent and unforeseen challenges throughout the project period, such as the emergent international standards and codes as well as domestic regulations, the demonstration had to be halted.

1.2 Project Proposal/Objectives

This project represented the first inland waterways project in the U.S to convert a towboat to natural gas. PRCC considered proposing it because it represented a gateway project that if successful, it would open the door to deploy new and emergent dual fuel technologies and dedicated natural gas engine. In other words, this project could provide information and options for others in the industry that were considering other fuel choices. As the Blue Skies Foundation report concluded:

> "*Successful projects will require both a motivated vessel owner and a motivated LNG supplier. Given significant first-mover disadvantages, initial projects may also require government intervention to offset some*

of the cost of vessel conversion and/or LNG infrastructure development, in the context of promoting greater use of domestic fuels for transportation. After one or more vessel conversions within a given geographic area, further vessel conversions will become easier to justify on economic grounds."

At the onset of the project, we had both a motivated vessel owner and LNG supplier and also had MARAD step in to help offset the initial demonstration project. Conversion technologies were proposed based on available funding and beliefs that government regulatory bodies would permit reasonable and sound engineering decisions to complete the demonstration project. As the project evolved, however, it became clear that additional hurdles that were put into place due to emergent international marine standards and codes based on ocean going vessels as well as domestic regulations such as U.S. Coast Guard (USCG) Subchapter M would make this project unachievable for the project cost and timeline as it evolved. As always, time has a way of changing the principle paradigms that were in place when this project was initiated. This report summarizes the work completed and also the challenges that this project continued to face.

Some in the marine industry believe converting terminal towboats (smaller workboats) can be challenging for a number of reasons. The two most often cited concerns are 1) technology availability for smaller-scale installation and 2) the ability to scale the installation cost for the smaller fuel-consuming vessels. There is limited natural gas conversion technology readily available for smaller scale terminal towboats because the majority of the equipment, such as LNG tanks, gas valve units, and engines are designed for larger-scale line haul vessels. However, there are over-the-highway LNG technologies that can be "marinized" to meet inland river operational requirements. This project planned to innovate and develop the scaled technology solutions for smaller vessel operations and help quantify the exhaust emissions reductions that can be achieved through the use of this alternative fuel technology.

The most often cited significant entry barrier to operators is the cost of conversion because the costs for larger vessel installations are not readily scalable. When combined with the fact that the amount of fuel used by an inland terminal towboat is much less than fuel used by the larger inland line haul towboats, the payback period for conversion to natural gas can be much longer. This is especially true when the differential cost between natural gas and diesel fuel is lower. This demonstration project was proposed to be an essential part of helping to reduce conversion costs and effectively show the cost benefits to smaller vessel operations. The project proposed to create the required design and integrate scaled components that meet all local, state, and federal regulatory requirements as well as help answer other key questions that are essential for natural gas conversions, especially regional or terminal workboats. Key questions that were to be resolved included:

- Is fumigation technology (insertion of natural gas into combustion air stream prior to cylinders) effective in inland marine propulsion applications?
- How much cleaner is dual fuel natural gas engine operation than the same diesel engine in the same service?

- Can a cost-effective conversion package be developed for inland towing vessels under 1,500 horsepower?
- What is a realistic substitution rate (ratio of the substitution of natural gas for diesel fuel) for natural gas using fumigation methods at various operating load points for inland towing vessels under 1,500 horsepower?

The marine community is distinctly missing real data from a conversion project that relates to terminal-type vessels on the inland waterways. This category of vessel represents over 50 percent of the towboats in use on the United States inland waterways. These vessels typically operate within a limited geographic area moving small numbers of barges between local landings, making up tows, and shifting barges. From an emissions perspective, because these vessels tend to operate in a specific area, they are a mobile source that operates more as a point source. Their operating cycle/profile consists mainly of low load operations and idling, which can generate higher levels of particulate matter (PM) emissions among other things.

This project started with the design of a replacement natural gas system for the *M/V RON-CHRIS*. PRCC made the decision to change the vessel to the *M/V PRINCIPIO* based on operational and technical considerations. It should be clearly noted that after the likelihood of the *M/V PRINCIPIO* undergoing modifications became low, due to unforeseen owner/operator issues, it was determined that a replacement with a newer vessel would also be accompanied by application of the newer regulations.

The vessel initially chosen for this project was the *M/V RON-CHRIS*, owned by Walden Industries, Inc. The plan was to convert only one engine to natural gas using fumigation technology that is capable of up to 60-70 percent substitution of natural gas. This single engine conversion was proposed because it would provide a unique side-by-side, direct performance comparison between the same type of engine, using different fuels. For fueling of the vessel chosen and modification to burn natural gas, the project would have relied on the use of all existing or modified fueling infrastructure while still meeting existing applicable regulations.

M/V RON-CHRIS and later *M/V PRINCIPIO* was selected because it is representative of the approximately 260 vessels that operate within the Pittsburgh region. Fumigation for natural gas conversion was selected not because it was the optimum natural gas technology, but because the conversion cost was affordable considering the bulk of the effort is the process of getting natural gas approved for fuel use on the engine and the limited availability of natural gas engines in this lower power range. The Clean Skies Foundation study indicated a vessel of this size would require $1.5 - 2M for a complete gas system and replacement engines – after non-recurring design costs fumigation insertion could potentially be $600K when applied to the existing engines, which would improve the Return on Investment (ROI) for future projects.

Pre-conversion exhaust emissions measurements were to be taken both with and without natural gas so that vessel operation modeling can be done in the future. Also, it was proposed to map the engine and vessel performance at the different natural gas substitution rates at varying loads both with and without diesel oxidation catalysts (DOC) installed. It was expected that a DOC would reduce nitrogen oxide (NO_X) and PM emissions overall.

1.3 Summary of Results and Findings

There are some clear results and findings from this project. From the start, the perspective of making natural gas fuel insertion as viable as diesel fuel was daunting on inland water vessels considering the vessels in use. To begin with, these vessels are designed to work in calm river water and close locations and their smaller size makes available space a premium. Until Subchapter M, these vessels were "uninspected" (see 4.4.2) and unclassed by any classification societies or regulatory bodies. Age and condition of terminal vessels on the rivers vary with the size and operation of each owner/operator. While this poses a unique challenge, it also promised many opportunities.

Unforeseen issues and changes in regulations and business conditions, and a long design approval process, adversely affected the project timing, and ultimately the project as originally envisioned had to be terminated. Timing of a project is often paramount to the success of any project. Even though the series of unfortunate events led to a decision to ultimately terminate the project, the work that was accomplished can be used as a building block for future efforts.

In summary, the project was started during a time when the natural gas regulations for a fuel were evolving in the international marine community based on what was seen as a requirement for ocean going vessels. At the start of the program, neither engines nor fuel tanks were available in the size range required for this project. Therefore, fumigation technology was selected for gas supply and commercial over-the-road DOT approved tanks were chosen for gas storage. At the same time, international regulations were coming into being and the USCG became less flexible to consider these options.

As the design evolved for the vessel and equipment, the choice of our original operator turned out to be impacted due to economics. PRCC made the decision to change operators and venue to ensure that sufficient vessel operation was at a tempo to permit a successful demonstration. The timing of the change coincided with a change of the USCG Marine Safety Center (MSC) personnel reviewing the technical submittals by the team. This further added to the renewed USCG scrutiny of the design decision as the design was contrasted with the newest International Gas Code Requirements.

The final blow to the project came from multiple fronts – first Subchapter M came into force in 2018 and caused operators to consider the cost of upgrading their vessels to meet the new requirements. Many smaller operators and even the larger operators are considering whether to upgrade their vessels to meet the emergent or build new vessels to replace one or more older vessels. Second, the political/environmental concerns of using coal to generate power is changing the business outlook for many operators in the Pittsburgh Region; revenues from the transport of coal by barge have decreased with the change in demand. This has put a different light on any interest in converting vessels that will likely be laid up or sold. Third, delays from staff changeover within the USCG MSC and adherence to changing international gas regulations for ocean going vessels and codes severely hindered the timeline and ability to proceed with the actual demonstration phase of the project. Finally, for this project, the winter of 2017-18 caused ice damage on the *M/V PRINCIPIO* to the point where meeting Subchapter M requirements and vessel repairs caused the operator to not be in a position of continuing the project and possibly scrapping the boat.

The key findings of this project are as follows:

1. Timing for these projects is critical – changing fuel prices, regulations, and business conditions all are important aspects of this type of project.
2. Delays in technical reviews and rigid application of oceangoing and International Code of Safety for Ships using Gases or other Low-flashpoint Fuels (IGF) code for inland vessels of this type and size was a detriment to the success of this project.
3. Regulations (Subchapter M, which came into play mid-project) require expensive vessel modifications, which made conversion to LNG much lower on the operations decision tree.
4. Conversion of existing vessels without modification of IGF requirements will make insertion of natural gas improbable – only new builds may (subject to ROI studies) make sense in the future.
5. Design Findings
   a. Natural gas fumigation technology was chosen to ensure the project could move forward, however, as the project progressed it became a hindrance to acceptance due to the low substitution rates and regulatory agency restrictions.
   b. Hybrid drive or natural gas generators in electric drive propulsion towboats makes the most sense for natural gas insertion, under current regulations.
   c. Over-the-highway DOT approved LNG tanks are as safe as large commercial natural gas tanks used (built into) ocean going vessels.
   d. Depending on the size of required tanks, membrane tank technology is evolving and emerging as the design technology that may be applied to towboat tankage, but was not available for this project to consider.
   e. Natural gas engines and/or dual fuel engines were not available in the size range required for this project

2 OCEANGOING/INLAND INTRODUCTION

The Greater Pittsburgh area consisting of Pennsylvania, Ohio, and West Virginia is uniquely situated in a region with a large supply of shale gas formation (the Marcellus and Utica formations). This has allowed the hydraulic fracturing industry to prosper and provide the market with a new source of lower cost fuel. With a domestic drive towards cleaner emissions and energy independence, industries utilizing reciprocating engines for normal business operations have been interested in how this domestically supplied natural gas can help lower costs while meeting stricter regulations.

Pittsburgh's iconic point, where the three rivers (Allegheny, Monongahela, and Ohio) meet, also provides a symbolic representation of the confluence between several intermodal industries that utilize reciprocating engines. Where highway and rail transport has been adopting natural gas combustion technologies for their engines, the barge transportation system along the rivers has not. PRCC and POP identified this opportunity and commissioned a feasibility study to examine the viability of the use of CNG or LNG for towboats operating in the Pittsburgh region.

Among the many conclusions of the study was the recommendation to initiate a natural gas conversion demonstration project in a small, terminal-sized (defined as less than 1,200 horsepower) towboat to determine the viability for local companies. At the onset of the project, we had both a motivated vessel owner and LNG supplier and had MARAD step in to help offset the initial demonstration project. This report chronicles the efforts performed in pursuit of this objective.

2.1 Background

The Port of Pittsburgh feasibility study conducted extensive industry analyses on the natural gas and towboat industries. Combining the two, the results illustrate the interdependence between the two industries should natural gas towboat conversions be adopted. Among the resulting conclusions of the report, it was suggested that a natural gas towboat conversion demonstration project be completed.

Within the Ohio River towboating industry, towboats are loosely classified into three categories according to shaft horsepower (hp): terminal (less than 1,200 hp), mid-range line haul (between 1,200 and 2,500 hp), and long-range line haul (greater than 2,500 hp) vessels. For this conversion study, a terminal vessel up to 1,200 hp was targeted for conversion since work was ongoing investigating new builds and conversion of larger line-haul towboats.

2.2 Objective

The goal was for the team of personnel to:

1. Determine appropriate solutions for implementation
    a. Fueling: How to deliver the natural gas for vessel refueling
    b. Plant Design: Determine the appropriate design for installation to ensure regulatory compliance, uncompromised vessel operation, and operator safety.
    c. Training: Determine the appropriate requirements and certifications for vessel personnel to operate and refuel
2. Regulatory Compliance: Work with regulatory bodies to ensure all requirements specific to the design are met
3. Install the equipment at a local Pittsburgh shipyard
4. Operate the vessel according to its normal profile during a demonstration period and record the exhaust emission and fuel performance. Additionally, the fueling requirements and details were to be worked out.

2.3 Historical Perspective

As described in the POP feasibility study, many inland operators have looked at and/or are considering the use of natural gas as a fuel. Oceangoing LNG carriers have been using the boil-off of LNG carried onboard to fuel their boilers and diesels for over 50 years. Similar to the slow adoption of inland vessels to diesel fuel from coal/steam, the river industry has yet to fully realize a towboat conversion to natural gas.

With some oceangoing vessels fully converting to LNG, the cost-savings advantages are much more pronounced on oceangoing vessels than would be on inland vessels. This is due to several factors that include operating profile, fuel types/switching, fuel consumption, and fueling infrastructure. Consequently, these same factors are some of what keeps inland operators from adopting LNG as a fuel. Due to the several types of vessels (terminal, mid-range, and long-range line-haul) and their associated operating profiles, the ROI calculation results are less appealing. In addition, a conversion requires the synchronization of the natural gas supplier as well. Without a cost-effective fueling infrastructure in place, the resulting savings from natural gas are lowered.

It should also be mentioned that the environments in which the vessels operate have a major impact on the decision for operators to convert. For example, oceangoing vessels tend to have shorter lifespans due to the harsh salt-water conditions on their carbon steel construction. Inland vessels do not need to worry about this; inland waterways are freshwater and less corrosive on steel. It is not uncommon to find inland vessels that have been in operation for over 50 years with minor modernization upgrades and overhauls made throughout the vessels life. Stainless steel-hulled vessels can even be found in some companies.

At the beginning of the POP study in 2008, the cost of crude oil was around $145 per barrel. At the conclusion of the study in 2015, the price dropped to $50 per barrel. At the submission of this report, crude oil was listed at $55 per barrel. The volatility of the market is explained in detail in a later section, but it should be mentioned that this unpredictable change in prices also affects LNG adoption.

With the aforementioned variables taken into effect, the POP study found that operators were less inclined to invest in vessel conversions until the economics of a conversion would make sense. This project was intended to help bridge this gap of knowledge and cost details. Regardless, this conversion had it been successful, would have provided the industry with a confident reference to determine the cost-benefit associated with adoption of LNG on the inland waterway system.

2.4 Terminology

The following terminology will be used throughout this report and has been defined by the POP Study:

<u>Barge</u>: Steel hull flat bottom vessel designed to carry the bulk and liquid cargoes transported along inland waterways. The vast majority of barges have no means of propulsion, but some do have engines on board to support cargo requirements.

<u>Oceangoing</u>: Typically used to describe the ocean business. Vessels that ply these waters are specifically designed to handle salt environments, as well as other ocean conditions such as waves.

<u>Inland</u>: Typically used to describe the freshwater inland waterway business. Vessels that ply these waters are specifically designed to handle freshwater environments, including shallow water operation and narrow channel river currents.

<u>Terminal Towboat</u>: Towboat vessels designed to move barges around. Also called fleet boats, they assist the loading and unloading of cargo and push barges around in a river port facility. These vessels will also push a smaller tow of barges for short stretches of river. Terminal towboats typically do not have any overnight accommodations for crew and are crewed in shifts from a port location. For this study, we have defined terminal boats as those vessels with up to 1,200 horsepower of propulsion power.

Line Haul Towboat: These vessels are designed to move barge tows for greater distances. Many of these boats have accommodations and galley spaces to support crews living on the vessels. For this report, we have created two categories of line haul boats. The first category is a mid-range line haul vessel. These vessels have propulsion horsepower from 1,200 to less than 2,500 horsepower. The second is the long-range line haul vessel. These vessels have propulsion horsepower of 2,500 horsepower or greater.

Towboat: Modern vessels referred to as towboats are designed to push barges, although the term push boat is occasionally used. The name comes from steamboat days when the boats would often tow several boats alongside for additional revenue. Towboats today are flat-bottomed steel hull vessels that consist of a propulsion train for providing the thrust for movement, steering gear for maneuvering the vessels, and diesel engine generator sets for vessel electrical needs.

2.5 Prior Work

Several key players within this effort participated in the POP Feasibility Study. In an effort to further expand upon a drive towards petroleum independence, the study investigated the hurdles of transitioning towboats to natural gas. Aside from major economic, engineering, and regulatory hurdles, the study found that a conversion would require the successful collaboration of suppliers and operators.

2.6 Proposed Effort

MARAD awarded the proposal submitted by PRCC. The proposal focused on efforts to convert a small, terminal-sized (1,500 HP or less) vessel to natural gas and demonstrate operation including refueling. A PRCC team made up of industry leaders in natural gas supply, storage, promotion, and engineering came together to determine the requirements for the task.

The *M/V RON-CHRIS* was selected for the project because it fit the necessary requirements including vessel size, propulsion equipment, and operating tempo. This also brought to the team an experienced owner and operator who was willing to work with the PRCC design team, make the necessary equipment and vessel modifications and accept the risk of the conversion effort. The vessels main propulsion engines were suitable for insertion of fumigation technology.

One of the key elements of the project was the diesel engine conversion technology. Since funding was limited and natural gas and dual fuel engine were not available in the power range required for this project, new natural gas engines were not proposed and instead fumigation technology was proposed to convert the existing engines to enable them to burn natural gas. Engineering and design for changes played a major role in the conversion. The goal was to provide an alternative power plant that does not change the operating characteristics of the vessel. This requires similar throttle response time, power/torque, and basic operating range. Various solutions were proposed to be researched (engine manufacturers, dual vs. dedicated fuel usage, hybrid design, etc.). Additionally, the fuel system infrastructure from the tanks to the engines, the safety systems, and the increased ventilation systems were to be designed.

Another key element to the success of the project was the ability to safely refuel the towboat and store natural gas in spaces in sufficient capacity to permit operation for a selected time period without refueling. Feasible storage and refueling solutions were proposed to be identified to ensure safe and continued use. Natural gas providers and storage solution companies were to be contacted to provide the fueling solutions.

As part of the design process, discussions with the applicable regulatory bodies were required. The design team worked with the USCG to obtain approval for the conversion to ensure the vessel can operate safely.

After the conversion, a period of 6 months of operation was to be completed to show the impact of using natural gas as an alternative fuel. Elements of this project included:

- Exhaust emission measurements
  - Pre-conversion
  - Post-conversion
  - Operational during test period
- Documentation of operational data from the demonstration project
- Preparation and submission of a final report.

3 NATURAL GAS CONVERSION

Natural gas has been used as a fuel for marine propulsion for decades on oceangoing LNG cargo vessels in boilers to produce steam. Only recently have these vessels started to use internal combustion engines to create propulsion power. In recent years, there have been a number of projects worldwide to convert other types of vessels to use natural gas as a fuel. The U.S. inland waterways had yet to demonstrate natural gas as a propulsion fuel on towboats. PRCC and the POP identified this opportunity, especially with the rise of crude oil prices at the time of proposal and in conjunction with the increased natural gas production in the Marcellus Shale within the greater Pittsburgh region. Peoples Natural Gas partnered with Life Cycle Engineering (LCE) to study the inland waterways industry profile to determine the viability for towboat fuel conversions. As a result, and as described in the POP Feasibility Assessment, it was determined that LNG on line-haul vessels would produce the best return-on-investment, but pose other challenges including refueling along the length of the rivers. For successful operation on the rivers, a cost-effective supply-chain of natural gas would need to be created. It was confirmed that the towboat operators and natural gas supplies would have to operate in a mutually inclusive environment to ensure success.

From a recommendation made in the feasibility study, PRCC wanted to investigate the effects of conversion of a towboat. PRCC identified an opportunity through a MARAD Request for Proposal and submitted a proposal. LCE worked with the naval architecture and marine engineering firm The Shearer Group, Inc. (TSGI) to identify candidate vessels and design the new systems accordingly to allow for a successful installation.

Ensuring operational safety and regulatory compliance was paramount for a successful conversion project. Since this project was a first of its kind, considerable coordination was needed across all parties involved, including leading regulatory bodies. The two primary regulatory bodies that govern towboat operations are the USCG and the EPA. Despite being the main players for guidance and policymaking, much of the industry knowledge for LNG comes from other sources in the highway and international markets. The USCG and EPA have thus adopted many of the common practices from other organizations, such as the International Maritime Organization (IMO) and the National Fire Protection Association (NFPA), to structure their requirements. This use of cross-industry knowledge has been indexed within USCG policy letters, such as in USCG CG-OES Policy Letter No. 02-15 where the NFPA is listed as acceptable alternatives to 33 CFR Part 127 (LNG Fuel Facilities).

4 TECHNOLOGY OPTIONS

A successful conversion to natural gas has two major considerations: engine and fuel storage. There are several options available for both, but it is important that the political, logistical, and economic constraints of each mesh together to form a feasible solution. The following sections detail the options available and the associated environmental impacts.

4.1 Engine Technology

There are three primary options for towboat natural gas engine technologies, each with their own set of advantages and disadvantages:

1. Dedicated Spark Ignited Natural Gas Engines
2. Bi-Fuel Engines
3. Dual-Fuel Engines

<u>Dedicated Spark Ignition (SI) Engines</u>

Spark ignition natural gas engines are commercially available for industrial, utility, and marine application. They are used extensively in the natural gas industry for compressor engines and also in the drilling industry to take advantage of available natural gas fuels.

Application of spark-ignited engines to towboats requires both logistic and engineering design considerations. The decision to install a spark-ignited engine is a commitment to use 100 percent natural gas for as long as the engine is installed on the boat. For many operators conversion to spark-ignited engines is untenable at this time because of the current uncertainty of natural gas supply compared to the known availability of diesel fuel. As LNG becomes more widely available along the entire river system, this option may be considered more. Additionally, as many towboats are sold between operators, a completely natural gas engine choice may restrict the sales price of the vessel for current owners and limit potential buyers.

From a design standpoint, natural gas engines when compared to diesel engines have a lower horsepower output for the same weight. To get the same horsepower output, natural gas engines will have to be bigger and heavier which can influence the design for a boat. Engine controls for marine natural gas engines need to be designed to ensure that engine load following and response times are equivalent to their diesel engine counterparts. Roll-Royce Bergen engines currently installed on marine vessels require control system design for the propulsion engines. These engines are provided as part of a natural gas only fueled vessel where the only fuel on board is natural gas and both the main propulsion and generator engines operate on natural gas.

Considering the main propulsion engines on towboats consume the majority of fuel and require responsiveness to maneuvering load changes, spark-ignited engines do not seem to be the favored choice for natural gas technology insertion. The most likely application for natural gas only engines for towboats initially would be generator engines. Spark-ignited generator sets are in service throughout the world. These units are already designed to efficiently respond to electrical loads.

Bi-Fuel Spark Ignition (SI) Combination Engines

Bi-fuel spark-ignited, combination engines are engines that are capable of running on a bi-fuel application. These applications are available currently in highway vehicles where typically natural gas and gasoline are the fuels of choice. The fuels are not actually mixed or blended but are used separately. The engine and fuel control system is automatically configured to permit either fuel to be combusted in the engine. This technology is mostly applicable to natural gas/gasoline combinations that are based on spark- ignited Otto-cycle engines. To make this technology work in diesel engines, the engines are converted to add an ignition spark when natural gas is used. It must retain the high compression required for the compression ignition of the diesel cycle.

Due to the complexity of these systems and the fact that they are better suited for automotive applications, bi-fuel engines are not considered to be candidates for use in towboats.

Dual Fuel Engines

Dual fuel technology. This type of combustion relies on the combination or blending of two fuels and simultaneously introducing them into an engine's combustion chamber. Together these dual fuel technologies comprise the most likely method for incorporation of natural gas on towboats.

By far, dual fuel engines have the most diverse set of technologies to accomplish mixing diesel fuel and natural gas and combusting it in an engine. This mixing is accomplished using a variety of techniques that can be incorporated as part of an engine design or as an aftermarket retrofit insertion. Regardless of the method chosen to mix the fuel and where it is mixed, these technologies require the compression ignition of the diesel fuel to combust the blended fuel mixture. The majority of the fuel burned in a dual duel engine is diesel. Depending on the method of mixing the natural gas with the diesel fuel, levels of natural gas can get up to about 80% of the combusted fuel. This project has chosen to use fumigation technology, which converts a diesel engine to use up to 60 percent natural gas as replacement for the diesel fuel.

The benefits of dual fuel engine technology include lower fuel costs and lower exhaust emissions, especially lower particulate matter and NOx emissions. While the performance is not quite as good as a pure spark-ignited natural gas engine for reducing fuel costs and exhaust emissions, these technologies have the advantage of closer load following response and being able to revert back to use diesel fuel only when natural gas is not available, both being major advantages to terminal vessels and their applications.

4.2 Fuel Storage Technology

Because CNG and LNG are in different physical states, pressures, and temperatures, they need to be stored differently.

CNG is typically stored around room temperature at 3000 PSI. CNG is, however, temperature sensitive. For example, as the tank temperatures fluctuate, or the speed of fueling is altered, the vessel may not be able to take on as much fuel (higher CNG temperatures lead to expansion of the gas, thus providing less fuel). Because CNG is at a higher pressure, special pressure vessels and safety precautions need to be installed to handle the higher pressures.

Conversely, LNG is typically stored around -260°F (-162°C) at pressures much lower than CNG. This causes a special set of considerations since the fuel is at such a low temperature. The storage tanks are specialized cryogenic insulated tanks required to maintain the low temperatures of the LNG. As the LNG is stored for longer periods of time, "boil off" is naturally created within the tank to maintain the colder temperatures of the liquid state.

For most towboat applications, LNG is the choice fuel for towboat applications due to its increased energy density over CNG. There are three LNG tank types used as storage options: A, B, and C. Tank types A and B require full or partial secondary barriers to prevent the release of LNG to the atmosphere. Type A tanks, known as prismatic tanks, provide the most appealing solution for future use due to their availability to use existing tank structure and form for LNG fuel storage. Per regulatory constraints, however, the tanks cannot be adjacent to crew berthing areas, effectively removing these tanks as options until further regulatory review. This poses quite a challenge for the smaller, compact towboat vessels.

Type C tanks are independent tanks designed to handle the additional pressures experienced with boil-off gasses. As such, they require no secondary barriers and can hold the increased pressures for up to three weeks. Smaller forms of these tanks can commonly be found on over-the-highway applications. Because of the Type C tank prevalence interior of the country on the highway and the restrictions to Type A and B placement on the vessel, Type C tanks are ideal candidates for towboats at this time. The over-the-highway tanks from companies such as Chart were selected for use in this project.

4.3 Environmental Impact

Compared to diesel fuel, natural gas has some advantages to emissions reduction. Without the use of sulfur in the mixture, SO_X emissions are practically non-existent. Additionally, natural gas has been shown to cause roughly a 20 percent reduction in carbon dioxide (CO_2) emissions compared to diesel fuel[3]. There are, however, additional considerations to take into effect when using natural gas. For example, ultrafine particulate matter and nitrogen oxide (NO_X) emissions are greater.

[3] Per product information supplied by Rolls-Royce's spark-ignited engines and Wartsila's dual-fuel engines. This information can be found in the previously referenced Pittsburgh Marine Corridor Natural Gas Conversion Feasibility Assessment, Port of Pittsburgh, June 2015.

More importantly is the concern for methane slip, or the emission of unburned gas in the exhaust of engines and also leaking storage tanks and piping. Methane has a greenhouse gas (GHG) effect factor over 20 times higher than CO_2. Thus, any methane slip that occurs quickly negates any advantage natural gas has over mitigating the greenhouse gas (GHG) effects of increased CO_2 emitted from diesel engines.

Aside from the need to tightly monitor methane slip in engines, as well as the boil-off and storage concerns of natural gas, it should be noted that different engine technologies offer different levels of emissions advantages. For example, spark-ignited (solely dedicated) natural gas engines offer the best design advantages over emissions reduction, followed by manufactured dual-fuel engines and dual-fuel conversion kits. With the aforementioned operating risk of solely dedicated natural gas plants, as well as the yet to be industry approved designs of manufactured dual-fuel engines, operators are more inclined to use retrofit dual-fuel kits. This inherently diminishes the advantages in emissions reduction seen with natural gas.

Another consideration towards environmental impact is the operational profile of the vessels. The most reduction in emissions for many constituents like particulate matter on a per horsepower basis occurs during high-load operation of the vessels, such as during normal transit. As the engines get closer to low load idle conditions, emissions on a per horsepower basis are increased. This is common across all modes of fuel usage, be it diesel, natural gas, or dual fuel. Where markets such as the Mississippi River see less idle running of the engines, the Ohio River towboat industry has more idle running of engines. This is primarily due to smaller tows (more make-up and break up time) and the locks and dams (waiting for passage) where vessel engines are run at idle during waiting periods.

4.4 U.S. Coast Guard (USCG)

The proposed modifications were fundamentally dependent on the applicability of two references:

1. USCG CG-521 Policy Letter 01-12 Equivalency Determination: Design Criteria for Natural Gas Fuel System
2. International Maritime Organization (IMO) Resolution MSC.285(86) - Interim Guidelines On Safety For Natural Gas-Fueled Engine Installations On Ships, ANNEX 11, (1June 2009)

The foundation of the design for the project was to use existing engines, and the above references initially provided enough flexibility to comply.

In 2015, IMO adopted new rules, the IGF Code, and in 2017, the new regulations entered into force. With the newly adopted regulations, new design constraints brought new challenges, most notably regulations regarding the internal piping of the engines. Simplifying, this means that if we switched vessels, we would need new engines.

The towboats intended to be modified were for inland service in United States waterways and US Flagged. Future structural modifications (if required) would be to the standards of *ABS Rules for Building and Classing Steel Vessels for Rivers and Intracoastal Waterways*, as applicable.

Modifications to the vessel in regards to the LNG containment and fumigation systems were to be carried out in accordance with USCG CG-521 Policy Letter 01-12 and IMO Resolution MSC.285(86). As stated in the Policy Letter, the USCG allows the use of the "gas safe" configuration, and does not provide guidance for an Emergency Shutdown Protected (ESD)-protected space as it falls outside the scope of the Policy Letter. Because an ESD-protected machinery space configuration is far less practical for this project, the goal of the vessel conversion was to not have the entire engine room a hazardous area, and thus to comply with the "gas safe" configuration by ventilating hazardous items and areas as required by the Policy Letter.

Due to the innovative nature of this system in the inland marine environment and the available systems, the intent was to request special considerations from the USCG. The ahead-of-time submittals of design documents and risk analyses by the PRCC team intended to show that the designs would accomplish an equal level of safety, and meet the intent of the regulations. Appendix A and B provide the documents submitted to the USCG. Additional Appendices C-F provide a few examples of special considerations are: LNG tank penetrations below liquid level, dry chemical fire protections requirements, solenoid valve ratings at the tank and gas train, and the double block and blead valve configuration as described in IMO Resolution MSC.285(86). These documents were developed to begin the design discussion with the USCG.

4.4.1 Natural Gas Code

Before IMO adopted new vessel rules in 2015 (the IGF Code), they developed a set of interim guidelines (IMO Resolution MSC.285(86)) to provide an international standard for ships, other than vessels covered by the ICG Code, with natural gas-fueled engine installations. The goal of these interim guidelines was to provide criteria for the arrangement and installation of machinery for propulsion and auxiliary purposes, using natural gas as a fuel, which would achieve an equivalent level of safety and reliability as compared to conventional oil-fuel machinery.

As is typical, USCG developed their own interpretation of these interim guidelines (Policy Letter 01-12 "Equivalency Determination: Design Criteria for Natural Gas Fueled Systems"). USCG released this policy letter to outline where USCG requirements differ, and also provided more guidance on other areas, unless noted otherwise in the USCG policy letter, the guidance provided by the interim guidelines were acceptable. These two documents (the Policy Letter and the IMO Resolution) were the controlling documents for this design from day one of the project. It was not until the vessel in consideration was potentially going to be changed in 2018, did discussion of the recent USCG approval of IMO and ICG occur. For the bulk of this design effort, these two documents were the controlling and applicable sets of regulation for the intended modifications.

4.4.2 Subchapter M

While Subchapter M specifically does not relate to the natural gas conversion project design, it does play a role in the project's evolution so it is discussed in this section. During the start of the project, this requirement on inland vessels was under development by the USCG. It specifically applies to the design and safety requirements of vessel in the inland towing industry.

Title 46, Subchapter M (herein referred to as "Subchapter M") of the CFRs is a recent promulgation to address an increasing need for towing vessel safety. Towboats had been previously classed as "uninspected vessels" which limited the main industry auditors, the USCG, to only requiring onboard inspection of firefighting; fire-prevention; navigation safety equipment; documentation; towing and terminal equipment, pollution prevention equipment; life-saving equipment; and hazardous conditions. Unlike the oceangoing (ocean) industry where the USCG also regulates the working conditions of crewmembers, the Occupational Health and Safety Administration (OSHA) oversaw this component in the inland (river) industry. This changed with the institution of Subchapter M in July of 2017 when the USCG assumed the duties previously held by OSHA.

Subchapter M primarily addresses the institution of required Towing Safety Management Systems (TSMS) programs for vessel operators and their method of periodic approval through USCG inspections. While the focus is on crew safety and risk management, Subchapter M inherently tightens the design and safety requirements across all vessel systems (the previously mentioned systems, plus electrical and machinery systems, as well as operational requirements). This has required operators to bring their vessels into full compliance, increasing operating expenses and adding pressure to profit margins already reeling from market changes away from traditional coal transport. Installing systems onboard vessels to handle and operate under the use of natural gas are no exception to the compliance requirements of Subchapter M.

46 CFR 136.110, however, defines certain "Excepted Vessels" as exempt from certain callouts in Subchapter M. These vessels are defined as serving small geographic areas, conducting basic terminal-assist operations, providing emergency response, or being specially considered by the Officer in Charge, Marine Inspection (OCMI). These constraints essentially remove most of the vessels in the industry as contenders and are not practically considered for application by operators. Many operators in this region are working to get their vessels up to speed with these requirements. It is causing the smaller operators to consider their options closely.

4.5 Environmental Protection Agency (EPA)

In an attempt to curb the increasing amount of industrial emissions, the EPA has targeted the inland waterways towing industry to meet compliance of the organization's emissions reduction efforts. In 1999, the EPA adopted Tier 1 and 2 emissions standards that inherently call for marine engine manufacturers to limit the amount of emissions their vessels produce. These standards stratify by engine horsepower and are the sole responsibility of the engine manufacturer to meet; towboat operators need only ensure they are installing engine technologies onboard that meet the EPA Tier requirements. In 2008, the EPA increased the constraints on emissions to Tier 3 and 4 standards, as well as regulating the use of ULSD for all engines along the inland waterways.

Aside from the mandated fuel requirements, all existing engines onboard towing vessels are grandfathered into compliance. When converting a vessel to a dual-fuel LNG engine set-up, however, the same Tier emissions requirements apply. Solely dedicated, spark-ignited LNG engines are currently not regulated in the same fashion as diesel engines, but are very close to meeting the existing Tier 4 emissions requirements (further after treatment may be required). For kit converted or directly manufactured dual-fuel engine options, Tier 3 compliance may be achieved depending on the design; Tier 4 compliance technologies are still in progress.

To curb conversion kits that produce more than desired emissions, the EPA has also essentially required all manufacturers to obtain full EPA or California Air Resources Board (CARB) certification of the technologies.

4.6 International Maritime Organization (IMO)

As stated in 4.1.1, IMO provided to guidance for the installation of gas-fueled machinery. In addition, to gas systems, they also provide guidance on all matters concerning the maritime industry, such as safety, the environment, as well as other aspects. Much of the guidance however is concerning larger ships on unprotected waters; a considerable departure from towboats operating on the rivers. As result, there were no applicable changes of significance required on the vessel, due to IMO, other than those arising from the gas-fueled aspects.

4.7 National Fire Protection Association (NFPA)

The USCG utilizes industry guidance set forth by the NFPA, either directly or indirectly through IMO Resolutions, particularly USCG Policy Letters CG-521 No. 01-12 and CG-OES No. 02-15.

USCG Policy Letter CG-521 No. 01-12 references IMO Resolution MSC.285(86), "Interim Guidelines on Safety for Natural Gas-Fueled Engine Installations in Ships". "Chapter 4 – Electrical Systems" refers to NFPA 70 for onboard Electrical System compliance dependent on the Class X location of the equipment.

USCG Policy Letter CG-OES No. 02-15 refers primarily to shore side fueling storage and station requirements. The Table of Alternatives to 33 CFR Part 127 in the Policy Letter cross-references the CFR sections approved for alternative design and compliance, most notably referencing multiple NFPA regulations.

NFPA 52, "Vehicular Natural Gas Fuel Systems Code", outlines the requirements for onboard vehicular fuel systems as well as the requirements for fueling from transport vehicles. Marine vessels are mentioned twice in this regulation without reference to specifics:

- 14.3.2.5.9 The unneeded protection from static electricity using specific transfer hose metallic coupling arrangements.
- 14.3.2.27.2 Marine Vessel Transfer (reserved for revision; no content provided)

During this towboat conversion effort, no other sources of onboard requirements for NFPA compliance were identified by the USCG.

5 CLASSIFICATION SOCIETIES

The American Bureau of Shipping (ABS) and Det Norske Veritas (DNV) are two of the largest and most renowned marine classification societies in the world. Both have published their respective guidance and rules for gas-fueled vessels. Where DNV has focused on the successful construction of natural gas-fueled vessels in Europe, ABS has more limited classification experience in the United States due to lower demand.

5.1 American Bureau of Shipping (ABS)

ABS is a non-profit certification society that supports maritime industry compliance of national and international regulations. Their efforts allow companies to ensure their vessels and operations adhere to current USCG and IMO regulations. Until the release of Subchapter M, ABS was not particularly involved in inland waterway regulatory compliance, only offering guidance for construction of vessels if desired ("ABS Class Rules for Building and Classing Steel Vessels for Service on Rivers and Intercostal Waterways").

To assist with the safe implementation of natural gas on marine vessels, they have released two guidance documents:

- ABS "Guide for Propulsion and Auxiliary Systems for Gas Fueled Ships"
- ABS "Bunkering of Liquefied Natural Gas-Fueled Marine Vessels in North America"

These documents, particularly the first guide, allow for concept design approval of proposed vessel installations. ABS provides three approval levels of increasing scrutiny to allow for different ranges of compliance: Approval in Principle (AIP), Statement of Compliance, and LNG Fuel Ready. While the AIP is required, the other two are optional.

5.2 Det Norske Veritas – Germanischer Lloyd (DNV-GL)

Det Norske Veritas (DNV) & Germanischer Lloyd (GL) is a similar organization to the ABS, publishing rules and guidelines for classification of ships and vessels, as well as offering certification and classification of vessels. DNV-GL has a longer, more involved history with natural gas options for maritime vessels compared to ABS. Europe has comparably more natural gas vessels in use than America. Additionally, DNV-GL worked with the MARAD to prepare a bunkering study for the use of LNG.

DNV-GL has provided three major guidelines for natural gas fueled vessels:

- DNV Rules for Classification of Ships, New Buildings, Special Equipment and Systems Additional Class, Part 6, Chapter 13, "Gas Fueled Engine Installations"
- DNV-GL recommended Practice, DNVGL-RP-006:2004-01, "Development and Operation of Liquefied Natural Gas Bunkering Facilities"
- DNV-GL Standard, DNVGL-ST-0026:2014-04, "Competence Related to the On Board Use of LNG as Fuel"

The combination of these guidelines and rules has given the industry an almost beginning to end guidance for vessel classification, LNG bunkering facilities, and crew fueling competency.

6 PROJECT EVOLUTION

This section describes the activities performed to prepare the vessel design for conversion and the negotiations of the design with the USCG. PRCC led the effort and the team worked over many months to develop a concept design, submit concepts to the USCG, develop a detailed design and specify and obtain quotes for equipment and work out a refueling strategy. In the end, however, the timing of this project was not good and through the nexus of many seemingly disparate problems, culminated in a decision PRCC and MARAD made to terminate the project because it made no sense to continue to the conversion and demonstration phases since there was no boat.

6.1 Kick-Off/Initial Plan of Attack

This project was kicked off in September 2015 through a Cooperative Agreement between MARAD and PRCC (DTMA91H15000010). The project was kicked off in November of 2015 with a meeting at the operators facilities included a tour of their facilities and a visit to the *M/V RON-CHRIS.*

The design team comprised of LCE and TGSI were to begin evaluating the *M/V RON-CHRIS* and build design documents for submittal to the USCG. Work would commence to develop communications with natural gas companies to provide the plans for fueling the vessel. PRCC made the decision to propose to convert both engines instead of the originally proposed one engine to ensure that both engines would have comparable response and power since it is a twin propeller system. Additionally, the PRCC team began discussions with West Virginia University to perform the exhaust emission measurement for both pre-alteration and during the demonstration project.

6.2 Project Timeline Discussion

After kick-off, technical work began in early 2016.

- No drawings of the vessel exist so ship-checks were required to gather information about the equipment, layout, and frame and scantling design.
- DATE Concept design work commenced and included fumigation equipment vendor discussions, regulatory body and regulation review, and additional surveys and ship-checks.
- Summer 2016 - Initial discussions began with the USCG,
- July 2016 - two submittals to USCG
    - Basis for Design
    - Risk Analysis documents (Appendices A and B).
- October 2016, USCG responded to the design documents (Appendix M) submitted and provided areas that must be addressed prior to proceeding with the plan review phase of the project. It was this document that changes the IMO Resolution reference from Interim Guidelines to the IGF code, however, they stated that although the IGF Code will enter force in January 2017, that the design basis submitted may not be available for future vessels. In other words, the design that was submitted would be grandfathered under the Interim requirements to enable the project to continue with this demonstration project. This letter provided details of the elements of design to be worked out and required more specific details of equipment. Work began to develop design requirements and purchase specifications for the fumigation system, fueling system, gas detection and alarm system, and other ancillary systems required for the retrofit.
- Early 2017 PRCC issued a request for proposal to get vendors input and quotes for the equipment. Access for prospective bidders was provided to the *M/V RON-CHRIS*

- *Spring 2017* equipment bids were received
- Spring of 2017, PRCC began having concerns with the ability of providing the amount of demonstration hours proposed to MARAD on board the *M/V RON-CHRIS* and made a decision to terminate their agreement with Walden Industries. Prior to this termination, PRCC had begun discussion with Gulf Materials in Braddock Pa. about hosting the demonstration project on the *M/V PRINCIPIO*. Once the agreement with Walden was terminated, PRCC immediately began negotiating an agreement with Gulf Materials. Upon execution, the design team immediately began survey of the new vessel.
- Spring 2017 - The equipment vendors that had been selected for participation in the project were informed of the change in venue and provided an opportunity to visit the *M/V PRINCIPIO*. The propulsion engines on the *M/V PRINCIPIO* were actually two different makes and models, which is not uncommon, especially on terminal vessels for smaller companies. Detailed design and equivalency documents were updated to include *M/V PRINCIPIO* by the PRCC team for several systems as well as alerting the USCG to the change.
- June 2017 - The USCG informed the PRCC team that the change of towboats did not affect the comments from their original review (Appendix N). It was at this point the team also began discussions with the local USCG OCMI and requested a visit to ensure the condition of the vessel was acceptable for this conversion.
- Late 2017 through mid-2018 - Design and equivalency work continued.
- Winter of 2017-18, the *M/V PRINCIPIO* sustained some hull and propeller damage during winter ice events. Gulf Materials alerted PRCC that they had made arrangements to have another vessel provide the fleeting support as they made arrangement for purchase of two boats from Campbell Transportation, the *M/V TIMMY* and *M/V OKAN*.
- June of 2018 - PRCC Team surveyed both the *M/V TIMMY* and *M/V OKAN* to see about the suitability of the vessels for the conversion. The *M/V OKAN* was eliminated from the discussion because of its smaller size. Planning began on the *M/V TIMMY*; however, the issue with the boat was that the main propulsion engines were two cycle engines, which means they are not suitable candidates for fumigation insertion. New plans began to form about repowering and investigation of alternative natural gas conversion including hybrid drive propulsion insertion.
- Summer 2018 - Internal business discussions within Gulf Materials about which vessel to convert. Gulf Materials decided to dry-dock *M/V PRINCIPIO* and determine the extent of the damage, as they were interested in the conversion still taking place on that boat.
- August of 2018, the *M/V PRINCIPIO* was dry-docked and surveyed. The damage and repairs would cost Gulf Materials in excess of $250K which essentially pushed out any hope Gulf Material had of using the *M/V PRINCIPIO*. This led to PRCC being without a vessel to convert.
- Summer/Fall 2018 - PRCC technical team was still working with USCG on a major sticking point and one of the principal tenets of this project – use of over-the-highway fuel tanks for storage on board the boat. This is discussed in Section 6.3.4 in detail as part of the design challenges. Chart Industries had been selected as the tank vendor for the project and they met with the USCG and provided proprietary details. It was at this point, however, that the vessel issues ceased the effort.
- Late 2018 and early 2019 – PRCC team worked to identify a replacement vessel for the project. Unfortunately, no vessel was found in the region as most operators were focused

on Subchapter M compliance and not interested in discussion about conversion to natural gas. Conversations were held with one of the region's largest operators and the results of the discussion are provided in Section 6.9.
- May 2019 - PRCC notified MARAD that they were ceasing activity and the project and would wrap up the effort with a final report.

6.3 *M/V RON-CHRIS* & *M/V PRINCIPIO* Design

The conversion of the *M/V RON-CHRIS* (then the *M/V PRINCIPIO*) was intended to be the first of its kind for towboats; a sound and novel solution for the implementation of dual-fuel technology in the inland marine industry, highlighting the advantages and safety of natural gas as an alternative fuel source. The conversion was intended to demonstrate the ability to apply shore side natural gas conversion technology to towboats as a more economical way. The demonstration part of the project was intended to provide a proof of concept for fueling, operation, and environmental benefits of conversion of a terminal boat.

In late 2016, PRCC decided to change vessels from the *M/V RON-CHRIS* to the *M/V PRINCIPIO*. The following design discussion applies to both vessels, as our discussions with USCG continued under the same project through this transition.

6.3.1 *M/V RON-CHRIS* As-Is

The *M/V RON-CHRIS* is a 58' x 20' x 6' inland twin-screw towboat powered by twin Cummins NT855 (350 HP each) diesel fuel engines, seen below:

Figure 1: Port-side view of *M/V RON-CHRIS*

The *M/V RON-CHRIS* was built in 1952 by St. Louis Shipbuilding for the Weirton Steel Company and was named *M/V WEIRITER*. In 1976, it was purchased by AM&O Towing, Inc. and renamed the *M/V RON-CHRIS*. It was repowered by them and was sold and operated by Walden Industries in Tiltonsville Ohio.

The vessel is configured with two main propulsion engines powering twin propeller shafts and two generator sets for hotel load. Figure 2 shows the *M/V RON-CHRIS* Cummins propulsion engines.

Figure 2: Starboard-side view of MPDE on board *M/V RON-CHRIS*

6.3.2 *M/V PRINCIPIO* As-Is

The *M/V PRINCIPIO* is a 65' x 24' x 6' inland twin-screw towboat powered by two diesel fuel engines: a Caterpillar-D343 on starboard side and a Cummins KTM-1150-M on the port side. Both engines are of older designs and do not have electronic fuel injection equipment, seen below:

Figure 3: Starboard-side view of *M/V PRINCIPIO*

The *M/V PRINCIPIO* was built in 1940 by Sturgeon Bay Shipbuilding and Dry-dock for Lea River Lines and was originally named *M/V POLLYWOG*. It was sold, renamed and resold multiple times before ending up being sold to Gulf Materials in 2008. Over the vessel life, it has been repowered multiple times, most recently by Gulf Materials. Gulf Materials chose to use available rebuilt Caterpillar and a rebuilt Cummins engine for the port and starboard engines as shown in Figure 4.

Figure 4: Port and Starboard Engines on *M/V PRINCIPIO*

6.3.3 Design Concept

The best practical solution for dual fuel conversion of the vessel is an engine designed specifically for both fuels, however, since cost was a practical limitation for the project new engines were not proposed. Instead, fumigation conversion systems were selected for this project. Air fumigation technology injects a small amount of natural gas into the diesel engine turbochargers' air intake compressor, making approximately an air-fuel ratio of 50:1. The turbocharger compressors mix the gas and air into a homogenous mixture prior to entry into the engine air intake manifolds. The higher energy value of the mixed natural gas and air allows reduced amounts of diesel fuel to be injected into the engine cylinders to reach the point of the compression ignition. The relative amount of diesel fuel displaced with natural gas is called the substitution rate and can be as high a as 50%. Fumigation systems can substitute as much as 70% of the diesel fuel, but at higher substitution rates "knock" becomes as issue, so 50% to 60 % is considered a safe substitution rate. Currently, the technology is widely accepted and being implemented for use in the off-road mining and oil industry, locomotive industry, and on-road trucking.

6.3.4 Design Challenges

Due to the innovative nature of this system in the inland marine environment and the available systems, the intent was to request special considerations from the USCG while demonstrating that the design accomplishes an equal or equivalent level of safety, and meets the intent of the corresponding regulations. This section summarizes some of the design challenges that the PRCC Team faced for this project. Appendix V provides more details on the challenges and process.

The biggest obstacle in obtaining USCG approval to move forward was that the USCG MSC and CG-ENG mostly held gas-system drawings and requests for special considerations in abeyance until they received a full design package; this included reaching a few milestones such as a regulatory review of the tanks and fumigation systems. Obtaining a go-ahead to use highway tanks quickly became the bottleneck to obtaining any sort of ruling on other key elements to the design. Receiving tank approval from Coast Guard was a major challenge for this project. The intent was to use approved highway tanks. While these tanks held multiple classification society approvals (SAE J2343, DOT 4L, NFPA 52), they were not specified as being designed to the standards of the ASME Pressure Vessel Code, or the applicable portions of 46 CFR 154. Without intimate knowledge of the tank design, the only way to get approval to use approved highway tanks was either to work with the tank vendor, convince the tank vendor to work directly with USCG, or to conduct a gap analysis on the regulations themselves. The goal of this was to show that the tanks are designed an equivalent level of safety, or meet the intent of the regulations to an adequate level as determined by USCG. Even though our studies showed that the approved highway tanks were fundamentally sound, tank approval was never received from USCG.

<u>Fumigation System</u>

Concerning fumigation systems, standard land-based systems do not need to meet the same level of stringency as marine systems. This presented the team with obstacles when using an already proven system. While the team believed it was safer to use a tried-and-true and all-incorporated system, USCG regulations required certain modifications to the system (such as changing the solenoid valves in class 1 / div 1 and div 2 locations) that proved difficult.

The fumigation system, which receives natural gas from the LNG tanks, consists of a few integral systems:

- Gas train monitors and controls
- Supply piping delivers to gas to the engines.

Both of these systems had unique challenges. The gas train needed an enclosure due to the hazardous zones, and this enclosure was required to be ventilated. The supply piping was also required to be enclosed by ventilated piping, referred to as double wall piping. As mentioned in Section 4.4 in this report, the applicable regulations for the *M/V RON-CHRIS* and *M/V PRINCIPIO* allowed for this arrangement, provided that gas was supplied at low pressure and gas detectors were fitted above the engines. Since the international regulations were still under review and not approved, the USCG granted these vessels some flexibility with the rules. If a substitute vessel was chosen, they advised that the conversion would be required to meet the new regulations. Instead, the double wall piping would be required for gas pipes on the engine itself, all the way until gas is injected into the chamber. This means new engines would be required, and the core purpose of this dual fuel conversion project related to retrofitting existing engines with an air fumigation system.

<u>Firefighting System</u>

For firefighting, the vessel was required to have a water spray system and a dry chemical powder system. The water spray system was intended for use against accidental flammable gas releases, which create LNG vapor clouds. The vessel as currently designed however, did not have a fire main nor a sea chest. Adding a sea chest would likely require the vessel be docked for the install. There were understandable economic challenges to installing an appropriate fire protection system.

As noted above, a dry chemical system was also required for firefighting. The rules for dry chemical systems specify flow rates and times. These rates and times however are not dependent on the quantity of LNG carried, meaning the required flow rates for a large tanker are the same as the rates for a 58’ towboat carrying less than 300 gallons of LNG. There exists an off-the-shelf 300 lbs semi-potable unit that meets the required flow rate, yet comes up seven seconds shy on flow time. The team submitted a letter to USCG requesting special consideration on this matter, thinking this would be a relatively simple decision, however it was held in abeyance pending the submission and approval of the fire and gas detection systems. Approval was never received.

There were other design challenges due to hazardous zones such as rerouting engine exhaust outlets, moving /closing engine room windows and modifying bulkheads and decks to be of the appropriate “A” class. The design team did receive USCG MSC approval for the fire boundary plan on the *M/V PRINCIPIO*.

The *M/V PRINCIPIO* required quite a bit more hazardous zone modifications that are explained in more detail in Appendix V.

While the *M/V PRINCIPIO* is 7 feet longer than the *M/V RON-CHRIS*, the *M/V RON-CHRIS* was much more receptive to receiving the modification due to the arrangement of the vessel as well as the condition of the equipment onboard. A significant amount of work, such as structural modifications, and rerouting of systems, would be necessary on the *M/V PRINCIPIO.*

The *M/V RON-CHRIS* was not short of challenges either. On both vessels, in addition to the items mentioned earlier and in more detail in Appendix V, many electric receptacles, lights, light stands and other electrical equipment needed to be replaced or removed. Both vessels required significant structure additions for the tanks and especially the vent pipe, the outlet of which needed to be approximately 28 feet above the main deck.

6.3.5 Technology Insertion Discussion – CNG Tank Gap Analysis

As part of the project to install a liquefied natural gas system on the towboat *M/V PRINCIPIO*, the design required a number of LNG tanks. In the desired tank size, manufacturers use SAE specification J2343 that meets the requirements of DOT 4L for the tank design. International Code of the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IGC) compliant tanks were not commercially available in 2017 in the required size. Coast Guard rules on LNG tanks requires the use of the IGC code, which then specifies the ASME Boiler Code. The Coast Guard requested that the PRCC team prepare a gap analysis to highlight the differences between the two sets of specifications. Two gap analyses were performed for the USCG because of a personnel change at the USCG MSC and the adoption/application of new IMO regulations. Appendix W provides more details on the process and findings.

The gap analyses showed:

- Areas Where the ASME and SAE/DOT Tank Requirements are Similar
- Areas Where the SAE/DOT Tank Requirements are Superior to the ASME Code
- Area Where the ASME Requirements are More Stringent Than The SAE/DOT Requirements

The first gap analysis was delivered to the USCG MSC in early December 2017. In early January 2019, the USCG MSC rejected the analysis. The Coast Guard letter stated that the SAE/DOT tank was not equivalent to the IGF code. After the Coast Guard rejection was received, the PRCC team prepared and submitted a revised gap analysis. At the publish of this report, no response has been received from the Coast Guard.

6.3.6 Equipment Quotes

During the course of the project, the PRCC team obtained bids for most of the equipment that was to be used for the conversion. Appendix X provides more details on the equipment and other associated costs. These included the equipment, installation, and testing costs for each system.

6.4 USCG Interaction

As mentioned in Section 4.4, the proposed modifications were fundamentally dependent on the applicability of two references:

1. USCG CG-521 Policy Letter 01-12 Equivalency Determination: Design Criteria for Natural Gas Fuel System
2. International Maritime Organization (IMO) Resolution MSC.285(86) - Interim Guidelines On Safety For Natural Gas-Fueled Engine Installations On Ships, ANNEX 11, (1June 2009)

At the start of the program, the above references and the examination of existing over-the-road technology for proposed transfer, provided enough flexibility to use the existing engines for the conversion. What made this project especially challenging was the fact that as time progressed, the draft IMO IGF regulations became requirements. Changing from the *M/V RON-CHRIS* to *M/V PRINCIPIO* did not create much of an issue, however, when the *M/V PRINCIPIO* sustained ice damage, any change to a different vessel would require adherence with the newly approved IMO regulations.

In 2015, IMO adopted new rules (IGF Code) and in 2017, the new regulations entered into force. With these regulations, new design constraints brought new challenges, most notably the prohibition of using fumigation technologies. In short, this means that if we switched vessels from *M/V PRINCIPIO*, we would need new engines designed for the use of natural gas.

Due to the innovative nature of this system in the inland marine environment and the available systems, the intent was to request special considerations from the USCG. The ahead-of-time submittals of design documents and risk analyses by the PRCC team intended to show that the designs would accomplish an equal level of safety, and meet the intent of the regulations. A few examples of special considerations included:

- LNG tank penetrations below liquid level;
- Dry chemical fire protections requirements;
- Solenoid valve ratings at the tank and gas train; and
- The double block and bleed valve configuration as described in the IMO Resolution.

At the start of the program, the PRCC team held a face-to-face meeting with the USCG. In addition, numerous conference call meetings were held. Due to the extended timeline of the project, many of the USCG staff that participated in the initial meeting did not remain on the project as it progressed. This brought some repetition and rework for the PRCC team as new USCG personnel had to be briefed about the decisions made earlier. The interactions between the PRCC Team and the USCG are provided in Appendices A-U.

6.5 Hybrid Design Concept

When the project team was faced with the prospect of switching from *M/V PRINCIPIO* to a boat required the main propulsion engines to be changed out in order to convert to natural gas, other conversion concepts were discussed as options. One such option was to convert the boat to a hybrid electric propulsion system. The hybrid propulsion concept is starting to become popular in the marine industry and is even making its way into the inland waterways. Hybrid-Electric vessel propulsion towboat designs are more widely accepted in Europe than North America. Appendix Y provides more details on the hybrid design concept.

With the hybrid design concept, natural gas would be used for the generator sets and not the main propulsion engines. In theory, the generator sets would run on natural gas to provide ships service power to the craft while also providing hybrid-electric propulsive power to the vessel. The main engines would have their reduction gearboxes replaced with a hybrid-design gear set that can couple with a motor. Depending on the configuration, this motor could provide the vessel with a sole source of power, or could provide assistive, load-sharing power.

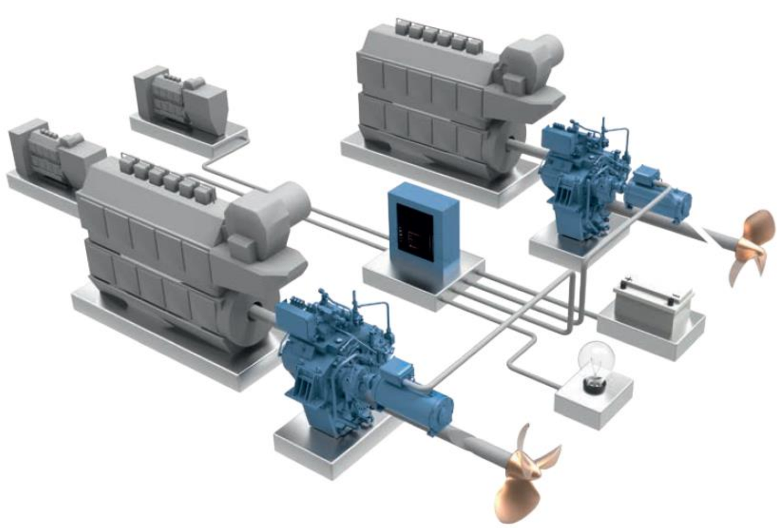


Figure 5: Reintjes Hybrid Drive System

6.6 Catastrophe

M/V PRINCIPIO was built in 1940. After 70 years of operation, the boat was still in good operating condition and was used daily by Gulf Materials for fleeting services and to move coal barges to their tipple facility at Braddock Pa. Operations are suspended on the river only in the winter during ice conditions. In January 2018, the *M/V PRINCIPIO* and two other smaller Gulf Materials towboats were damaged by ice floes on the river. As was discussed in Section 6.2, Gulf Materials had determined that all three boats were a total loss and began searching for replacements (Section 6.7 describes the replacement boats).

During this process Gulf Materials decided to dry-dock *M/V PRINCIPIO* to assess the damage. The PRCC Technical Team was requested to participate in the damage survey to provide input to Gulf Materials regarding the vessel condition and investigate the hull for sufficient sea chest and other conversion requirements.

Figure 6 provides some dry-dock pictures of the *M/V PRINCIPIO*. Damage sustained included a lost steering rudder, bent port propeller, strut bearing damage along with miscellaneous hull cracking and damage. According to Gulf Materials, the shipyard provided an estimate of $250K to repair the damages and replace the port rudderstock. Gulf Materials concluded that the repair of *M/V PRINCIPIO* was not feasible because in addition to the ice damage sustained by the vessel, they would have to make investments to meet the new Subchapter M requirements.

Figure 6: *M/V PRINCIPIO* on Dry-dock

6.7 Replacement Boat/s

Gulf Materials identified two vessels to take the place of *M/V PRINCIPIO* for natural gas conversion. *M/V TIMMY* and *M/V OKAN*. The following sections introduce the two potential candidate vessels. Only *M/V TIMMY* was suitably sized for the conversion.

6.7.1 Gulf Materials - *M/V TIMMY* and *M/V OKAN*

The uncertainty around the use of the *M/V RON-CHRIS* opened up the opportunity for another candidate vessel to be selected. Gulf Materials had recently acquired two new terminal vessels from local operator Campbell Transportation Company, Inc. that were identified by the owner as possibilities: the *M/V TIMMY* and the *M/V OKAN*.

The *M/V OKAN* is a twin-screw towboat built in 1956 by Marietta Manufacturing Co. (Point Pleasant, WV). At a length of 48ft. and a breadth of 15ft, it is rated at 600 total horsepower with two Detroit Diesel 8V-71s. Representatives from the PRCC team conducted an overall ship-check of the vessel in June 2018 to determine its overall suitability for the natural gas engine conversion. Due to the overall condition of the vessel, however, it was concluded that it would not be a suitable candidate. Figure 7 shows the *M/V OKAN*.

Figure 7: Bow View of the *M/V OKAN*

The *M/V TIMMY* is a twin-screw towboat built by Barbour Metal Boat Works (Lemay, MO) in 1957. With a length of 60 feet, breadth of 21 feet, and two Detroit Diesel 12V-71 engines providing 800 total horsepower, it is ideally suited to provide terminal fleeting services for Gulf Materials. The PRCC team conducted an overall ship-check of the vessel, Figure 8, and concluded that it would be more suitable to receive the conversion technology due to vessel condition and space availability. However, the two-cycle Detroit Diesel engines would not be suitable for fumigation insertion because of operational concerns (See Section 7.2), but would be very suitable for the hybrid-design concept as discussed in Section 6.5.

Figure 8: View of *M/V TIMMY* during Barge Operations

6.7.2 Survey

As mentioned in the previous section, surveys of the vessels were made by PRCC team personnel to verify the condition of the vessel as well as known requirements for conversion equipment. Two surveys were made in 2018: one in June and another in July. Appendix Z provides more details on the boats considered for replacement.

After considering the design, PRCC determined that the *M/V TIMMY* was not suitable for conversion since it was not actually owned by Gulf Materials, but an employee's family. New contracts would have to be written for an owner that was not the operator. Based on this complexity, PRCC began to look for another operator in the region to host the conversion project.

6.8 Port of Pittsburgh

The Port of Pittsburgh was contacted to provide information on operators in the region who might be willing to host the PRCC Conversion projects. They provided few leads as most operators in the region were focused on Subchapter M and the shifting business climate.

6.9 Barge Operator Perspective

During the hunt for another towboat to host the conversion, the PRCC team arranged to discuss the project with a large, local towboat operator. Unfortunately, they were not interested, however, they were willing to share some insight as to their reasons why as well as the current state of the business on the inland waterways in the Pittsburgh Region. The following insights were shared with the team:

- Inland industry and their business is in year 5 of an economic downturn so expenditure of capital dollars are closely and carefully controlled. Many inland shipyards have closed their doors. They have been considering natural gas conversion and spent significant resources studying the benefits and have determined that it does not make sense operationally or economically at this time.

- The safety and risk requirement mandated in Subchapter M is taking operating costs to a whole new level. Owners' interests in a retrofit at this time were diminished because it is cost prohibitive considering the cost of Subchapter M compliance combined with natural gas conversion costs – especially since conversion of an older terminal towboat in their fleet would cost upwards of $500K - $1M to comply with Subchapter M. The business downturn from reduced coal transport does not allow for much budgetary flexibility. The economics to support the Subchapter M vessel modifications with natural gas conversion costs dwarf the environmental emission reduction benefit to be gained. At this point, they have no business need to do so.
- They would only consider a new-build for natural gas insertion. Recently, they looked at the cost of construction of a traditional 6,000 hp line-haul towboat, which was $14 - $18M. Insertion of natural gas would drive those costs even higher.
- Fuel pricing is important, but many of their contracts are written now so that fuel increases can be passed on to their customers. Also, the price of diesel versus LNG is an inconsistent variable that puts any ROI calculation at risk. The price spread between diesel and natural gas is currently not as large as at the start of the project. Although, there still remains the opportunity to provide price stability for the customer that may require larger volumes of natural gas.
- Their business/customer base is shifting – transitioning from traditional coal cargoes and expanding into the liquid transport markets. The customers, such as Chevron and Shell, have requirements more stringent than Subchapter M to qualify as a vendor. For example, they require that any vessels used to service their cargo needs to have a 'born-on' date not exceeding 25 years old. This pushes operators to update their fleet and remove the older vessels from their inventories. Therefore, instead of retrofit considerations for the 50 to 70 year old towboats, they are selling or scrapping them and buying newer vessels to add to their fleet.

In summary, they believed that the economics and simply are not there for consideration of natural gas insertion into their business operation. They understand that the original premise of this demonstration was to find a way to convert older terminal boats to natural gas; however, they do not feel that this is a viable path to natural gas – only new-builds. Fuel cost increases are not a big issue, as they have gotten smarter about contracts covering differential prices so one big potential incentive is removed for use of natural gas – especially considering the conversion or insertion costs. Yet emissions remain an important consideration on our inland waterways where commerce for shipping goods and services is not only the importance for use of these corridors. These inland waterways are part of the fluid fabric of our community, improving and sustaining the quality of life for youth and adults providing education and leisure.

The ebb and flow of the design challenges of the project combined with issues of the natural gas production side of the business (i.e. taxes and fees on drilling and permitting issues) and the downturn in towboat cargo shipment including the impact of reduction in the coal shipment also contributed to the cancellation of the project. Based on this discussion, the lack of another boat and working with limited funds, the PRCC Board made the decision to cease the project.

7 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

The following sections provide a summary of the discussion surrounding natural gas retrofit of inland waterways vessels. The original recommendation made in the POP study and proposed to MARAD for this work was not overly complicated. The key to getting natural gas onto the river was to be able to convert the large population of terminal vessels using less expensive and available shore side natural gas technologies. The sections below provide discussion of why this may not now be possible as a result of several hurdles including lack of business drivers, market changes, emergent natural gas requirements applied in a one-rule-fits-all manner, and new requirements for vessel inspection.

7.1 Summary of Drivers for Natural Gas Conversion – Oceangoing vs. Inland

There are distinct differences in the economic drivers and incentives for natural gas conversion between oceangoing and inland waterways businesses. The most significant of these is the worldwide environmental regulations that are driving a major shift in the types of fuel used by oceangoing operators. Stricter IMO air emissions regulations for vessel above 400 gross tons are driving these marine operators to look at alternative fuels and technologies. Ocean going operators are seeking to switch to lower sulfur fuels, exhaust treatment, and alternative engine and fuel technologies to meet these requirements. For inland operators, however, regulations to use ultra-low sulfur diesel (ULSD) fuel have been in place since 2014. Inland operators may also have some mechanisms in contracts to help defray the added cost of purchasing cleaner fuels by passing some of the costs onto their customers.

Natural gas engine technology development by equipment manufacturers has focused on the larger oceangoing ships where the equipment is exponentially larger and the cost/profits are larger. Since inland vessels are not required to be classed by any classification society as are oceangoing vessels and prior to Subchapter M inland vessels were not inspected vessels, regulatory bodies have not been specifically focused on the needs of inland operators. Based on the experience of the PRCC team, the apparent inflexibility of regulatory bodies to consider the level of technology on inland vessels and their missions as part of the regulatory equation is actually a negative driver for inland operators.

Unlike ocean going vessels where the market and therefore the profit margin on engines sold is worth the investment cost to develop new engines/technologies, there is very little emphasis from the engine manufacturers to develop new engines/technologies for towboats where the market and therefore the profit is much smaller than for ocean going vessels. The result is that most engines in the horsepower range of towboats are developed for on or off highway markets, and adapted for powering inland towboats.

7.2 Inland Waterway Market Changes

As mentioned previously in this report, the two main factors driving natural gas conversion are emissions regulations and economic considerations. Inland waterway vessels already comply with current emissions requirements, thus making the price differential between ULSD and natural gas the only current driver.

The cost differential between ULSD and natural gas provides the basis for conversion justification (i.e. return on investment (ROI)). As the prices of ULSD have historically risen and fluctuated, natural gas has been more closely considered as an alternative. At the beginning of the POP Feasibility Study, fuel prices were at an all-time high. As time progressed, however, it became apparent how hard it is to forecast trends in crude oil pricing. Economic downturn, market supply, and political trends have brought the prices of crude oil back down to the lowest they have been in years.

In addition, vessel operators are seeing a shift in business trends and regulations. Where coal once was in high demand, liquid cargoes are becoming more prevalent. Lower demand in coal potentially equates to shorter routes in service. This further extends the ROI and lessens any interest in conversion. In addition, the implementation of Subchapter M by the USCG has either caused operators to spend more capital bringing vessels up to compliance, or has anchored vessels out of compliance. Though both of these factors require cost-cutting and tighter budgeting efforts across all companies in the industry, it has changed the way services are provided on the rivers.

7.3 Natural Gas Regulation Discussion

Section 4.6 discussed how many aspects of IMO were not applicable or reasonable for a small towboat on the river.

For example, IMO regulations, such as the IGC, concerning fire main pumps do not align with USCG requirements for towboats on inland river systems. However, a fire main system was determined to be a necessity for the LNG and gas-fuel systems. While IMO provides guidance related to fire mains and pump, it would have been overdesigned for our much simpler applications found on inland boats. Many riverboats (especially the smaller ones) simply have a portable fire pump where they drop the suction line into the river. Rather, it was preferable to rely on engineering judgment and decades of maritime experience with towboats on the rivers to design a more practical system. However, any specifics related to the gas-fueled system would be carefully analyzed.

During the engineering design phase, some regulations within the USCG CG-521 Policy Letter 01-12 and the IMO Resolution MSC.285(86) were found to be nearly impossible to accommodate, and would need to be considered on a case-by-case basis. Similar to that described above, the regulations were written with a much larger ship in mind. As a result, all parties involved understood that some deviations due to the size and nature of the vessel would need to be considered. Some specific examples of this are noted in Section 6.3.4, “Design Challenges”.

7.4 Regulatory Challenges

There were several design challenges impacted by existing regulations that do not necessarily conform to inland vessel design and operation. Inconsistent regulations exist between USCG, DOT-4L, IMO, ASME and others. Due to the novelty of this system in the marine environment, especially the rivers, and the available systems, the intent was to request special considerations from the USCG while demonstrating that the design accomplishes an equal level of safety, and meets the intent of the existing regulations developed for ocean going vessels. The biggest obstacle in obtaining USCG approval to move forward was that USCG held most gas-system drawings and requests for special considerations in abeyance until receipt of a full design package. Because of this, it became very difficult to make engineering, design and financial decisions regarding the direction of the project when the uncertainty of the review status of major key elements of the design remained unclear.

The first thing that would have significantly helped the project is if USCG could offer some kind of conditional approval, or approval in principle, similar to ABS. The first submittal made to USCG was a “basis of design” document, which was intended to illustrate all technical aspects of the project in an effort to receive confirmation that that major elements of the project would be approved provided all relevant criteria were met.

Second, it would have helped the project to have more continuity of USCG MSC personnel throughout the project. Due to the length of this project, reviewer/personnel turnover was inevitable and it did not help to have to repeat discussions with new personnel of challenges/obstacles that had already been resolved at earlier stages in the USCG MSC review process. Approximately a year into the project, during a phone conference with USCG, just after a personnel turnover, it became apparent that some were not aware of the previous design documents such as the design basis letter and risk analysis, and the most critical components of these design documents were not understood. Early in the design, there was a mutual understanding between the PRCC team and USCG regarding the direction of the project that was lost in the course of turnover. This, combined with no official conditional approval presented many obstacles for both the PRCC team and USCG.

Due to USCG MSC personnel turnover, which slowed approval in principle for key elements of the project (such as tanks), the team soon became stuck in a “Catch-22” situation. USCG would not approve key portions of the project until they had received a full design package. Without gradual/incremental design approvals from USCG, we were not able complete add-on or further design work without knowing if the USCG had any major objections because of the project’s limited funds. These design packages included full vendor drawings for systems such as the fire and gas detection alarm and shutdown systems, LNG containment system, and gas supply and monitoring systems. Due to budgetary constraints, the team could not fund the various vendors to produce the detailed system design without any of the major milestone approvals for USCG such as tank approval, gas system approval, etc.

With respect to the difficulties regarding the submittals of detail design packages, the unwillingness of the tank vendor to work with the team and provide proprietary technical information to USCG, there was an additional obstacle to the progression of the project.

This inability to move forward forced the teams’ hand to pursue alternative routes, such as conducting a gap analysis on over-the-highway LNG fuel tanks, as requested by the USCG MSC, comparing the over-the-highway design to separate regulatory groups. The PRCC team knew that the tanks were approved by DOT-4L for highway use. Also, the USCG MSC required that the tank be designed to ASME specifications, or per applicable portions of 46 CFR. Without intimate knowledge of the tank design, the team could not confirm the adequacy of tanks with respect to either USCG direction. Thus, the team compared the requirements for all aspects of the tank design of ASME to DOT-4L, NFPA 52, and IMO Resolution MSC.285(86). According to USCG, this gap analysis did not suffice, as they wanted us to also include comparison to the ICG code. The team disagreed with this determination, since USCG CG-521 Policy Letter 12-12 (2.8.1) specifically states: "Type C independent tanks may, as an alternative, meet ASME Boiler and Pressure Vessel Code, noted in Section VIII, Division 1 or 2". The team felt this was an incorrect and unfair determination, and that a reconsideration was appropriate.

We could not receive regulatory approvals on one end and fund vendors detailed designs on another, while the USCG continued to delay decision on any attempt the team made to bridge the approval gap via objective engineering proposals or gap analyses, notwithstanding the limited avenues, in an attempt to create some momentum.

7.5 Recommendations

Despite the fact that the project team did not have the opportunity to convert a towboat to LNG for demonstration, the team was able to identify several key facts on the state of the towboat industry post-Subchapter M. These findings led to three important recommendations before a conversion of this nature be attempted again within the inland system. Those recommendations are:

1. <u>Create a more appropriate ruleset for smaller vessels, vessels with smaller fuel capacity, or vessels operating within a restricted geographical region (i.e. the inland waterways)</u>

   The project team ran into several design considerations that were operationally prohibitive to the vessel or unrealistic. For example, the fire protection systems and firefighting requirements required by the USCG called for quantities of dry chemical fire extinguishing agents that would have been greater than the amount of LNG onboard. In addition, defined hazardous zone for various emissions placed the majority of the vessel within a hazardous zone.

   The project team took fire safety and hazardous zones seriously, but suggest a revisit of the current rules to ensure that they are realistically applied to certain vessels and industries.

2. <u>Allow for the acceptance of cross-industry standards</u>

   In the case of this project, the team had difficulty receiving USCG acceptance for the use of over the highway fuel tanks onboard the vessels. These tanks met several industry standards for highway use in arguably more unpredictable and dangerous applications.

   The project team believes that realistic consideration of design and safety should be made when equipment regulated and approved by other government agencies is installed on vessels inspected by the USCG.

3. <u>Revisit the classification of "Major Modifications"</u>

   The USCG allows certain levels of leniency for older vessels complying with Subchapter M, in some instances only requiring them to meet specific safety requirements. However, this changes if vessels undergo "major modifications", in which case the vessel must fully comply with Subchapter M. "Major modifications" seem to be defined as a cost percentage greater than or equal to a vessel's current value. As discussed within this report, this was a limiting factor when determining the possibility of converting vessels. Despite the fact that the conversion had the potential to improve emissions and operating costs, it would have required the vessel to fully comply with Subchapter M, drastically increasing the overall costs of conversion.

The project team believes that this actually has a negative impact on the industry and suggests the classification of "major modifications" be revisited by regulatory authorities.

Regardless of the outcome of this project, the team also believes that the findings summarized in this report can provide an invaluable baseline for consideration again in the future should changes to the industry or markets occur:

1. Although as the cycle of the natural gas industry is experiencing a bit of an upturn and a current increase in drilling, an opportunity to revisit this research demonstration may be in the near future. Such a revisit and the designs proposed/used would be highly dependent on USCG approval of the use of fumigation system or the availability of new engine designs.

   As the price differential between diesel and natural gas increases, the efforts of this project can provide a baseline from which future companies or research teams can start again.

2. The Inland Waterways remain important corridors or key factors of success to maintain the movement of goods and services that support and supply the needs of our ever-growing neighborhoods, businesses, educational and health institutions. With implementation of natural gas as a fuel for river vessels, emission reduction is inevitable whether using fumigation and insertion or by employing a hybrid fuel system. In each case, natural gas presents one of the simplest, cleanest, and in our gas-rich region the most reliable, potentially viable option for these owner operators of towboats.

   Additional/stricter changes in emissions regulations can allow for the revisit of this project.

3. The improving technology of the fueling infrastructure (fixed and virtual; methodology and methods available) for on-board clean fuel storage of over-the-road vehicles, that can be employed as technology transfer for marine vessels fueling options, has promise to catapult affordable clean options to the forefront of the industry, if other regulations not necessary to vessels operating on the Inland Waterways (as opposed to oceangoing vessels) might be waived. Membrane tank systems for example are evolving and may eventually permit natural gas to be loaded in voids and tank spaces traditionally filled with diesel fuel.

   Changes in this technology that fall within the bounds of regulation have the potential to provide additional solutions, preventing major design and vessel operational changes.

APPENDICES

Appendix A **Dual Fuel Inland Towboat, Basis of Design**

THE SHEARER GROUP

PRELIMINARY

DUAL FUEL INLAND TOWBOAT

BASIS OF DESIGN

Date: 07-28-2016

TSGI Corr. No. 0315-002-900R0

NAVAL ARCHITECTS : MARINE ENGINEERS : MARINE SURVEYORS

Member: THE AMERICAN WATERWAYS OPERATORS

TABLE OF CONTENTS

Dual Fuel Inland Towboat 1

Basis of Design 1

1. References 3
2. List Of Acronyms 3
3. Overview 4
4. Applicable Regulations 5
5. Vessel Design 5
   - 5.1 Vessel Type and Principle Characteristics 5
   - 5.2 Hull Structure 6
6. Arrangements and Design Relating to Gas Systems 6
   - 6.1 General 6
   - 6.2 Material Requirements 7
     - 6.2.1 General Design Specifications 8
     - 6.2.2 Prohibited Materials 8
   - 6.3 Location and Separation of Spaces 8
   - 6.4 General (GAS) Pipe Design 8
   - 6.5 System Configuration 9
   - 6.6 Gas Supply System for Gas Safe Machinery Spaces 9
   - 6.7 Gas Fuel Storage 9
   - 6.8 Fuel Bunkering System 10
   - 6.9 Ventilation System 11
7. Gas and Non-gas Related Systems 12
   - 7.1 Main Propulsion 12
   - 7.2 Air Fumigation and Gas Blending Technology 12
   - 7.3 Generators 14
   - 7.4 Diesel Oil Fuel System 14
   - 7.5 Steering System 14
   - 7.6 Nitrogen Storage System 15
8. Fire Protection and Fire Extinction 15
   - 8.1 Firefighting Philosophy 15
   - 8.2 Water Spray System 15
   - 8.3 Dry Chemical Powder Fire-Extinguishing System 16
   - 8.4 Fire Detection and Alarm System 17
9. Alarm and Monitoring Systems 18
   - 9.1 Fire Detection and Alarms 18
   - 9.2 Gas Detection and Alarms 18

9.3 Safety System Functions for Gas Supply System 18
10. Hazardous Zone Areas 20
11. Preliminary Stability 22

1. References

A. USCG CG-521 Policy Letter 01-12 Equivalency Determination: Design Criteria for Natural Gas Fuel System
B. International Maritime Organization (IMO) Resolution MSC.285(86) - Interim Guidelines On Safety For Natural Gas-Fueled Engine Installations On Ships, ANNEX 11, (1June 2009)

2. List Of Acronyms

LNG: Liquefied Natural Gas

NG: Natural Gas

ESD: Emergency shut down

ICG: International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk

USCG: United States Coast Guard

ABS: American Bureau of Shipping

TSGI: The Shearer Group, Inc.

PRCC: Pittsburgh Region Clean Cities

MARAD: United States Maritime Administration

MARVS: Maximum Allowable Relief Valve Setting

3. OVERVIEW

Through a cooperative agreement, MARAD has provided $730,000 to Pittsburgh Region Clean Cities (PRCC) to convert a towboat engine from diesel to dual fuel diesel/LNG. Results from this demonstration project will help expand the development and availability of natural gas conversion technology for smaller scale tug, tow, and harbor vessels. PRCC will collect air emissions data before and after the conversion, which will allow for operational and emissions comparisons. This document describes the basis of design for the conversion of the 58' x 20' x 6' inland towboat "Ron-Chris". The twin screw towboat is powered by twin Cummins NT855 diesel fuel engines.

Figure 1: Ron-Chris

The best practical solution for dual fuel conversion of the *Ron-Chris* due to its installed power and arrangements, is utilization of air fumigation (pre-mixed gas injection). Air fumigation technology injects a small amount of natural gas into the diesel engine's turbochargers air intake compressor, making approximately an air-fuel ratio of 50:1. The turbocharger compressors will mix the gas and air into a homogenous mixture prior to entry into the engine air intake manifolds. The higher energy value of the mixed natural gas and air allows reduced amounts of diesel fuel to be injected into the engine cylinders to reach the point of the compression ignition. The amount of diesel fuel displaced with natural gas is called the substitution rate and can be as high a as 50%. Fumigation systems can substitute as much as 70% of the diesel fuel, but at the higher rates "knock" becomes a problem so 50% is considered a safe substitution rate. The technology is currently widely accepted and being implemented for use in the off-road mining and oil industry, locomotive industry, and on-road trucking.

This document serves as a sound and novel solution for the implementation of dual-fuel technology in the inland marine industry. The conversion of the *Ron-Chris* would be the first of its kind for towboats, highlighting the advantages and safety of natural gas as an alternative fuel source.

4. Applicable Regulations

The modified towboat is intended for inland service in United States waterways and is US Flagged. The scantlings of the vessel are currently unknown, however future structural modifications will be to the standards of *ABS Rules for Building and Classing Steel Vessels for Rivers and Intracoastal Waterways*.

Modifications to the vessel in regards to the LNG fumigation system will be carried out in accordance with references A and B (as applicable):

USCG allows the use of the "gas safe" configuration, and does not provide guidance for the ESD-protected space as it falls outside the scope of reference A. Because the ESD-protected machinery space configuration is far less practical for this project, the goal of the vessel conversion is to not have the entire engine room a hazardous area, and thus to comply with the "gas safe" configuration by ventilating hazardous items and areas as required by reference A. See section 5.5 of this report for further details.

International standards for the design of gas-fueled ships are currently in development by the IMO.

5. Vessel Design

5.1 Vessel Type and Principle Characteristics

The vessel is an all-welded steel, diesel fuel-powered, twin screw, towboat suitable for push towing on inland and intracoastal waterways.

The principle dimensions of the vessel as designed are:

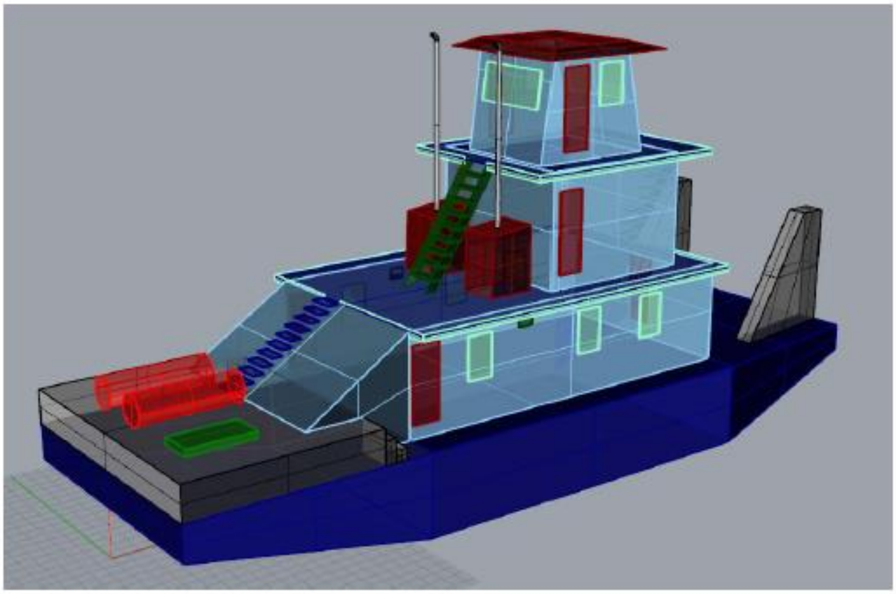
Length, molded	17.7m (58'- 0")
Beam, molded	6.1m (20'- 0")
Depth, molded at side	1.8m (6'- 0")
Draft	1.3m (4'- 3") est.

The hull is of all-welded steel construction consisting of the main hull, main deckhouse, upper deckhouse, and pilot house.

The main hull is divided into various compartments to house the main machinery, auxiliary systems, deck stores, access ways, independent tanks and consumable liquids.

On-deck storage will house the following consumable liquids:

Liquefied Natural Gas	Approximately 250 gallons



5.2 Hull Structure

Due to the relatively small tankage being installed on the aft deck, no significant structural changes will have to be made to the vessel's hull. Modifications to the deck house structure will be necessary due to hazardous zones considerations; these are outlined in following sections. To accommodate tank/manifold arrangements, tank support structure will be incorporated into the stern deck structure. 250 gallons of LNG weighs approximately 1,000 pounds, plus the weight of the tank/s. Inspection of the scantlings will be conducted prior to tank installation to ensure structural adequacy to handle the loads from the tanks.

Cutouts into the main deckhouse will be made to run gas supply and ventilated pipe to the engines. These cutouts will be made so no structural members will be intersected or have to be modified, if possible, and the interface between the pipes and steel deck will be made watertight.

Additionally due to the small size of the LNG storage system, it will be proposed to have the tanks skid mounted for easy removal for inspection purposes.

6. Arrangements and Design Relating to Gas Systems

6.1 General

A risk analysis will be conducted in accordance with section 2.1 of reference B in order to ensure that any hazards associated with installation, operation and maintenance are eliminated when possible, and when not possible, mitigated as necessary.

The proceeding subparts of section 6 and 7 describe the design, arrangement and operation of the gas system and closely related systems. Please see the gas system schematic, Figure 2, for reference. The items in figure 2 will be explained in the subsequent sections.

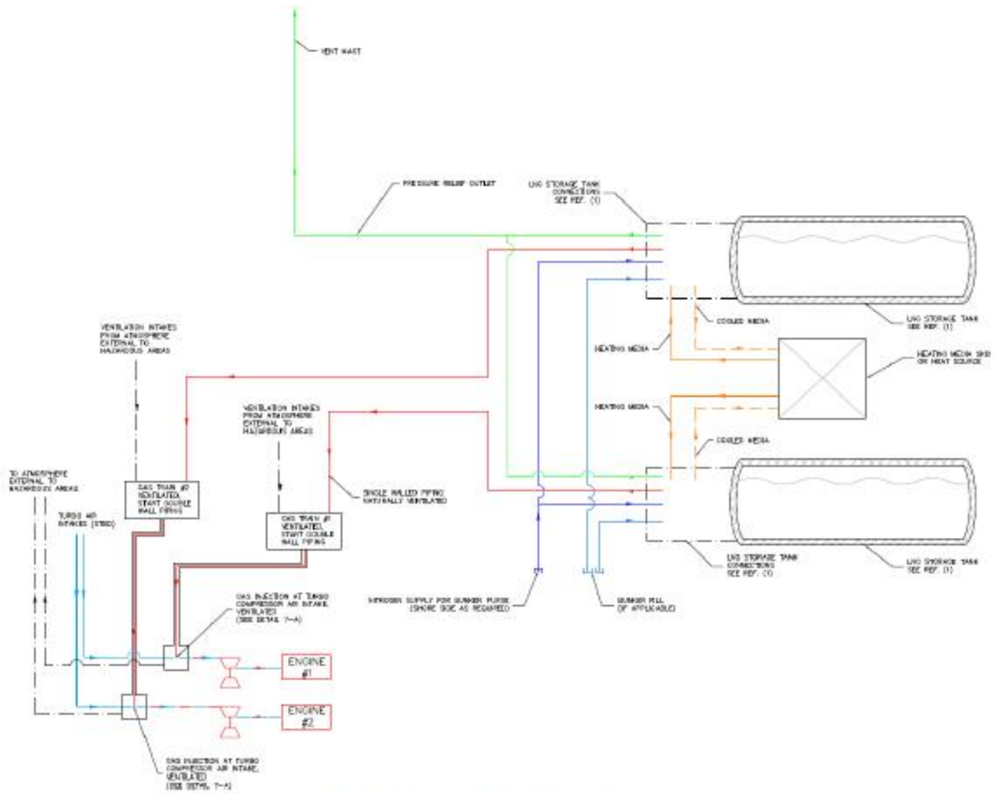


Figure 2: Gas Fuel System Schematic

6.2 Material Requirements

The materials used in gas piping, pressure vessels, and other components in contact with gas will be in accordance with chapter 6 of the IGC Code. Materials for liquefied gases in particular will follow section 6.2 of IGC. Materials used for gas piping other than short sections attached to gas tanks, will not have melting points below 925°C (1697°F); short pipe sections mentioned below this melting point are to be wrapped in A-60 insulation. See section 6.4 for more detailed piping specifications.

6.2.1 General Design Specifications

The following general design specifications will apply to the containment and delivery systems (as applicable):

a. SAE J2343
b. ASME Boiler and Pressure Vessel Code
c. ASME B31.3 (Code for Pressure Piping)
d. NFPA 52, 59A
e. DOT4L (49CFR178.57)

6.2.2 Prohibited Materials

The following materials are prohibited in construction for any areas anticipated to be below 32° F:

a. Carbon Steel
b. 400 Series Stainless Steel
c. Zinc
d. PVC
e. Rubber

6.3 Location and Separation of Spaces

Locations of hazardous areas will be consolidated such that the number and extents of hazardous locations is kept to a minimum. Natural gas fuel storage will be outside on the vessel's stern deck, therefore not below any accommodation, service or control spaces. Arrangement of doors will be such to prevent direct access through doors from gas-safe to gas-dangerous spaces, eliminated the requirement for airlocks. Class A60 structural fire protection will be required on certain areas of the vessel that are adjacent to the LNG storage tanks and the bunkering areas. These areas include the stern deck plating, the aft side of the main deckhouse and machinery spaces surrounding the bunkering stations, and the exhaust stacks.

6.4 General (GAS) Pipe Design

Piping runs will be designed to minimize the number of flanged connections by welding ends when possible. The minimum wall thickness of the pipes will be designed to the greater of ASME code for pressure piping (ASMEB31.3, process piping.) The pressure used shall be the maximum of the following design conditions: vapor pressure specified in 4.2.6.2 of IGC Code, the MARVS of the gas tanks, pressure of the discharge relief valve setting, maximum total discharge or loading head of gas piping system, a pressure of 10 bar. The design condition and allowable stress for gas piping shall be in accordance with section 2.5.5 and 2.5.6 of reference B. All lines that carry LNG Liquid will be 300 series stainless steel tubing. Fill and fill cross over lines may be rigid or flexible metallic or non-metallic tubing rated for cryogenic services. Vent and relief lines may be constructed out of flexible tubing or hose suitable for natural gas service. Any section of pipe containing liquefied gas, which may be isolated, will be fitted with a relief valve. Gas piping will be installed with sufficient flexibility, and color marked. Since liquid and vent lines repeatedly go from ambient to cryogenic temperature allowance for thermal expansion will be designed into the piping system. This will be accomplished by incorporating S Bends or expansions loops into the rigid lines. Gas piping will be at least 2'-6" from ships side. Gas piping will pass from outdoors directly to the machinery space containing the engines. In the engine room, double walled gas piping will be vented from an external location to another external location (both nonhazardous in absence of the vent inlet/outlet in consideration). A complete stress analysis for each branch of piping which will see temperatures below -166°F will be conducted in accordance with 2.5.15 of reference B; this stress analysis will account for the weight of the pipes plus cargo and accelerations, internal pressure, thermal contraction, and loads induced by movements of the vessel.

6.5 System Configuration

The system will comply with the "gas safe" machinery spaces configuration outlined in 2.6 of reference A, and in more detail in section 2.6.2 of reference B by ventilating hazardous items and areas as required by 2.7.1 of reference A for low pressure piping, i.e. double walled piping. Specifics for this piping system are detailed in the following sections.

6.6 Gas Supply System for Gas Safe Machinery Spaces

The gas supply lines passing through enclosed spaces (machinery space containing main engines) will be completely enclosed by a pipe to act as a double wall. The space between the inner gas pipe and the outer pipe will be equipped with mechanical under pressure ventilation with a capacity of at least 30 air-changes per hour. The connection of double wall gas piping to the gas injection valves will be completely covered by the outer pipe per 2.7.1.2 of reference B. Gas detectors will then be fitted above the engines per footnote 7 of 2.7.1.2 of reference B; additionally gas detectors will be fitted in the upstream-air intakes. The outer pipe in the double wall piping will be a larger pipe, designed to the max working pressure of the gas pipes per 2.7.1.4 of reference B.

6.7 Gas Fuel Storage

A cryogenic storage system consisting of 2 tanks will be used to store LNG. The tanks will be a type C double wall vacuum insulated pressure tank, which meets ASME Boiler and Pressure Vessel Code, Section VIII, Division 1 or 2. Pipe penetrations will not be below the liquid level. The storage system will have a design pressure of approximately 8 bar (116 psi), but no more than 10 bar (145 psi).

Pressure relief valves will be fitted to the storage system and vented per requirements of reference A and B. The gas vent mast serves as the outlet for all system pressure relief valves and bleed lines for purging the gas supply lines. The buffer zone (not a hazardous zone) created by the vent mast outlet is 10 m (33'.) All potential ignition sources will be located out of this buffer zone created by the gas vent mast. Outlets from the pressure relief valves to be located 6 m (20') above the weather deck/working area. Outlets from the pressure relief valves are also to be located at least 10 m (33') from the nearest air intake/outlet, opening to accommodations, service, control space, gas-safe space, or exhaust outlets from machinery. All the pressure relief valve outlets in the gas system are located at the vent mast.

Gas storage will be located on the aft deck (or on modified on-deck structure) open to atmosphere. Tank locations and gas piping are all at a minimum 760 mm (2'-6") away from the vessel's side shells. The storage system are located in the atmosphere, such that there is sufficient natural ventilation to prevent accumulation of escaped gas. Piping will then be routed externally to the engine room, and will allow for the use of single wall piping for piping runs in the weather.

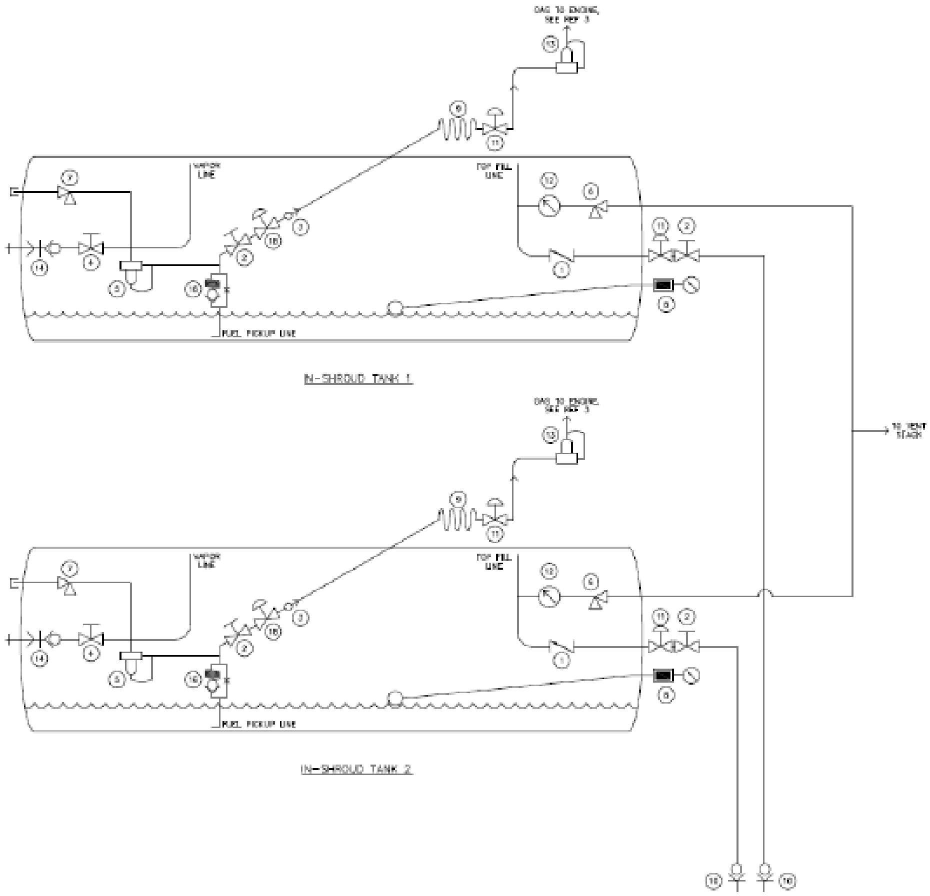


Figure 3: LNG Storage and Bunkering Arrangement

6.8 Fuel Bunkering System

The selection of the LNG storage system (tank manufacturer) has not been finalized, once this system is chosen, the bunkering arrangement will be finalized. Bunkering will either be accomplished via bunkering lines, as shown in Figure 3, or direct fill at the tanks.

The bunkering station and manifold shall be located on the aft end of the vessel on the open deck to ensure sufficient natural ventilation. Bunkering is a combination of bottom filling and top spraying (depending on tank manufacturer) of LNG. By spraying LNG the gas cushion on top of the LNG fluid decreases, resulting in lower tank pressure. The bunkering station is shielded from vessel plating and structure by a stainless steel barrier. Drip trays are to be arranged under the bunkering manifolds to contain any possible spillage during bunkering operations, with drainage arrangements during bunkering.

Class A-60 insulation shall sufficiently shield the bunkering station from the adjacent machinery room (aft and side bulkheads of the generator room.)

Bunkering will initially be conducted from truck to ship. A supplier will be chosen and an agreed fueling interval will be decided upon. Bunkering will be overseen by the truck operator, or another individual trained in the handling of cryogenic liquids.

During bunkering, the process and control system installed is continuously controlling the level and pressure of the LNG in the tank to prevent overflowing or overpressure the system. The control panel for the bunkering process is located in a safe location from the bunkering station with a visual view of the bunkering process. At this control location, pressure and tank level will be monitored; also overfill alarms, automatic shutdowns and gas detection in the ducting around bunkering lines will be indicated here. The final location will be decided upon by the system and tank manufacturer.

The bunkering manifold consists of a fill pipe and a vapor return line. The vapor return line will return evaporated gas to the bunker supplier and in some cases will be used to balance delivering and receiving tank pressures. A manually operated stop valve and a remote operated shutdown valve will be combined and fitted in the bunkering line.

The hose connections used for bunkering will have a quick-release coupling installed and will be drip free. The hose connection is typical for cryogenic gas use, with two lift handles, press and rotate to lock actuation. The receiving connection in the cold box will be an insulated flange.

Located on the vessel's loading manifold during bunker operations will be a break-away emergency release coupling to each LNG hose. The coupling acts as the weakest part of connection during bunkering, so the hose is protected. Inside the coupling are two quick-close shutoff valves, which in the event of disconnections close to prevent any system leakage. Bunkering lines should be arranged for inerting and gas freeing.

LNG should be of the following quality:

• LNG main components	CH_4, C_2H_6, C_3H_8, C_4H_{10}, C_5H_{12}, N_2
• LNG minimum Methane Number	80
• LNG maximum nitrogen (N_2) content	0.8 mole-%
• Minimum LHV (Lower Heating Value)	35.5 MJ/Nm³
• Maximum density (as a base for calculations)	450 kg/m³
• LNG bunkered Temperature	-162 °C (-260 °F)
• LNG bunkered pressure	1 atm

6.9 Ventilation System

Ventilation of hazardous and non-hazardous locations will be separate. Ventilation fans will be in accordance with 2.10.1 of reference A and not recycle any vapor from vent discharges. Intakes and exhausts will have protective metal screens in accordance with 2.10.1.1(b) of reference A. Operational controls to be located outside of ventilated areas. Audible and visual alarms will be signaled should any required ventilation be lost; these alarms to be located at a permanently manned location.

For required ventilation systems (such as double wall piping around gas pipe), independent fans, each of sufficient capacity, will be installed. Ventilation air inlets for these hazardous areas shall be located in non-hazardous locations. For non-hazardous locations (such as generator room or engine room,) ventilation inlets shall be located in non-hazardous locations at least 1.5 m (5') away from the boundary of any hazardous area.

Ventilation air outlets for non-hazardous spaces (generator & engine rooms,) will be located in non-hazardous locations. Ventilation air outlets for hazardous spaces (double wall pipe ventilation) will be located in areas of the same or lesser hazard (i.e. zones 1, 2 or non-hazardous.) The main engine and generator exhausts are both external to hazardous zone areas.

The vessel will be designed utilizing the gas safe machinery space guidance of 2.6 of reference A. Machinery spaces are fitted with sufficient mechanical ventilation to prevent the accumulation of gas vapors in dead spaces. The ventilation for the engine room will be independent of all other ventilation systems. The ventilation fans are such that if one fan fails, or a group of fans on a common circuit, the total ventilation capacity remains 50% of that required. In the event of gas detection in the engine space, the engine room ventilation system shall have capacity of at least 30 air changes per hour.

The double wall pipe ventilation surrounding the gas pipes will have a ventilation system with a capacity of at least 30 air changes per hour.

7. Gas and Non-gas Related Systems

7.1 Main Propulsion

Two (2) Cummins NTA-855 diesel fuel engines of 350 horsepower each are currently installed, producing approximately 700 total horsepower based on the engine nameplate data.

The air intakes for the engines on the starboard side of the vessel *may be* required to shift due to hazardous zone considerations. The air intake for the engine room will be located in a non-hazardous area.

7.2 Air Fumigation and Gas Blending Technology

Air fumigation technology is not invasive to the engine. Engine integrity and normal governor operation is not interfered with. Air fumigation kits are installed externally to the engine allowing for easy installation and removal, if necessary. Air fumigation dual fuel conversion kits operate on the principle of blending small amounts of natural gas, at approximately an air-fuel ratio of 50:1, injecting the gas prior to the turbocharger compressor air intake.

Gas injection rates vary based on the load on the engine. The engine cannot operate on 100% natural gas since a level a level of diesel fuel is required for ignition of the gas/diesel mixture. The engines are able to operate on 100% diesel fuel in case gas supply is not available. While idling and during initial startup the engine operates on 100% diesel fuel. The normal operating range for the air fumigation kits is an engine load greater than 10%, when engine coolant temperatures and exhaust gas temperatures are at normal OEM operating values. The change from diesel to a blended mix of gas and diesel is automatic by the dual fuel controller, which takes input from the electronic control units which monitor the base engine functions. The vessel operator will not need to initiate the gas blending system when it is on and set for normal operation parameters.

The electronic control units installed monitor base engines functions within the OEM engine system, including: coolant temperature, exhaust gas temperature, load/manifold absolute pressure. The control system will not allow gas flow to the engine unless the base engine parameters are met. The OEM engine governor controller will read engine parameters and act to reduce diesel fuel flow as gas is introduced to maintain the specified engine speed and load.

The gas train is the regulator unit which allows gas to the engine turbocharger and intake manifold. A typical gas train consist of a manual shutoff valve, gas filter, vapor draw regulator, dual solenoid shut off valve, electronic throttle body valve and induction gas mixer upstream of the engine turbocharger. See Figure 4.

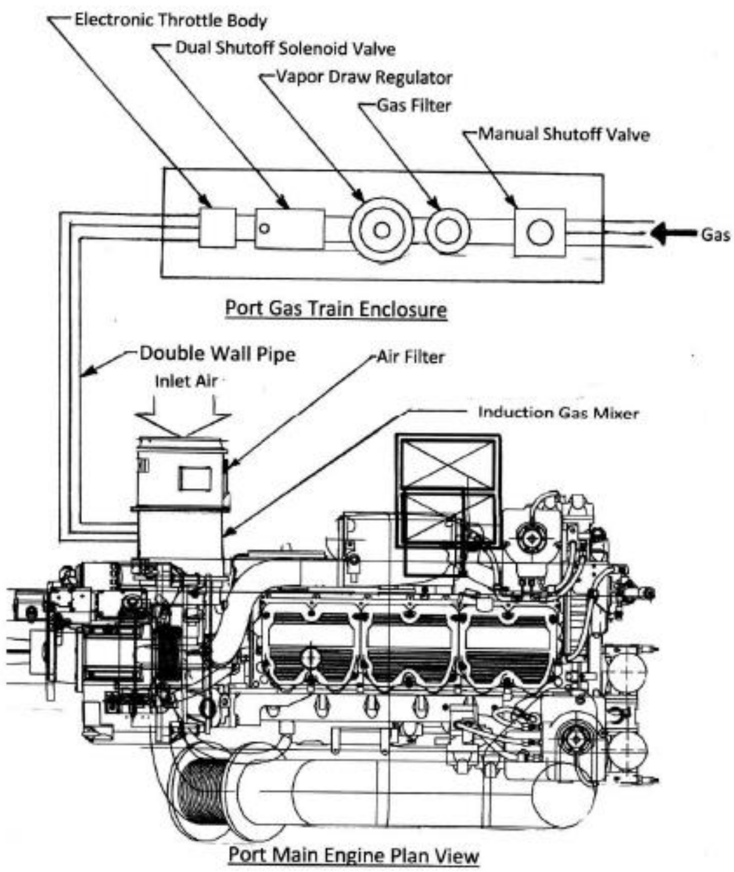


Figure 4: Sketch of an Air Fumigation System in a Gas-Safe Engine Room Configurtation

The gas trains will be located on the vessel's weather deck (outside) above the engines within gas-tight ventilated enclosures. The purpose of the gas tight gas train enclosure is to mitigate the possibility of a gas leak from any of the gas train components out of the enclosure, and contain hazardous zones emanating from the valves. It is approximately five feet long and is of gas tight stainless steel construction. It is a component of the double wall piping and under operating conditions it is ventilated at a rate of 30 air-changes per hour.

Typical dual fuel engines have to use glyocol-heating units to circulate warmed glyocol to heat the LNG to change the LNG to the gaseous phase. However, sometimes the evaporator, instead will use the heat of the engines to warm and evaporate the LNG to a usable intake temperature to the gas train. The specifics of the system will be decided upon by the owner, the third party fumigation company, and/or the tank manufacturer. Therefore, the vaporizer and/or LNG/NG heater systems are not finalized nor defined at this stage. At this stage, the vaporizer/heater shall be located in the open atmosphere near the tank, not in a ventilated enclosure or box. Once more information on these systems are known, a more refined arrangement shall be provided. Currently in the on-road truck conversion industry, the engine heat is used in a similar process. This is enabled because of the smaller amount of gas used by air fumigation technology, as opposed to a spark ignited gas engine displacing 100% diesel.

There are multiple third party vendors available for providing the gas fumigation technology. A couple include Altronics, and American Power Group. Altronics has had discussions with the US Coast Guard to get their system approved for use on marine vessels. However, to our current knowledge, they currently do not have approval. It's recommended that the vendor chosen to supply the kits and work with to get regulatory approval, will already be actively pursuing approval from marine regulatory bodies.

7.3 GENERATORS

There are currently two generators on board the vessel located in the furthest aft space. The current power outputs of the two generators are roughly 10 kW and 19kW. The generators will need to supply all the new loads for the ventilation, gas-detection, and monitoring systems related to the gas systems. Additionally, the systems must be connected in such a way that the redundancies and inherent safety measures required in previously noted systems are met.

7.4 DIESEL OIL FUEL SYSTEM

There is no intention to make any changes to this system.

7.5 STEERING SYSTEM

The vessel has conventional steering including main and flanking rudders which appear to be either hydraulically or cable-operated. This will need to be confirmed, however whether it is hydraulic or cable steering, neither will cause any issues since it is not electric.

7.6 Nitrogen Storage System

Nitrogen will be used on the vessel to purge gas-bunkering lines during bunkering procedures. It will not be used to inert the outer wall in double walled gas supply piping running below deck, as it will be ventilated per 2.7.1 of reference A, see section 5.6 and 5.9.

Due to the size of the vessel and amount of nitrogen demand, nitrogen will be stored in a non-hazardous location on the vessel in compressed cylinder tanks, instead of installing a nitrogen generation system. However should it be feasible, and allowed by regulatory, the nitrogen will be stored shore side, as it would only be used for purging the lines during bunkering process. Piping from the nitrogen storage tank pressure regulator would be run to the gas train and bunker station. The piping will have working pressure less than 10 bar. Shore side inerting and nitrogen will be used during bunkering operations if available in order to reduce use of the vessel's onboard nitrogen supply, if applicable.

To prevent the return of flammable gas to the gas safe nitrogen storage space, the inert gas supply line will be fitted with two shutoff valves in series with a venting valve in between. These valves will be located outside of any non-hazardous area and must be fully functional under all normal vessel operating conditions. The valves will be automatically operated, taking signals from the inert gas flow or differential pressure.

If the tank manufacturer chosen allows for the tanks to be filled at the tanks, nitrogen gas will not be required.

8. Fire Protection and Fire Extinction

8.1 Firefighting Philosophy

In the event of a fire, attempts will first be made to isolate the event by shutting down ignition sources and the fuel source of the fire. The fire will be addressed with a maximum rate of application of dry powder. If located at the bunkering area, the powder will be automatically deployed by the fixed dry chemical system installed. In other areas, powder will be swept across the entire area of the fire by portable dry chemical units installed. Direct pressure of the powder jet will not be applied to a pool of liquid. Depending on the level of isolation of the fire, consideration will be given to allow the fire to burn out due to the risk of exhausting dry powder supply before the fire is extinguishing or re-ignition of the fire.

Water spray will not be used to extinguish liquefied natural gas fires, as it increases the vaporization rate of the gas, and as a consequence, the burning rate. Water spray will be used to protect personnel and cool areas nearby the fire. Water may be used during liquefied natural gas spills, to increase the evaporation rate of the liquefied gas and protect the vessel's steel hull, provided the spill is not burning.

8.2 Water Spray System

The water spray system shall not be used to fight LNG fires. The water spray system is intended for use against accidental flammable gas releases which create LNG vapor clouds. The water acts to directly contact the LNG vapor and disperse the gas cloud. The vapor cloud becomes diluted and warmed, allowing it to mix more readily with the surrounding air.

The water spray system also acts to provide thermal shielding and cooling for LNG storage tanks and surrounding vessel structure when a LNG fire is present.

The water spray system will provide coverage for all exposed parts of the gas storage tank and adjacent deckhouse structure. Coverage will reach to all valves and loading manifolds, offering a uniformly distributed water spray of 10 l/m^2 per minute for horizontal projected surfaces and 4 l/m^2 per minute for vertical surfaces.

The capacity of installed water spray system will be approximately TBD gal/min to meet regulatory requirements. To meet the water spray system demand, two (2) water spray/fire main pumps connected to the fire main system will be installed, adding a level of redundancy in the case one (1) pump became non-operational. One of these pumps must be located in a different space in case the space containing the main pump becomes inaccessible or out of commission.

The vertical distances between water spray nozzles for protection of vertical surfaces will not exceed 12 ft. The capacity of the spray pumps will allow for delivery of the required amount of water, as mention above, to all areas simultaneously.

All pipes, valves, nozzles, and other fittings in the water spray systems will be resistant to corrosion by seawater. Remote starting of the pumps supplying the water to the water spray system and remote operation of any normally closed valves in the system will be arranged outside the bunkering area.

8.3 Dry Chemical Powder Fire-Extinguishing System

For the bunkering areas, a permanently installed dry chemical powder extinguishing system will cover all possible leak points. It will consist of at least one hand hose line that will be non-kinkable and be fitted with a nozzle capable of on/off operation and a discharge rate not less than 3.5 kg/s for a minimum of 45 seconds.

The quantity of dry chemical powder stored onboard the vessel in a container will provide a minimum of 45 seconds of discharge time for all monitors or hand hose lines attached to each powder unit.

One portable dry powder extinguisher of 5 kg capacity will be located at the bunkering station.

The manufacturer's instructions for the installed dry chemical powder extinguishing system will be referenced to for proper operation and maintenance. After a dry chemical powder hose has been used, it will be blown clear with nitrogen to remove any remnants which would provide blockage to the system during subsequent use.

Ansul provides dry chemical fire suppression systems, specifically The ANSUL® S-CR-LR-K-350-C Stationary Dry Chemical System meets the required discharge rate and duration described above. This system is USCG approved.

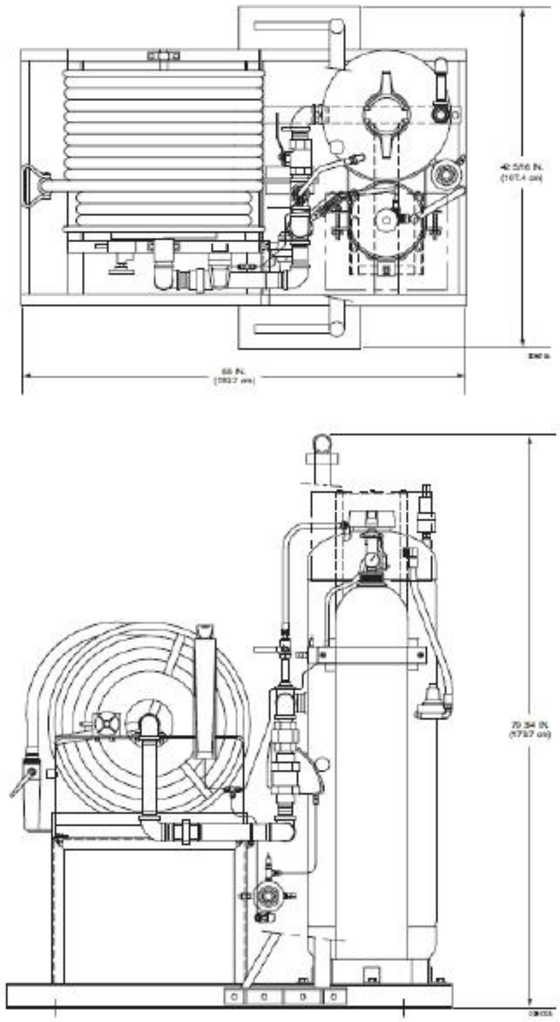


Figure 5: ANSUL Dry Chemical System

8.4 Fire Detection and Alarm System

An approved fire detection system shall be provided for enclosed spaces containing gas-fueled engines or spaces were equipment containing gas is located (i.e. the engine room.) It must be approved by the Commandant in accordance with 46 CFR 161.002 and installed in accordance with 46 CFR 76.27. Fire detection cables will be routed so in the case of a fire, the ability to detect a fire in another location will not be affected. Heat detection will be used, in addition to other not yet specified forms of detection, in protected spaces. The fire detection system will either be independent or will have redundancy in the control system.

9. Alarm and Monitoring Systems

9.1 Fire Detection and Alarms

See section 8.4.

9.2 Gas Detection and Alarms

Gas detectors will be installed in any ventilated double wall piping and enclosed spaces containing gas equipment or gas piping. Gas detectors will be placed where gas is most likely to accumulate and near ventilation outlets. An independent gas detection system will be installed and it will communicate with the gas control system.

Increased gas detection will be located around the main engines where the air fumigation kits are injecting gas into the turbocharger air intake as an increased means of safety. Two (2) portable gas detectors will be located on the vessel at all times.

An audible and visible alarm will be activated prior to the vapor concentration reaching 20% of the lower explosion limit. The audible and visible alarms will be located in the bridge and at the bunkering control station. Gas detection is continuous without delay.

The gas detection system is to be designed such that when a detector actuates, the vessel operator is able to identify the specific gas detector and its location. The gas detection alarm system will have an indicator panel in the wheelhouse. The gas detection system will have two sources of power; independent cabling systems will supply power from the power main and emergency power.

The fixed automatic gas detection and alarm system will meet performance requirements of IEC 60079-29-1; installation, use and maintenance will meet IEC 600079-29-2.

9.3 Safety System Functions for Gas Supply System

The requirements of 5.6 of reference A and Table 2 of reference A will apply as applicable. The tanks are stored outside open to the atmosphere; there is no tank room. The ventilated double wall piping is only located in the machinery space containing the engines, elsewhere they are open to atmosphere. There is no compressor room. See table 1 below:

Table 1: Faults and Effects Table

Parameter	Alarm	Response
Gas detection in ventilated double wall piping inside machinery space containing gas-fueled engines above 20%LEL	Yes	Automatic shutdown of main tank valve
Gas detection on one detector in ventilated double wall piping inside machinery space containing gas-fueled engines above 40%LEL	Yes	Automatic shutdown of gas supply to machinery space containing gas engines (3)

Gas detection in air inlet to gas-fueled engines above 20%LEL	Yes	Automatic shutdown of main tank valve
Gas detection on one detector in air inlet to gas-fueled engines above 40%LEL	Yes	Automatic shutdown of gas supply to machinery space containing gas engines (3)
Loss of ventilation in ventilated double wall piping inside machinery space containing gas-fueled engines (6)	Yes	Automatic shutdown of gas supply to machinery space containing gas engines (3), (4)
Fire detection in machinery space containing gas-fueled engines (1)	Yes	Automatic shutdown of gas supply to machinery space containing gas engines
Abnormal gas pressure in gas supply pipe	Yes	Automatic shutdown of gas supply to machinery space containing gas engines (4)
Failure of valve control actuating medium	Yes	Automatic shutdown of gas supply to machinery space containing gas engines (5)
Automatic shutdown of engine (engine failure)	Yes	Automatic shutdown of gas supply to machinery space containing gas engines (5)
Emergency shutdown of engine manually released	Yes	Automatic shutdown of gas supply to machinery space containing gas engines

Notes:

(1) Ventilation to the space shall stop automatically and fire dampers shall close.
(2) If the tank is supplying gas to more than one engine and the different supply pipes are completely separated and fitted in separate ducts and with the master valves fitted outside of the duct, only the master valve on the supply pipe leading into the duct where gas or loss of ventilation is detected to close.
(3) If the gas is supplied to more than one engine and the different supply pipes are completely separated and fitted in separate ducts and with the master valves fitted outside of the duct and outside of the machinery space containing gas-fueled engines, only the master valve on the supply pipe leading into the duct where gas or loss of ventilation is detected is to close.
(4) This parameter is not to lead to shutdown of gas supply for single fuel gas engines, only for dual fuel gas engines.
(5) Only double block and bleed valves to close.
(6) If the duct is protected by inert gas, then loss of inert gas overpressure shall lead to the same actions as given in this table.

10. HAZARDOUS ZONE AREAS

The vessel arrangements are such to minimize and confine hazardous zone areas. These areas are located on the aft end of the vessel. Lighting and other necessary electrical equipment located inside the hazardous zone for bunker operations is to be intrinsically safe.

Hazardous zone 0 locations include the interiors of the gas storage tanks, pipes and systems containing gas, and pressure relief and venting systems for gas tanks.

Hazardous zone 1 locations include areas ten feet (10') around gas tank and vapor outlets, bunker manifold valves, gas pipe flanges, gas fuel preparation rooms entrances, ventilation inlets into zone 1 spaces, double wall piping around gas pipes, and areas on open deck within spillage coamings surrounding the bunkering manifolds, and ten feet (10') beyond these up to a height of eight feet (8') above the deck. Zone 1 locations also include enclosed or semi-enclosed spaces in which gas pipes are located (ventilated double wall piping.) The ventilation-air *inlets* to the double wall piping do not create a hazardous zone.

Hazardous zone 2 locations include areas on the weather deck or a semi-enclosed space five feet (5') beyond zone 1 locations. Also a zone within eight feet (8') of the outer surface of a LNG tank where the surface is exposed to weather.

The gas vent mast outlet is located twenty feet (20') or greater above the working area above the storage tanks at the aft end of the vessel. The pressure relief valves from the storage tanks, as well as pressure relief valves built into the gas system are all routed to the single vent mast. Forced ventilation for areas requiring 30 air changes per hour that are not inerted will intake air five feet (5') away from hazardous zone areas. The outlets of forced ventilation will result in a fifteen feet (15') hazardous zone, resulting from zone 1 and 2.

The air intake for the engine room is located away from all hazardous zones. Modifications of exhaust pipes will be made to ensure that they are outside of the 33' buffer zone emanating from the vent outlet in accordance with the requirement of 2.8.1.4 of reference B.

The vessel design is based on the *gas safe machinery spaces* outlined in 2.6 of reference A, utilizing a double-walled piping concept, allowing the main engine room to be a non-hazardous zone. The goal of regulatory review with the vessel is to meet the requirements for the *gas safe machinery spaces* by showing alternative arrangements which meet the interim Class requirements.

A 3-D model was created to ensure compliance with hazardous zone requirements. Below are a few screen shots for reference only. The large teal bubble is the 33' sphere around the vent outlet per 2.8.1.4 of reference B. The dark orange bubbles are hazardous zone 1 locations and the yellow bubbles are hazardous zone 2 locations. These hazardous locations are due to the vent outlet, air-duct outlet, tank connections, valves and flanges in the gas line, the drip pan/s and the LNG tanks.

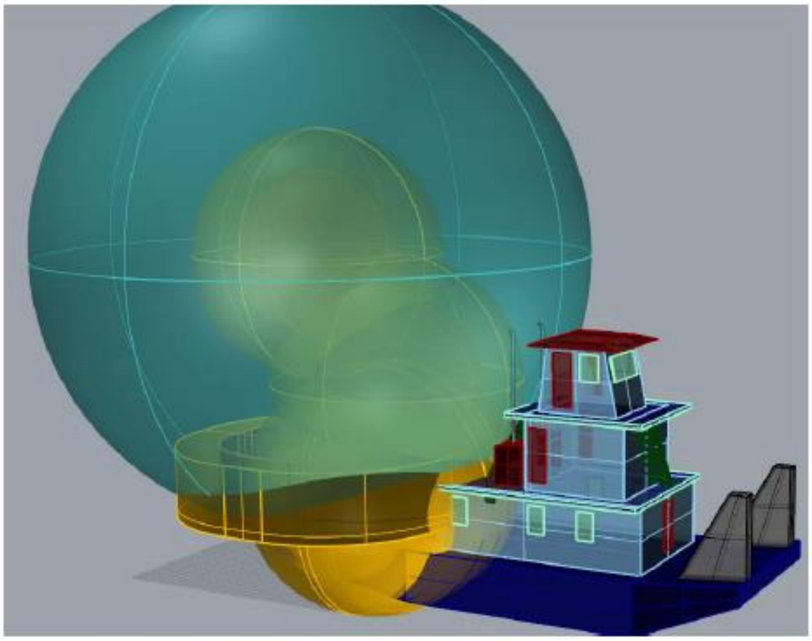


Figure 6: Starboard Side, 33' Vent radius and Hazardous Zones 1 & 2 shown

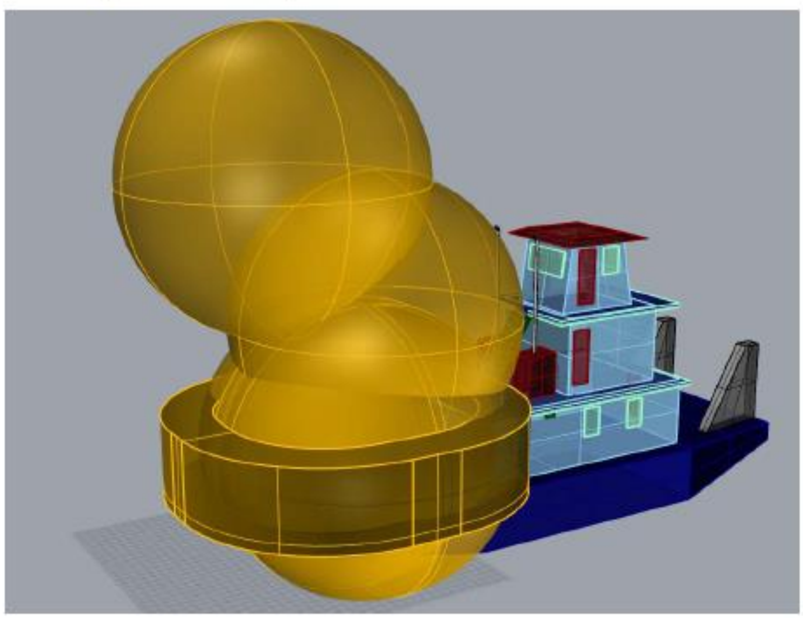


Figure 7: Starboard Side, Hazardous Zones 2 shown

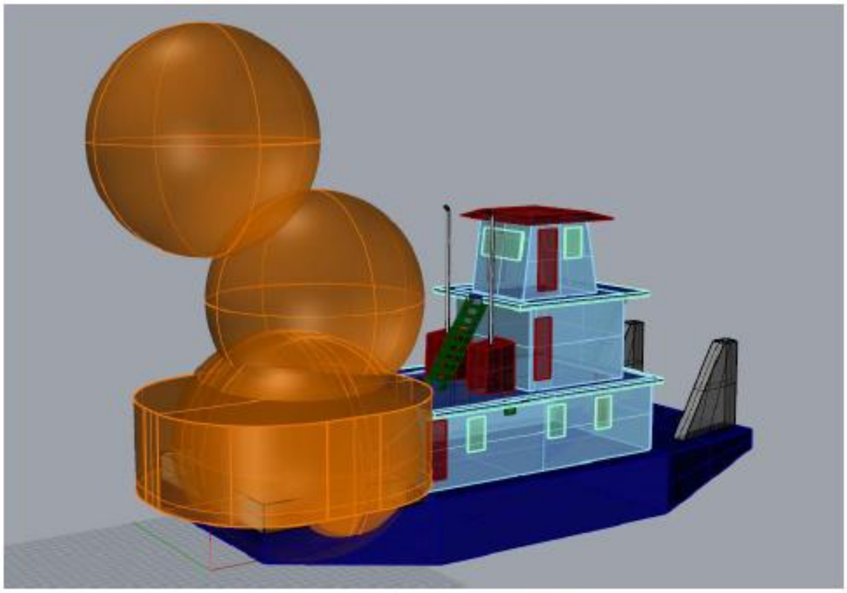


Figure 8: Hazardous Zones 1 Shown

11. Preliminary Stability

Preliminary stability calculations will be completed to ensure the seaworthy integrity of the vessel is maintained thought modifications and weight changes.

Appendix B Dual Fuel Inland Towboat, Preliminary Risk Analysis

THE SHEARER GROUP

Dual Fuel Inland Towboat

Preliminary Risk Analysis

Date: 28-JULY-2016

TSGI Corr. No. 0315-002-903R0

NAVAL ARCHITECTS : MARINE ENGINEERS : MARINE SURVEYORS

Member: THE AMERICAN WATERWAYS OPERATORS

TABLE OF CONTENTS

List of Figures 3

1. Introduction 4
2. Analysis Of The Air Fumigation System 5
   - 2.1 How the APG 3000 Dual Fuel System Functions 6
   - 2.2 The Gas Train 6
     - 2.2.1 The Gas Train Gas Tight Enclosure 7
   - 2.3 The Induction Gas Mixer 7
   - 2.4 The Air Fumigation Electronic Control System 8
   - 2.5 Risks Inherent of the Air Fumigation Control System 9
   - 2.6 Risk Controls 9
3. Analysis of the Integrated Gas Handling System 11
   - 3.1 The LNG Tank 11
     - 3.1.1 The LNG Tank 11
     - 3.1.2 The LNG Tank 11
     - 3.1.3 Risks Inherent to the LNG Tank 12
     - 3.1.4 Risk Controls 12
   - 3.2 The Bunkering System 12
     - 3.2.1 Risks Inherent to the Bunkering Station 14
     - 3.2.2 Risks Inherent to the Bunkering Station 14
   - 3.3 The Gas Supply System 14
     - 3.3.1 Risks Inherent To the Gas Supply System 16
     - 3.3.2 Risk Controls 16
   - 3.4 The Master Programmable Logic Controller (PLC) 17
4. Summary and Conclusions 18

List of Figures

Figure 1: Inherently Safe Engine Room Installation Schematic 5
Figure 2: Gas Train Components 6
Figure 3: Gas Train Enclosure 7
Figure 4: Induction Gas Mixer 7
Figure 5: Electronic Control Module 8
Figure 6: The LNG Tank 11
Figure 7: Tanks and Fuel Bunkering System 13
Figure 8: Gas Supply Systems 15

List of Tables

Table A1: Likelihood Categories 18
Table A2: Representative Consequence Categories 19
Table A3: Risk Levels 19
Table A4: Summary of Risks 20

List of Appendices

Appendix A – This Risk Assessment Methodology Used .... A

1. INTRODUCTION

As stated in the basis of design, the solution selected for dual fuel conversion of the *RON CHRIS* is to add an **Air fumigation System** to each main propulsion diesel engine. There are multiple third party vendors capable of supplying air fumigation systems for diesel engines. A few include GFS, ALTRONIC, and AMERICAN POWER GROUP. Such systems have already 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.

LNG fuel is to be stored onboard and supplied as natural gas to each of the fumigation systems by a fully **Integrated Gas Handling System**. This is comprised of a Type C LNG Tank with a Bunkering System, a Tank Pressure Build-up System, a Gas Supply System, and an Electronic Control System. Similarly, there are multiple third party vendors capable of providing Integrated Gas Handling Systems. While systems such as those provided by TGE Gas Engineering and Wartsila have proven to be reliable on shipboard installations, they are much larger than required (and preferred) for this application. Smaller systems for highway applications, such as those provided by Chart Industries and Green Buffalo Fuel, will be used on the RON CHRIS.

Overall control of all gas related systems will be provided by a **Programmable Logic Controller** or **PLC** that integrates:

- The Air Fumigation Electronic Control System
- The Gas Handling System Electronic Control

The approach to this Risk Analysis is to examine the Air Fumigation System and the Integrated Gas Handling System in detail. To accomplish this with specificity, the American Power Group Air Fumigation System and the CHART Vehicle Fuel Tank System Integrated Gas Handling System have been selected as representative. In addition, two CUMMINS NT855 diesel engines will be used.

The Air Fumigation System is an individual system which is examined in detail, component by component. This system deserves particular emphasis because it is the only gas related system located in the confined space of the engine room and it is not yet proven in a marine application.

The Integrated Gas Handling System is a self-contained unit that includes four component systems. In this analysis each of these systems is examined individually. Even though this system is not located in a confined space, it is given careful attention as well.

The purpose of this risk analysis is to ensure that any risks arising from the use of gas-fueled engines in this vessel are carefully considered. Particular attention is paid to risks affecting the safety of personnel as well as the structural strength and the integrity of the ship that could result in:

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

The risk assessment methodology used is described in Appendix A. It is our intention that risks are eliminated whenever possible and that those that cannot be eliminated should be 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 control

2. Analysis Of The Air Fumigation System

As we considered the application of the American Power Group S 3000 system to a marine environment, three modifications were made to mitigate the risk of possible gas leaks in the engine room.

- Engine room piping is of double wall construction with air ventilated at 30 air-changes per hour.
- Gas train components are enclosed in a gas tight enclosure ventilated at 30 air-changes per hour.
- The slam shut regulator is relocated to the tank to minimize the number of gas train components in the engine room.

Figure 1 provides a schematic illustration of the Air Fumigation System as configured for the *RON CHRIS*, The gas train enclosure is to be located outside the engine room.

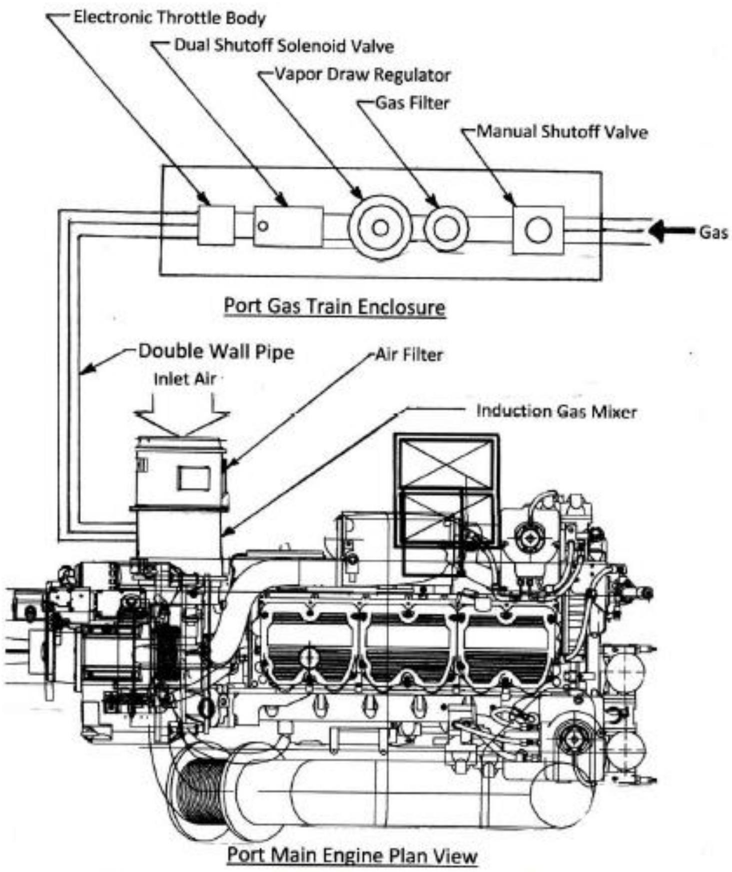


Figure 1: Inherently Safe Engine Room Installation Schematic

Even though this system has a demonstrated safety and reliability record in a number of stationary and on the road installations, risks associated with this basic system must be considered in this analysis along with any additional risks present in a marine environment. To accomplish this it is important to understand:

- How the existing APG 3000 dual fuel system functions.
- Risks inherent to the basic system.
- Additional risks in a marine environment.

2.1 How the APG 3000 Dual Fuel System Functions

Stated simply, the S3000 Stationary Dual Fuel System is an after-market upgrade system that meters natural gas into the induction system of a diesel engine. This dual fuel configuration does not change any of the 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 rate as high as 50% natural gas when cost is one of many significant factors. With input data from sensors throughout the gas delivery system, the APG 3000 system automatically delivers the correct mix of air to natural gas to the engine air intake system for all throttle settings.

The APG 3000 system in this application consists of four primary components:

- Gas Train
- Gas Train Enclosure
- Inlet Gas Mixer
- Electronic Control Module

2.2 The Gas Train

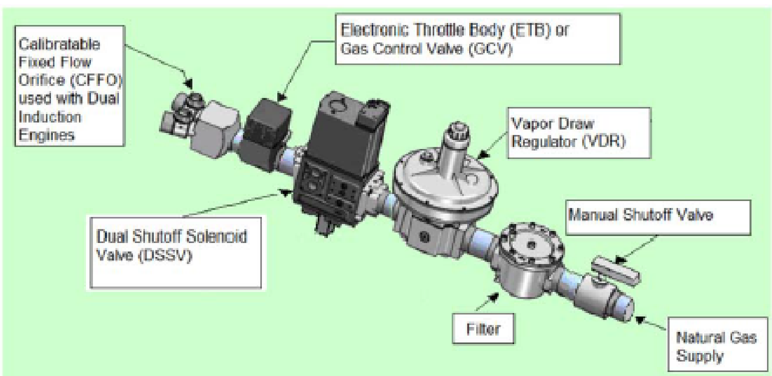


Figure 2: Gas Train Components

Figure 2 illustrates the Gas Train with flow from right to left. 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 periods 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.

2.2.1 The Gas Train Gas-Tight Ventilated Enclosure

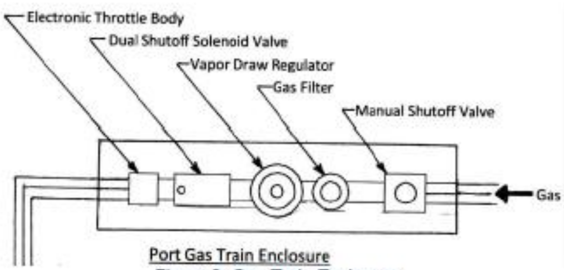


Figure 3: Gas Train Enclosure

Figure 3 illustrates the gas train ventilated enclosure. Its purpose is to mitigate the possibility of a gas leak from any of the gas train components out of the enclosure. It is approximately five feet long and is of gas tight stainless steel construction. It is located above (outside) the engine room on deck above the diesel engines. It is a component of the double wall piping and under operating conditions it is ventilated at a rate of 30 air-changes per hour.

Details to be developed during its design process include:

- A large, sealed access door on the top side to provide access for maintenance of the gas train equipment which includes regular gas filter changes and Dual Shutoff Solenoid Valve filter changes.
- Since the pressure sensor on the vapor Draw Regulator uses differential pressure and atmospheric reference pressure, its atmospheric sensor will be relocated to the outside of the enclosure.
- The valve stem on the manual Shutoff Valve will be extended through a gas tight penetration to allow for external operation.
- Gas tight electrical penetrations will be included for the Throttle Body Position Sensor, The Regulator Output Pressure Sensor, The Gas Supply Pressure Sensor, The Electronic Throttle Body Position Control, and the Dual shutoff Solenoid Valve Control.
- A sensor will be installed to ensure that the nitrogen purge is in place prior to and during operation of the system.

2.3 The Induction Gas Mixer

Figure 4: Induction Gas Mixer

Figure 4 illustrates the Induction Gas Mixer. It has no moving parts and is positioned between the engine air filter assembly and the turbocharger inlet. It receives gas from the gas train and functions to homogeneously blend natural gas with intake air.

2.4 The Air Fumigation Electronic Control System

Figure 5: Electronic Control Module

Figure 5 illustrates The Electronic Control Module in a NEMA enclosure. The Air Fumigation Electronic Control System receives input from nine monitors currently existing on the engine, four monitors on the gas train and four gas leak detectors. It then uses proprietary algorithms to automatically control the fumigation system and display pertinent information.

Air Fumigation Electronic Control System Inputs include:

From the engine:
- Engine Exhaust Gas Temperature
- Engine Coolant Temperature
- Engine Manifold Absolute Pressure
- Engine Oil Pressure
- Engine Air Filter Restriction
- Engine Load at Speed
- Engine RPM
- Engine De-Rate
- Engine Knock Detection

From the gas train:
- Electronic Throttle Body Position Sensor
- Regulator Output Pressure
- Supply Gas Pressure
- Regulator Output Pressure

From the engine room:
- Gas Leak Detectors (above each engine)
- Gas Leak Detectors (in each engine-air intake)

Gas Train Electronic Control System Outputs include:
- Electronic Throttle Body Position
- Dual Shutoff Solenoid Valve

Electronic Control System Safety Features

- If for any reason any OEM diesel system key parameters including Oil Pressure, Coolant Temperature, Exhaust Gas Temperature and Manifold Air Pressure are not within standard operating ranges, gas flow is automatically shut off and the engine seamlessly returns to 100% diesel fuel operation.
- If for any reason any of the fuel system parameters including Electronic Throttle Body Position, Regulator Output Pressure and Supply Gas Pressure are not in standard operating ranges, gas flow is automatically shut off and the engine seamlessly returns to 100% diesel fuel operation.
- If for any reason natural gas is detected in the engine room, above the engines or in the air intakes, gas flow is automatically shut off and the engine seamlessly returns to 100% diesel fuel operation.
- This system maintains the natural gas to air ratio under normal operating conditions at less than 3% which is well under the explosive limit of 5%. This ensures that:
  *Ignition will not occur until diesel fuel is injected.
  *The possibility of ignition in the inlet system due to engine backfire is minimized.

2.5 Risks Inherent of the Air Fumigation Control System

Note that the increased consequences of potential gas leaks in the confined space of the engine room are considered in the analysis of this system.

1. Ignition of Natural Gas in the Engine Induction System
2. Inadvertent Discharge of Natural Gas through the Induction Gas Mixer
3. Gas Line Failure
4. Pressure Regulator Failure
5. Dual shut Off Valve Failure
6. Throttle Body Failure
7. Gas Train Gas leak
8. Natural Gas from Any Source in the Engine Room (above engines or in air-intakes)

2.6 Risk Controls

1. The control system monitors the exact engine load from the engine's Controller Area Network bus. From that input the control system calculates the exact air flow rate into the engine and adjusts the gas train throttle position appropriately. The gas train throttle position sensor or TPS has a max open limit that is set at the highest commission point. It limits gas rate to a maximum of 3% of air which is below the 5 % lower explosive limit or LEL. In addition, knock detection on the engine will shut down the gas at the dual solenoid shutoff at sub rates above 3%.

2. Inadvertent discharge of natural gas through the induction gas mixer can occur only when the engine is shut down. To mitigate this risk, the control system only allows gas flow when the engine is running. The Dual Solenoid Valve is shuts off gas flow when any of the following conditions exist.

a. The engine RPM is not above zero
b. The gas train regulator output pressure falls above 0 psig
c. The engine oil pressure is below a preset level
d. The engine coolant temperature is below a preset level

In addition the gas flow is shut off at the master fuel gas valve whenever the engine room gas leak detectors detect gas in the engine room.

3. To mitigate the risk of a gas line failure, all gas piping in the engine room is of double wall construction. The annulus is ventilated at 30 air-changes per hour and gas leak detectors are installed. If gas is detected in the annulus (or anywhere in the engine room), the Programmable Electronic Controller will initiate an Emergency Shutdown closing all five valves in the gas system. In addition, any serious leak such as a burst line would result in a max gas flow rate above that set at the LNG controller which would also result in an Emergency Shutdown.

4. A regulator failure would result in a regulator output pressure above 0 psig which causes gas flow to be shut off by the Dual Shutoff Valve.

5. The dual shutoff valve is designed to be fail-safe close. In addition, if valve position sensors detect a difference between actual valve position and commanded position, the Programmable Electronic Controller will initiate an Emergency shutdown of all gas systems.

6. Pressure sensors detect throttle body failures which result in an Emergency Shutdown of all gas systems.

7. To mitigate the risk of a gas train gas leak, the entire Gas Train is enclosed in a gas tight, ventilated enclosure equipped with a gas detector. The detection of any leak will result in an Emergency Shutdown of all gas systems.

8. The machinery spaces are fitted with sufficient mechanical ventilation (which provide a minimum of 30 air changes per hour) to prevent the accumulation of gas vapors in dead spaces. In addition the engine room will be equipped with gas detectors (above engines and inside air-intakes) monitored by the independent alarm system and by the Programmable Electronic Controller. The detection of natural gas anywhere in the engine room will initiate an automatic Emergency Shutdown of all gas related systems and in alarm warnings to the crew.

3. Analysis of the Integrated Gas Handling System

3.1 The LNG Tank

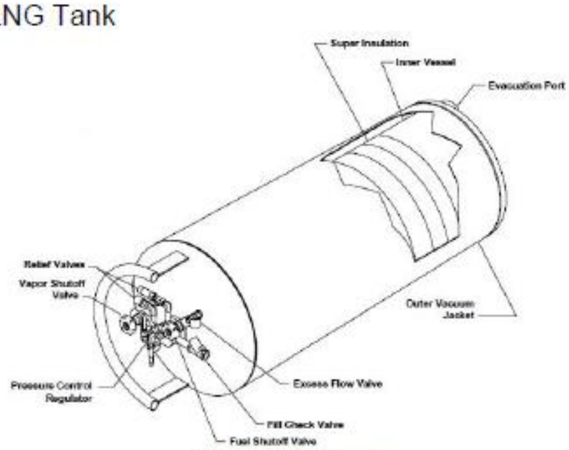


Figure 6: The LNG Tank

As discussed earlier, the ship's LNG is stored in two small (roughly 135 gallons each) Type C cryogenic storage tank located above deck on the aft deck of the vessel. Mounted on the tanks is an Electronic Fuel Contents Gauge, consisting of fuel gauge sender and dash mounted fuel gauge. The function of the LNG tank is to safely contain the LNG and two related critical systems safely under all conditions.

The two LNG tanks, the two critical systems described in paragraph 3.1.2 below and the electronic fuel gauging system are provided as a complete integrated package by an experienced tank supplier.

3.1.1 The LNG Tank

The tanks are Type C double wall vacuum insulated pressure tanks with a design pressure of approximately 15 bar and a normal operating pressure of 3 to 10 bar. It will be of a proven design configuration and supplied by an experienced tank manufacturer with appropriate ASME Code Stamps and ISO Registration. The design of the tank's structure and supports will account for marine related operational load requirements in accordance with IMO and ABS. It is equipped with boil off gas and thermal relief gas valves that vent to the vent mast. Simply stated its function is to provide **Primary and Secondary Containment** of the LNG.

3.1.2 The LNG Tank

The tank will contain two critical systems and the associated piping, valves, and sensors.

- The Gas Supply System
- The LNG Bunkering System

Also included in the tank package is the Gas Handling System Electronic Fuel Contents Gauge which is mounted to its exterior. These systems and their associated control system are discussed later in this document.

3.1.3 Risks Inherent to the LNG Tank

1. Tank Over-Pressurization
2. JT (Joule-Thomson) Effects and Impingement of Cooled Gas On Adjacent Structures
3. Dispersal of Released Gases
4. Jet and Pool Fire
5. Radiant Heat From Fire
6. Asphyxiation Due To Dispersed Gas and Nitrogen
7. Corrosion Due to Marine Environment
8. Fatigue and Fracture

3.1.4 Risk Controls

1. Two pressure relief valves are provided in the LNG Tank which are vented to vent mast.

2. Under the bunker station and tank penetrations, a spill pan of stainless steel construction is designed to contain LNG spills and discharge spilled LNG overboard.

3. Released gases are vented to the vent mast.

4. A self-contained dry chemical powder unit along with associated controls provide fire protection to the Tank.

5. A water spray system provides coverage of all exposed parts of the gas storage tank, and deckhouse.

6. The LNG Tank and Tank Room are located topside in the open air to minimize the possibility of gas accumulation from any potential leaks.

7. 300 series corrosion resistant steel will be utilized for all systems whenever possible.

8. The LNG Tank and internal systems have been designed to accommodate transient thermal, thermal and cyclic loads at stress levels well below anticipated fatigue limits. In addition, regular in service inspections will be performed.

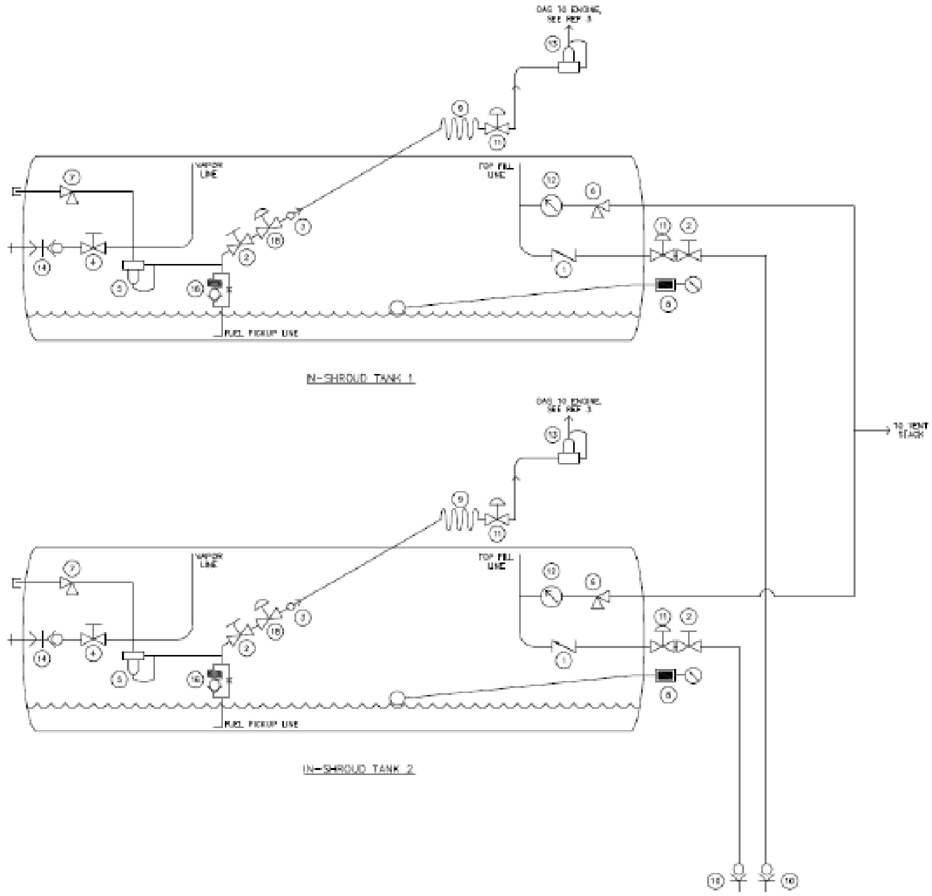
3.2 The Bunkering System

Bunkering takes place directly from truck to the tank fill manifold which is equipped with spill protection and an overboard drain. The bunkering manifold will be located near the tanks. This eliminates the need for separate bunkering stations.

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 communication are in place.

The process will be continuously controlled by the Tank Electronic Fuel Gauging System where tank level and pressure are monitored to prevent overfilling or over-pressurization.

For clarity the Bunkering System is illustrated schematically in Figure 7.



1	Fill Check Valve	7	Secondary Relief Valve	13	Overpressure Regulator
2	Fuel Shutoff Valve	8	Fuel Contents Gauge	14	Quick Disconnect Valve
3	Excess Flow Valve	9	Heat Exchanger	15	Low Temperature Signal Device
4	Vapor Shutoff Valve	10	Fill Fitting	16	Internal Check Valve
5	Auto Refrigeration Regulator	11	Automatic Valve	17	Vapor Shutoff Valve
6	Primary Relief Valve	12	Tank Pressure Gauge	18	Master Isolation Valve

Figure 7: Tanks and 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. Warm up or cool the system tanks by introducing LNG trough 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

3.2.1 Risks Inherent to the Bunkering Station

1. Leaks from Pipes, Hoses or Tanks
2. Inadvertent Disconnection of Hoses
3. Overfilling
4. Over-pressurizing Vessel Fuel Tanks
5. External Impact

3.2.2 Risks Inherent to the Bunkering Station

1. Pipes, hoses and Tanks will be well maintained and properly inspected prior to bunkering. Regular piping and tank inspections and hose certifications will be performed. Standardized connections will be used and bunkering connections will be made by qualified personnel.

2. The ship's mooring system will be inspected to ensure that the vessel is secure. The operator will ensure that there is adequate slack in the bunkering hoses to allow for anticipated ship motions and breakaway couplings will be used.

3. An ullage tank within the tank in combination with pressure and level sensors and overfill alarms will mitigate the chance of overfilling the tanks.

4. The Tank is equipped with a pressure gauge which is monitored by the operator at the Bunkering Control Panel. In addition, the Tank is protected from over-pressurization by two pressure relief valves. An independent alarm system will notify the operator if the safe pressure limit is exceeded.

5. The vessel will be securely moored in a navigational safety zone. The refueling truck will be parked in a properly protected restricted area which is clearly identified as a hazardous area with warning signs.

3.3 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 4 PSI gas as demanded by the Air Fumigation System. For clarity, this system is illustrated schematically in Figure 9.

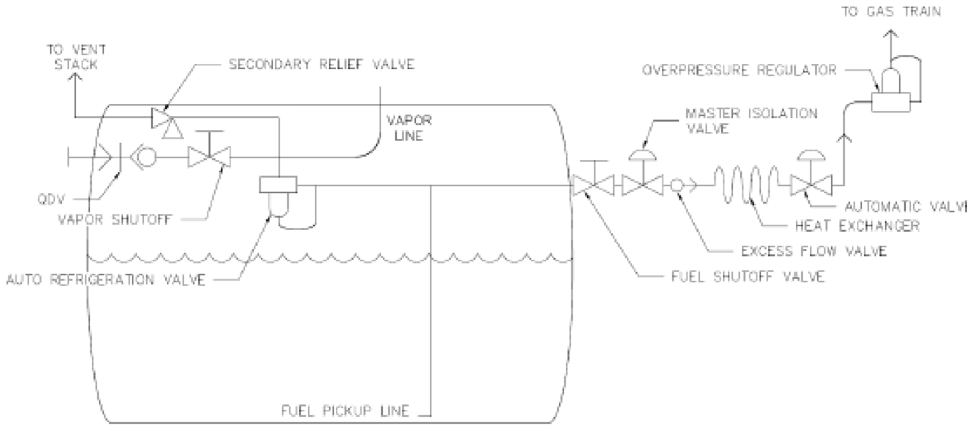


Figure 8: Gas Supply Systems.
Schematic only, not to scale, omissions for clarity, bunkering systems not shown.

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

- The **Fuel Shutoff Valve** is shown to the right of the tank. It is a bronze globe manual valve with a soft seat. Its function is to provide a positive shutoff of the fuel line for service and maintenance operations. It connects to the liquid withdraw line at the top of the tank through the pressure control regulator. It is open for normal dual fuel operations.
- The **Mater Isolation Valve** is shown to the right of the Fuel Shutoff Valve. It is a pneumatically remote controlled shut-off device. 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 eventabnormal situations including leakage anywhere in the system, etc.
- The **Heat Exchanger** evaporates the LNG liquid to natural gas. It is designed to ensure a stable gas pressure during all phases of intense evaporation. It heats the gas to the temperature range required by the Air Fumigation system.
- An **Auto Refrigeration Valve** is a pressure reducing valve that allows vapor to flow into the fuel line during dual-fuel operations.
- The **Secondary Relief Valve** opens to vent gas to the Vent Mast if the pressure is above a preset level, normally 1.5 times the maximum allowable working pressure of the tank. Its function is to prevent catastrophic failure of the tank in the event of a malfunction of the Primary Relief Valve or line. It is connected to the vapor withdrawal line providing a secondary relief path.
- The **Automatic Valve** is a pneumatically remote controlled shutoff device that can be activated as needed by the control system.
- An **Overpressure Regulator** regulates pressure to the Air Fumigation System to be within acceptable limits.
- An **Excess Flow Valve** is a specialized check valve designed to cut off fuel flow if it exceeds a certain limit.
- A **Vapor Shutoff Valve** is a manual valve that provides positive shutoff of the vapor withdrawal line for service and maintenance operations. The valve connects to the vapor withdrawal line at the top of the tank. This valve is closed for normal operations.
- A **QDV, Quick Disconnect Valve**, allows for venting of the tank system during refueling.

3.3.1 Risks Inherent To the Gas Supply System

1. System Gas Leak
2. LNG Leak
3. Master Isolation Valve Failure
4. Heat Exchanger Failure
5. Automatic Valve Failure
6. Overpressure Regulator Failure

3.3.2 Risk Controls

1. The system is entirely open to the atmosphere and located to ensure sufficient natural ventilation.

2. The area below the system is by a spill pan. In the event of an LNG leak, the master isolation valve will stop LNG flow to the system and the spill containment (spill pan) will isolate the spill and discharge LNG overboard per 2.9.1.2 of IMO Resolution MSC.285(86) - Interim Guidelines On Safety For Natural Gas-Fueled Engine Installations On Ships.

3. In the event of a Master Isolation Valve Failure, the automatic valve would be closed by the control system and stop gas flow to the air fumigation system. However, if for any reason the master isolation valve fails in the open position, any LNG or gas leak between the tank and the master fuel gas valve would continue to leak to the spill pan. The Fuel Shutoff Valve can be also manually closed in this scenario if safety permits.

4. If the heat exchanger fails to operate due to an inadequate flow of heating media or for any other reason, the control system would close the master isolation valve stopping gas flow to the entire system.

5. If the automatic valve fails to operate, gas flow to the entire system will be shut off by the control system at the master isolation valve.

6. The overpressure regulator consists of a pressure regulator that regulates gas pressure delivered to the air fumigation to the desired pressure range. If this device fails to operate properly, the gas train will detect an abnormal pressure and control system will shut down gas flow at the master gas valve and at the master isolation valve.

3.4 THE MASTER PROGRAMMABLE LOGIC CONTROLLER (PLC)

Overall control of all gas related systems is provided by a Master Programmable Logic Controller which integrates:

- The Air Fumigation Electronic Control System
- The Gas Handling System Electronic Fuel Gauge

The PLC also receives input from the fire and gas detection systems and can activate the independently controlled Alarm and Fire Suppression systems.

The Master Programmable Logic Controller provides seamless integration of both gas related systems enabling efficient operation by the crew and enabling information available to one system to initiate responses in the other.

For example the PLC will automatically initiate an Emergency Shutdown consisting of all five in line valves on the gas system consisting of two valves on the Gas Supply System and three valves on the Air Fumigation System. This action would be initiated in the event that any of the following conditions are detected:

- Heat or Fire Anywhere on the Ship
- Gas Leak Anywhere on the Ship
- LNG Leak Anywhere on the Ship
- Gas Train Malfunction on either Gas Train
- LNG Tank Malfunction (Temperature or Pressure)

In addition it will sound alarms to alert ship's personnel to respond by closing additional manual valves in the system and to initiate other emergency actions.

The safety integrity required of a system depends on the level of protection that it is assumed to provide. **The Master Programmable Logic Controller requires a very high level of safety integrity.**

4. Summary and Conclusions

As pointed out in the introduction, virtually all of the components and systems being installed on this vessel have proven, although non-marine, reliability and safety records. The Air Fumigation System has many years of proven service in over 300 land-based installations.

What is new and different here is the application of this proven land based Air Fumigation System to the confined space of a ship's engine room. Precautions have been taken to mitigate the associated risks:

- Engine room piping is of double wall construction with ventilated outer piping.
- Gas train components are enclosed in a gas tight enclosures with ventilated outer piping.
- Enhanced engine room ventilation has been added.
- Gas detectors have been added.

In this analysis we have examined the Air Fumigation System and the Integrated Gas Handling System in detail to identify their associated risks and risk controls. We would recommend in the next design phase the Programmable Logic Control System be examined in more detail. The next step is to proceed with a summary risk analysis applying the methodology outlined in Appendix A. To accomplish this we have made our best judgments to identify the likelihood and the severity of each risk.

Table A1 defines the alphabetic likelihood categories used.

Table A1 Likelihood Categories

Category	Category Descriptions
Almost Certain (E)	Occurs 1 or more times per year
Likely (D)	Occurs once every 1 to 10 years
Possible (C)	Occurs once every 10 to 100 years
Unlikely (B)	Occurs once every 100 to 1,000 years
Rare (A)	Occurs once every 1,000 to 10,000 years

Table A1: Likelihood Categories

Table A2 defines the numeric consequence categories used.

Table A2 Representative Consequence Categories

Severity Categories	Impacts			
	Death & Injury	*Economic*	*Environmental*	*Reputation*
Low (1)	Low level short-term subjective inconvenience or symptoms. No measurable physical effects. No medical treatment.	No shutdown, costs less than $1,000 to repair.	No lasting effect. Low-level impacts on biological or physical environment. Limited damage to minimal area of low significance.	Public concern restricted to local complaints. Ongoing scrutiny/attention from regulator.
Minor (2)	Objective but reversible disability/impairment and/or medical treatment injuries requiring hospitalization.	No shutdown, costs less than $10,000 to repair.	Minor effects on biological or physical environment. Minor short-term damage to small area of limited significance.	Minor, adverse local public or media attention and complaints. Significant hardship from regulator. Reputation is adversely affected with a small number of site focused people.
Moderate (3)	Moderate irreversible disability or impairment (<30%) to one or more persons.	Operations shutdown, loss of day rate for 1-7 days and/or repair costs of up to $100,000.	Moderate effects on biological or physical environment but not affecting ecosystem function. Moderate short-medium term widespread impacts (e.g., oil spill causing impacts on shoreline).	Attention from media and/or heightened concern by local community. Criticism by Non-Governmental Organizations (NGO). Significant difficulties in gaining approvals. Environmental credentials moderately affected.
Major (4)	Single fatality and/or severe irreversible disability or impairment (>30%) to one or more persons.	Operations shutdown, loss of day rate for 7-28 days and/or repair costs of up to $1,000,000.	Serious environmental effects with some impairment of ecosystem function (e.g., displacement of species). Relatively widespread medium-long term impacts.	Significant adverse national media/public/NGO attention. May lose license to operate or not gain approval. Environment/management credentials are significantly tarnished.
Critical (5)	Short or long term health effects leading to multiple fatalities, or significant irreversible health effects to >50 persons.	Operations shutdown, loss of day rate for more than 28 days and/or repair costs more than $1,000,000.	Very serious effects with impairment of ecosystem function. Long term widespread effects on significant environment (e.g., unique habitat, National Park).	Serious public or media outcry (International coverage). Damaging NGO campaign. License to operate threatened. Reputation severely tarnished. Share price may be affected.

Table A2: Representative Consequence Categories

Risk level is based on the combination of the likelihood and the severity of each risk. Table A3 defines the risk levels used in this analysis.

Table A3 Risk Levels

Likelihood Categories	Consequence Severity				
	Low	Minor	Moderate	Major	Critical
	1	2	3	4	5
Almost Certain (E)	Medium	Medium	High	High	High
Likely (D)	Moderate	Medium	Medium	High	High
Possible (C)	Low	Moderate	Medium	High	High
Unlikely (B)	Low	Low	Moderate	Medium	High
Rare (A)	Low	Low	Moderate	Medium	Medium

Table A3: Risk Levels

Applying this methodology, we developed the following summary that includes all risks identified in this study along with their likelihoods, consequences and resulting risk levels.

Table A4: Summary of Risks with Associate Likelihood, Consequence and Risk Level

Risk	Likelihood	Consequence	Risk Level
Risks Inherent to the Air Fumigation System			
1. Ignition of Natural Gas in the Engine Induction System	C	1	Low
2. Inadvertent Discharge of Natural Gas through The Induction Gas Mixer	D	2	Medium
3. Gas Line Failure	C	3	Medium
4. Pressure Regulator Failure	D	1	Medium
5. Dual shut Off Valve Failure	D	2	Moderate
6. Throttle Body Failure.	D	2	Moderate
7. Gas Train Gas leak	D	2	Medium
8. Natural Gas from Any Source in the Engine Room	D	3	Medium
Risks Inherent to the Tank and Tank Room			
1. Tank Over-Pressurization	C	3	Moderate
2. JT Effects and Impingement of Cooled Gas On Adjacent Structures	C	3	Medium
3. Dispersal of Released Gases.	D	1	Moderate
4. Jet and Pool Fire	B	4	Medium
5. Radiant Heat From Fire	B	3	Moderate
6. Asphyxiation Due To Dispersed Gas and Nitrogen	A	5	Medium
7. Corrosion Due to Marine Environment.	D	1	Moderate
8. Fatigue and Fracture	B	3	Moderate
Risks Inherent to the Bunkering System			
1. Leaks from Pipes, Hoses or Tanks	D	1	Moderate
2. Inadvertent Disconnection of Hoses	D	2	Medium
3. Overfilling	D	1	Moderate
4. Over-pressurizing Vessel Fuel Tanks	C	2	Moderate
5. External Impact	B	3	Moderate
Risks Inherent To the Gas Supply System			
1. System Gas Leak	C	2	Moderate
2. LNG Leak	C	3	Medium
3. Master Isolation Valve Failure	C	3	Medium
4. Heat Exchanger Failure	D	2	Medium
5. Automatic Valve Failure	C	3	Medium
6. Overpressure Regulator Failure	D	2	Moderate
1. Risks Inherent to the Programmable Electronic Controller.			
To Be Addressed in Future Study			

As measured by this methodology all five systems (including the Air Fumigation System) have medium to moderate risk levels which we consider to be acceptable.

As we progressed further in our risk analysis process we considered the fact that accidents usually progress through a chain of events that begin with an individual event that can progressively leads to others. As we reviewed the automated risk controls in place throughout all of the systems there is one common sequence of events which serves as the first line of defense against any of the more serious potential malfunctions:

1. A malfunction is detected by the Master Programmable Electronic Controller.

2. The Master Programmable Electronic Controller initiates an Emergency Shutdown closing all valves in the Air Fumigation System and in the Gas Supply System. The most critical of these valves is the Master Isolation Valve because it is closest to the LNG Tank.

3. The LNG tank is left to manage itself.

For this first line of defense to be reliable, three components are essential and all three must have the highest levels of safety integrity:

- **The Master Programmable Electronic Controller.**
- **The Master Isolation Valve.**
- **The LNG Tank including its Pressure Relief Valves.**

It should be noted that even if this automated first line of defense were to fail, independent alarm systems will initiate a manual Emergency Shutdown.

It is the conclusion of this Risk Analysis that the risks associated with this overall system are medium to moderate and are thus acceptable.

Appendix A
The Risk Assessment Methodology Used

The risk assessment methodology used in this analysis is described in the following pages. It is the same methodology used in an ABS report entitled "Bunkering of Liquefied Natural Gas-fueled Marine Vessels in North America" and was taken from that report.

Bunkering of Liquefied Natural Gas-fueled Marine Vessels in North America

APPENDIX A – Risk Assessment Worksheet Templates

Introduction

Each LNG bunkering operation is unique and therefore, has a unique set of hazards and risks. This appendix introduces a risk assessment methodology, describes a process for performing a risk assessment, and provides example worksheet templates for a truck-to-vessel bunkering operation.

Risk Assessment Methodology

To characterize the risk of LNG bunkering operations, risk assessment teams must tailor a sound risk assessment methodology that can successfully answer the following questions:

- **What can go wrong?** Risk assessment methods are used to identify hazards that can create accidents. These can include equipment failures, human errors, and external events. Based on the quantity and types of hazards that may affect the bunkering option, analysts can gain a good understanding of the risk associated with the operation.
- **How likely is it?** Likelihood is usually expressed as the probability or frequency of an accident occurring. If the likelihood is low enough, analysts may conclude that a possible accident scenario is not credible, not of concern, or of extremely low risk. But, the criteria for making such judgments often change with the type and severity of the consequence related to the possible accident.
- **What are the impacts?** An accident can affect many areas of concern with different degrees of negative results. The type and severity of consequences related to an accident help an analyst understand and judge risk.

The following are key terms and definitions associated with the risk assessment process:

Hazards — Situations, conditions, characteristics, or properties that create the possibility of unwanted consequences.

Causes — Underlying reasons (e.g., equipment failure, human error) why the initial incident occurs and safeguards fail to interrupt the chain of events.

Safeguards — Planned protections that are intended to interrupt the progression of accident sequences at various points in accident chains of events. Safeguards can be applied to prevent the likelihood of occurrence or to minimize the consequences. These planned protections may be physical devices, human interventions, or administrative policies.

Likelihood — The likelihood of events is often expressed as a frequency, events per year. To assess the frequency of any event, analysts must consider (1) how often the hazard is present (e.g., how many times an operation is performed) and (2) the probability of experiencing the accident during any exposure to the hazard.

Table A1 is an example of likelihood categories.

Bunkering of Liquefied Natural Gas-fueled Marine Vessels in North America

Table A1 Likelihood Categories

Category	Category Descriptions
Almost Certain (E)	Occurs 1 or more times per year
Likely (D)	Occurs once every 1 to 10 years
Possible (C)	Occurs once every 10 to 100 years
Unlikely (B)	Occurs once every 100 to 1,000 years
Rare (A)	Occurs once every 1,000 to 10,000 years

Consequences — Unwanted impacts that can negatively affect subjects of interest. These types of impacts can include: deaths/injuries to workers and the public, property damage, business interruption, environmental impacts, and impacts to company reputation. The severity of consequences can range from insignificant to catastrophic. Each owner/operator has unique considerations; therefore, impact and severity descriptions should be tailored to reflect organizational concerns. Table A2 provides an example of a consequence matrix containing representative impact and severity categories.

Table A2 Representative Consequence Categories

Severity Categories	Impacts			
	Death & Injury	*Economic*	*Environmental*	*Reputation*
Low (1)	Low level short-term subjective inconvenience or symptoms. No measurable physical effects. No medical treatment.	No shutdown, costs less than $1,000 to repair.	No lasting effect. Low-level impacts on biological or physical environment. Limited damage to minimal area of low significance.	Public concern restricted to local complaints. Ongoing scrutiny/attention from regulator.
Minor (2)	Objective but reversible disability/impairment and/or medical treatment injuries requiring hospitalization.	No shutdown, costs less than $10,000 to repair.	Minor effects on biological or physical environment. Minor short-term damage to small area of limited significance.	Minor, adverse local public or media attention and complaints. Significant hardship from regulator. Reputation is adversely affected with a small number of site focused people.
Moderate (3)	Moderate irreversible disability or impairment (<30%) to one or more persons.	Operations shutdown, loss of day rate for 1-7 days and/or repair costs of up to $100,000.	Moderate effects on biological or physical environment but not affecting ecosystem function. Moderate short-medium term widespread impacts (e.g., oil spill causing impacts on shoreline).	Attention from media and/or heightened concern by local community. Criticism by Non-Governmental Organizations (NGO). Significant difficulties in gaining approvals. Environmental credentials moderately affected.
Major (4)	Single fatality and/or severe irreversible disability or impairment (>30%) to one or more persons.	Operations shutdown, loss of day rate for 7-28 days and/or repair costs of up to $1,000,000.	Serious environmental effects with some impairment of ecosystem function (e.g., displacement of species). Relatively widespread medium-long term impacts.	Significant adverse national media/public/NGO attention. May lose license to operate or not gain approval. Environment/management credentials are significantly tarnished.
Critical (5)	Short or long term health effects leading to multiple fatalities, or significant irreversible health effects to >50 persons.	Operations shutdown, loss of day rate for more than 28 days and/or repair costs more than $1,000,000.	Very serious effects with impairment of ecosystem function. Long term widespread effects on significant environment (e.g., unique habitat, National Park).	Serious public or media outcry (international coverage). Damaging NGO campaign. License to operate threatened. Reputation severely tarnished. Share price may be affected.

Risk – The risk of a hazard is based on the combination of the likelihood and consequence assessment, allowing risks of different hazards, operations, and potential accidents to be compared using a common measuring stick. Table A3 presents examples of risk levels assigned for each combination of likelihood

Bunkering of Liquefied Natural Gas-fueled Marine Vessels in North America

and severity combination. Each owner/operator has unique considerations and risk tolerances, thus risk levels should be tailored to reflect those individual organizational risk tolerances.

Table A3 Risk Levels

Likelihood Categories	Consequence Severity				
	Low	Minor	Moderate	Major	Critical
	1	2	3	4	5
Almost Certain (E)	Medium	Medium	High	High	High
Likely (D)	Moderate	Medium	Medium	High	High
Possible (C)	Low	Moderate	Medium	High	High
Unlikely (B)	Low	Low	Moderate	Medium	High
Rare (A)	Low	Low	Moderate	Medium	Medium

Risk Assessment Process

Accidents usually occur through a chain of events ending in one or more unwanted effects. This chain of events begins with hazards capable of causing consequences. If there are no hazards, there are no consequences. An equipment failure, human error, or external event is necessary for a hazard to cause consequences. Sometimes one or more equipment failures, human errors, or external events must take place after the initiating event for an accident to occur. An accident has at least one unwanted consequence with a measurable effect. This outcome is influenced throughout the chain of events by the presence of safeguards and their success or failure.

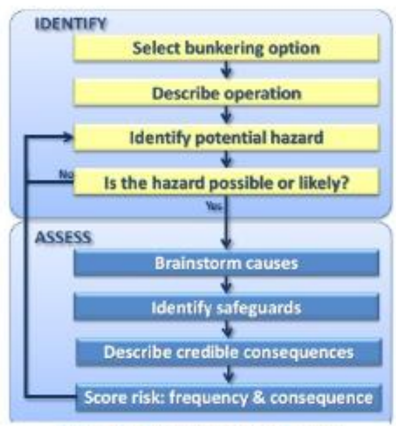


Figure A1 Risk Assessment Process

The risk assessment team should develop various accident chains for representative bunkering options by identifying potential hazards, causes, consequences, and safeguards by applying a sound methodology and structured assessment process (Figure A1). To do this, the team could employ the HazID methodology which leverages experts to brainstorm potential scenarios to facilitate in identification of health, safety, and environmental (HSE) hazards associated with various LNG bunkering options.

Key steps required to develop the risk profiles include:

- Assemble an appropriate team of experts familiar with LNG loading/unloading operations and LNG bunkering
- Provide an overview of each bunkering option, including major phases of the operations (e.g., connect, transfer, disconnect, lift) and types of vessels involved

Bunkering of Liquefied Natural Gas-fueled Marine Vessels in North America

- Brainstorm hazards that could potentially result in unwanted consequences
- Identify potential causes of the hazard
- Identify safeguards potentially in place to prevent the likelihood of occurrence (prevention) or minimize the consequences (mitigation)
- Describe the consequences and, if the hazard could result in a release of LNG, score the risk of the hazard as a function of likelihood and consequence considering all impact types: deaths/injuries, economic impacts, environmental impacts, and impacts to company reputation
- If applicable, document the linkage between hazards that could be causes of other hazards
- Record the team's discussions on HazID worksheets

LNG bunkering within North America is early in its development and there is relatively limited experience internationally. Therefore, at this time, there is a lack of historical accident data on which to base the risk assessment. To develop the risk profile, the team should consider hazards, causes, and consequences for historical accidents of analogous operations, including LNG import/export, traditional bunkering, and hazardous material transfers.

Table A4 provides an example worksheet template for a truck-to-vessel bunkering operation. Note: In the template, likelihood and consequences were not scored for LNG release scenarios.

Appendix C (TSGI Letter to USCG) Equivalency Considerations for Storage Tank and Bunkering Connections

THE SHEARER GROUP INC.

3118 Harrisburg Blvd.
Suite 100
Houston, TX 77003

281.532.2080 phone
281.326.1615 fax

shearer-group.com

Sep 26, 2017

LT William Cotta
US Coast Guard Marine Safety Center
United States Coast Guard Stop 7430
2703 Martin Luther King Jr Ave SE
Washington, DC 20593-7430

Corr. No: 0315-002-LETTER001

Project No: P020484

Subject: Equivalency considerations for storage tank and bunkering connections.

Reference: (a) USCG Letter: E1-1603079, dated 03 October 16

(b) 0315-002-900R1 "Basis of Design" dated 05 May 2017

(c) USCG CG-521 Policy Letter 01-12 Equivalency Determination: Design Criteria for Natural Gas Fuel System

(d) International Maritime Organization (IMO) Resolution MSC.285(86) - Interim Guidelines On Safety For Natural Gas-Fueled Engine Installations On Ships, ANNEX 11, (1June 2009)

(e) TSGI Drawing 0315-002-512 rev.0 "LNG Storage Details" dated 26 Sep 2017

LT Cotta;

The purpose of this letter is to clearly define special considerations regarding the tank connections and the bunkering arrangement.

Specifically we are requesting special consideration for the following regulations while demonstrating an equivalent level of safety:

- 2.8.1.2 (ref. d)
- 2.9.1.3 (ref. d)
- 2.9.2.2 (ref. d)

We intend to use two small road tanks for this operation which are equipped with spill protection, however it is unfeasible to meet the guidance of 2.8.1.2 (ref. d), without significant design changes to these tanks. See reference (e) for more details regarding the LNG tanks. We intend to fill the tanks in accordance with 2.8.1.5 (ref. d) and use stainless steel drip trays of sufficient capacity in

3118 Harrisburg Blvd.
Suite 100
Houston, TX 77003

281.532.2080 phone
281.326.1615 fax

shearer-group.com

accordance with 2.8.3.4 (ref. d) and 2.9.1.2 (ref. d) with regard to potential connection failure and bunkering leakage respectively.

Bunkering will be conducted via direct tank filling. Since there will not be any permanent bunkering lines on the vessel, some applicable safety features inherent to the bunker system will be achieved shore-side. Specifically, 2.9.1.3 (ref. d) refers to a control station where tank level and alarms are indicated; we intend for this to be shore side. Secondly, 2.9.2.2 (ref. d) indicates that manual and remote shutdown valves are required in the bunkering line close to the shore connection point; it is intended for the shore-side LNG delivery hose piping to have these particular valves. In addition, the delivery hose will be equipped with a break-away emergency release valve, and will have shore-side means of inerting. There will not be a permanent water-curtain system installed on the vessel.

Due to the size of the vessel, quantity of LNG and safety measures mentioned in this letter, we believe an equivalent level of safety is achieved.

If any additional information is required, please advise us and we will answer your comments accordingly.

Respectfully,

The Shearer Group, Inc.

Alex Ediger

Alex Ediger
Naval Architect

Appendix D (TSGI Letter to USCG) Equivalency Considerations for Dry Chemical Fire Protection

THE SHEARER GROUP INC.

3118 Harrisburg Blvd.
Suite 100
Houston, TX 77003

281.532.2080 phone
281.326.1615 fax

shearer-group.com

Sep 26, 2017

LT William Cotta
US Coast Guard Marine Safety Center
United States Coast Guard Stop 7430
2703 Martin Luther King Jr Ave SE
Washington, DC 20593-7430

Corr. No: 0315-002-LETTER002

Project No: P020484

Subject: Equivalency considerations for dry chemical fire protection.

Reference: (a) USCG Letter: E1-1603079, dated 03 October 16

(b) 0315-002-900R1 "Basis of Design" dated 05 May 2017

(c) USCG CG-521 Policy Letter 01-12 Equivalency Determination: Design Criteria for Natural Gas Fuel System

(d) International Maritime Organization (IMO) Resolution MSC.285(86) - Interim Guidelines On Safety For Natural Gas-Fueled Engine Installations On Ships, ANNEX 11, (1June 2009)

LT Cotta;

The purpose of this letter is to clearly define special considerations regarding the dry chemical fire protection.

Specifically we are requesting special consideration for the following regulations while demonstrating an equivalent level of safety:

- 3.3.3.1 (ref. d)

For the bunkering area, a permanently installed dry chemical powder extinguishing system will cover all possible leak points. 3.3.3.1 (ref. d) requires it to consist of at least one hand hose line that will be non-kinkable and be fitted with a nozzle capable of on/off operation and a discharge rate not less than 3.5 kg/s for a minimum of 45 seconds. Considering the very small size of the tanks (~150 gallons each) and since there is currently no USCG approved system, nor any small approved units appropriately sized for this size vessel, we are requesting special consideration regarding the following dry chemical units.

THE SHEARER GROUP INC.

3118 Harrisburg Blvd.
Suite 100
Houston, TX 77003

281.532.2080 phone
281.326.1615 fax

shearer-group.com

Ansul makes two semi-portable units that are very close to meeting the required regulations. The CR-LR-I-350-D and the CR-LR-I-K-350-D are 350 and 300 pound units respectively. The first one, achieves a 3.64 kg/s (7.7 lbs/s) agent flow rate (PLUS-FIFTY C) for 42 seconds; and the second one, achieves 3.64 kg/s (7.7 lbs/s) agent flow rate (Purple-K) for 38 seconds. These units meet the required flow rates however, the discharge times come up 3 and 7 seconds short. Due to our experience with other LNG projects, Purple-K is understood to be better for our application; therefore we are requesting to use the CR-LR-I-K-350-D unit.

In addition, and as required by 3.3.3.2 (ref. d), one portable dry powder extinguisher of 5 kg (11 lb) capacity will also be located at the bunkering station.

Considering the size of the vessel, quantity of LNG and the safety measures described in this letter, we believe the intent of the 3.3.3.1 (ref. d) is achieved.

If any additional information is required, please advise us and we will answer your comments accordingly.

Respectfully,

The Shearer Group, Inc.

Alex Ediger

Alex Ediger
Naval Architect

Appendix E (TSGI Letter to USCG) Equivalency Considerations for Class1/Div.2 Rating of Solenoid Valves.

THE SHEARER GROUP INC.

3118 Harrisburg Blvd.
Suite 100
Houston, TX 77003

281.532.2080 phone
281.326.1615 fax

shearer-group.com

Sep 26, 2017

LT William Cotta
US Coast Guard Marine Safety Center
United States Coast Guard Stop 7430
2703 Martin Luther King Jr Ave SE
Washington, DC 20593-7430

Corr. No: 0315-002-LETTER003

Project No: P020484

Subject: Equivalency considerations for Class1/Div.2 rating of solenoid valves.

Reference: (a) USCG Letter: E1-1603079, dated 03 October 16

(b) 0315-002-900R1 "Basis of Design" dated 05 May 2017

(c) USCG CG-521 Policy Letter 01-12 Equivalency Determination: Design Criteria for Natural Gas Fuel System

(d) International Maritime Organization (IMO) Resolution MSC.285(86) - Interim Guidelines On Safety For Natural Gas-Fueled Engine Installations On Ships, ANNEX 11, (1June 2009)

(e) TSGI Drawing 0315-002-701 rev.0 "Gas Train Ventilation System" dated 26 Sep 2017

(f) TSGI Drawing 0315-002-106 rev.0 "Gas Detector Arrangement" dated 26 Sep 2017

(g) TSGI Drawing 0315-002-691 rev.0 "Alarm Logic Diagram" dated 26 Sep 2017

LT Cotta;

The purpose of this letter is to clearly define special considerations regarding the Class1/Div.2 rating of the solenoid valves on the Altronics gas train.

Specifically we are requesting special consideration for the following regulation while demonstrating an equivalent level of safety:

- 4.3.2(6) (ref. c)

THE SHEARER GROUP INC.

3118 Harrisburg Blvd.
Suite 100
Houston, TX 77003

281.532.2080 phone
281.326.1615 fax

shearer-group.com

The solenoid valves we intend to use in the gas fumigation system, on the gas train within the ventilated enclosure, have Class1/Div.2 ratings. Since the area within the ventilated box around the gas train is part of the double wall piping, it is a zone 1 hazardous zone per reference (c). Electronics within Zone 1 hazardous zones require Class1/Div.1 ratings. As consequence, we are requesting special consideration allowing the use of solenoid valves with Class1/Div.2 ratings. The Altronics gas fumigation system has been widely used across many industries such as highway applications, for example. While the requirements call for Class1/Div.1 ratings on the valves, there currently isn't a solenoid valve available with this rating for such a small system, and switching the Altronics system to all pneumatics isn't economically feasible for this project.

The gas train is contained within the double wall piping, see reference (e), and will be ventilated at 30 air-changes per hour; this system will ventilate whenever the gas system is active. If a leak occurs in the gas piping, the ventilation air flow will draw out any gas through the double wall piping exhaust.

Additionally, gas detectors will be fitted within each of the gas train enclosures, in the immediate vicinity of the solenoid valves. If predetermined levels are detected, such as 20% and 40% of LEL, gas system shutdown will be triggered well before explosive levels are reached, and double wall pipe ventilation will continue as described above, see references (b), (f) and (g).

Considering the size of the vessel, quantity of LNG, small amounts of gas in the system, ventilation and strategic locations of gas detectors described in this letter, we believe an equivalent level of safety is achieved.

If any additional information is required, please advise us and we will answer your comments accordingly.

Respectfully,

The Shearer Group, Inc.

Alex Ediger

Alex Ediger
Naval Architect

Appendix F (TSGI Letter to USCG) Equivalency Considerations for Double Block and Bleed Valve Configuration

THE SHEARER GROUP INC.

3118 Harrisburg Blvd.
Suite 100
Houston, TX 77003

281.532.2080 phone
281.326.1615 fax

shearer-group.com

Sep 26, 2017

LT William Cotta
US Coast Guard Marine Safety Center
United States Coast Guard Stop 7430
2703 Martin Luther King Jr Ave SE
Washington, DC 20593-7430

Corr. No: 0315-002-LETTER004

Project No: P020484

Subject: Equivalency considerations for double block and bleed valve configuration.

Reference: (a) USCG Letter: E1-1603079, dated 03 October 16

(b) 0315-002-900R1 "Basis of Design" dated 05 May 2017

(c) USCG CG-521 Policy Letter 01-12 Equivalency Determination: Design Criteria for Natural Gas Fuel System

(d) International Maritime Organization (IMO) Resolution MSC.285(86) - Interim Guidelines On Safety For Natural Gas-Fueled Engine Installations On Ships, ANNEX 11, (1June 2009)

(e) TSGI Drawing 0315-002-701 rev.0 "Gas Train Ventilation System" dated 26 Sep 2017

(f) 0315-002-903R1 "Preliminary Risk Analysis" dated 05 May 2017

(g) TSGI Drawing 0315-002-106 rev.0 "Gas Detector Arrangement" dated 26 Sep 2017

LT Cotta;

The purpose of this letter is to clearly define special considerations regarding the requirements for a double block and bleed valve configuration.

Specifically we are requesting special consideration for the following regulation while demonstrating an equivalent level of safety:

- 5.6.3 (ref. d)

THE SHEARER GROUP INC.

3118 Harrisburg Blvd.
Suite 100
Houston, TX 77003

281.532.2080 phone
281.326.1615 fax

shearer-group.com

This section and Figures 1 and 2 referenced by 5.6.3 (ref. d) are applicable for high pressure systems that provide gas directly to the cylinder heads. The system we intend to use is a pre-turbo gas fumigation system that is dissimilar to that depicted in reference (d); it is described in more detail in reference (b) and (f). As consequence, we are requesting special consideration. It is our understanding that the intent of 5.6.3 (ref. d) is to prevent an explosive air-gas concentration within the system after a gas-system shutdown. We intend to show that the arrangement on the Principio will have an equivalent level of safety below.

In the event of the closure of the shutdown valve located on the Altronics gas train, gas supply to the engines will cease.

In the event of a normal shutdown of the gas system, the engine will automatically revert to normal diesel mode, in which case the residual gas downstream of the shutoff valve will be consumed very quickly, any potential concerns regarding residual gas will no longer be pertinent.

Should the engine encounter a shutdown unrelated to the gas system, a potential concern is that the gas between the shutdown valve and the injection point remains, unconsumed by the stopped engine. The Altronics gas fumigation systems will monitor key engine parameters (such as exhaust gas temperature, manifold air temperature, manifold air pressure, engine vacuum and vibration) and is designed to interpret these parameters and shut down the gas valve before the engine shuts down completely.

If the engine encounters an abrupt stop due to a catastrophic event, the remaining gas between the gas train and the injection point is minimal; the run of two inch gas pipe is less than six feet from the shutoff valve to the injection point at the air-gas mixer. As explained in reference (b), the regulator supplies gas to the engine at a slightly negative pressure. The negative gas pressure is an added level of safety since it prevents a rapid dispersion of the residual gas to the engine.

We also examined if, in the unlikely event of an abruptly-dead engine scenario, the residual gas escapes out through the engine's air intakes. The volume of the air intake system for the engine with the shortest air supply run was calculated; if all the residual gas immediately dispersed through the air intakes, the gas-to-air mixture would be approximately 1.5% which is well below the lower explosive limit of approximately 5% gas-to-air. Additionally, a gas detector will be located near the engine air inlets, see reference (g). If gas is detected at this location, the operator will be alerted to the situation allowing appropriate actions to be taken.

Additionally, if during the abruptly-dead engine scenario described above, the residual gas leaks through the air-gas mixer or anywhere else, the entire gas system is double-wall piped, refer to reference (e). The double wall piping system totally encloses the gas piping entirely throughout the engine room and includes a gas tight enclosure around the injection point. The double wall piping is ventilated at 30 air-changes per hour receiving external air, and exhausting external to the engine room.

THE SHEARER GROUP INC.

3118 Harrisburg Blvd.
Suite 100
Houston, TX 77003

281.532.2080 phone
281.326.1615 fax

shearer-group.com

Considering the size of the vessel, quantity of LNG and the safety measures described in this letter, we believe the intent of the 5.6.3 (ref. d) is achieved.

If any additional information is required, please advise us and we will answer your comments accordingly.

Respectfully,

The Shearer Group, Inc.

Alex Ediger

Alex Ediger
Naval Architect

Appendix G (TSGI Submission to USCG) *M/V RON-CHRIS*, Basis of Design & Preliminary Risk Assessment

THE SHEARER GROUP

3101 NASA Parkway
Suite I
Seabrook, Texas 77586
281.532.2080 phone
281.326.1615 fax
shearer-group.com

July 28, 2016

Commanding Officer (MSC)
Attn: Marine Safety Center
United States Coast Guard Stop 7430
2703 Martin Luther King Jr Ave SE
Washington, DC 20593-7430

via email: msc@uscg.mil

Attn: Chief, Machinery Branch

Corr. No: 0315-002-SUBMIT001

Subject: 58-0" x 20'-0 x 6'-0" Twin Screw Inland Towboat
Ron-Chris, O.N. 263103, St. Louis (Mo.) Shipbuilding & Steel Construction
Basis of Design & Preliminary Risk Assessment

Reference: (a) USCG CG-521 Policy Letter 01-12 Equivalency Determination: Design Criteria for Natural Gas Fuel System

(b) International Maritime Organization (IMO) Resolution MSC.285(86) - Interim Guidelines On Safety For Natural Gas-Fueled Engine Installations On Ships, ANNEX 11, (1June 2009)

Enclosures: (1) 0315-002-900R0 "Basis of Design" dated 28 July 2016
(2) 0351-002-903R0 "Preliminary Risk Analysis" dated 28 July 2016

Sir/Ma'am;

As technical support agents for Pittsburgh Region Clean Cities, we are submitting herein electronic copies of enclosure (1) and (2) your review. These documents are intended to be reviewed in accordance with references (a) and (b).

Through a cooperative agreement, MARAD has provided $730,000 to Pittsburgh Region Clean Cities (PRCC) to convert a towboat engine from diesel to dual fuel diesel/LNG. PRCC is working with Life Cycle Engineering and The Shearer Group Inc. to develop engineering and testing for this project. Results from this demonstration project will help expand the development and availability of natural gas conversion technology for smaller scale tug, tow, and harbor vessels. PRCC will collect air emissions data before and after the conversion, which will allow for operational and emissions comparisons. The conversion of the *Ron-Chris* would be the first of its kind for towboats, highlighting the advantages and safety of natural gas as an alternative fuel source.

If any additional information is required, please advise us and we will answer your comments accordingly.

Respectfully,

The Shearer Group, Inc.

Alex Ediger

Alex Ediger
Naval Architect

Appendix H **(TSGI Submission to USCG) *M/V PRINCIPIO,* Basis of Design & Preliminary Risk Assessment**

THE SHEARER GROUP INC.

3118 Harrisburg Blvd.
Suite 100
Houston, TX 77003

281.532.2080 phone
281.326.1615 fax

shearer-group.com

May 05, 2017

Commanding Officer (MSC)
Attn: Marine Safety Center
United States Coast Guard Stop 7430
2703 Martin Luther King Jr Ave SE
Washington, DC 20593-7430

via email: msc@uscg.mil

Attn: Chief, Machinery Branch

Corr. No: 0315-002-SUBMIT002

Subject: 65-0" x 24'-0 x 6'-0" Twin Screw Inland Towboat
Principio, O.N. 240091, Sturgeon Bay (Wis.) Shipbuilding & Dry Dock Co.
Basis of Design & Preliminary Risk Assessment

Reference: (a) USCG Project Number: P020484

(b) USCG Letter: E1-1603079

(c) USCG CG-521 Policy Letter 01-12 Equivalency Determination: Design Criteria for Natural Gas Fuel System

(d) International Maritime Organization (IMO) Resolution MSC.285(86) - Interim Guidelines On Safety For Natural Gas-Fueled Engine Installations On Ships, ANNEX 11, (1June 2009)

Enclosures: (1) 0315-002-900R1 "Basis of Design" dated 05 May 2017
(2) 0351-002-903R1 "Preliminary Risk Analysis" dated 05 May 2017

Sir/Ma'am;

As technical support agents for Pittsburgh Region Clean Cities, we are submitting herein electronic copies of enclosure (1) and (2) your review. These documents are intended to be reviewed in accordance with references (c) and (d).

Since the previous submission in 2016, the vessel has been changed to the "Principio." Enclosures (1) and (2) have been updated per the selection of the new vessel and the tank and fumigation system providers.

THE SHEARER GROUP INC.

3118 Harrisburg Blvd.
Suite 100
Houston, TX 77003

281.532.2080 phone
281.326.1615 fax

shearer-group.com

If any additional information is required, please advise us and we will answer your comments accordingly.

Respectfully,

The Shearer Group, Inc.

Alex Ediger

Alex Ediger
Naval Architect

Appendix I **(TSGI Submission to USCG) *M/V PRINCIPIO*, Drawing Package and Equivalency Letters (1 of 3)**

THE SHEARER GROUP INC.

3118 Harrisburg Blvd.
Suite 100
Houston, TX 77003

281.532.2080 phone
281.326.1615 fax

shearer-group.com

September 27, 2017

Commanding Officer (MSC)
Attn: Marine Safety Center
United States Coast Guard Stop 7430
2703 Martin Luther King Jr Ave SE
Washington, DC 20593-7430

via email: msc@uscg.mil

Attn: Chief, Machinery Branch

Corr. No: 0315-002-SUBMIT003

Subject: 65-0" x 24'-0 x 6'-0" Twin Screw Inland Towboat
Principio, O.N. 240091, Sturgeon Bay (Wis.) Shipbuilding & Dry Dock Co.
Drawing Package and Equivalency Letters

Reference: (a) USCG Project Number: P020484

(b) USCG Letter: E1-1702073

(c) USCG CG-521 Policy Letter 01-12 Equivalency Determination: Design Criteria for Natural Gas Fuel System

(d) International Maritime Organization (IMO) Resolution MSC.285(86) - Interim Guidelines On Safety For Natural Gas-Fueled Engine Installations On Ships, ANNEX 11, (1June 2009)

Enclosures: (1) TSGI Drawing: 0315-002-100R0 "General Arrangement" 26 May 2017
(2) TSGI Drawing: 0315-002-106R0 "Gas Detector Locations" 26 May 2017
(3) TSGI Drawing: 0315-002-140R0 "LNG Storage Arrangement" 26 May 2017
(4) TSGI Drawing: 0315-002-150R0 "Hazardous Zones Plan" 26 May 2017
(5) TSGI Drawing: 0315-002-190R0 "Waterspray System" 26 May 2017
(6) TSGI Drawing: 0315-002-191R0 "Fire Boundary Plan" 26 May 2017
(7) TSGI Drawing: 0315-002-290R0 "Structural Modifications" 26 May 2017
(8) TSGI Drawing: 0315-002-511R0 "Gas Fuel System Schematic" 26 May 2017
(9) TSGI Drawing: 0315-002-512R0 "LNG Storage Details" dated 26 May 2017
(10) TSGI Drawing: 0315-002-691R0 "Alarm Logic Diagram" 26 May 2017
(11) TSGI Drawing: 0315-002-701R0 "Gas Train Ventilation" 26 May 2017
(12) TSGI Letter: 0315-002-LETTER001, 26 May 2017
(13) TSGI Letter: 0315-002-LETTER002, 26 May 2017

3118 Harrisburg Blvd.
Suite 100
Houston, TX 77003

281.532.2080 phone
281.326.1615 fax

shearer-group.com

THE SHEARER GROUP INC.

(14) TSGI Letter: 0315-002-LETTER003, 26 May 2017
(15) TSGI Letter: 0315-002-LETTER004, 26 May 2017

Sir/Ma'am;

As technical support agents for Pittsburgh Region Clean Cities, we are submitting herein electronic copies of enclosure (1) through (15) your review. These documents are intended to be reviewed in accordance with references (c) and (d).

If any additional information is required, please advise us and we will answer your comments accordingly.

Respectfully,

The Shearer Group, Inc.

Alex Ediger

Alex Ediger
Naval Architect

Appendix J **(TSGI Submission to USCG) *M/V PRINCIPIO*, Drawing Package and Equivalency Letters (2 of 3)**

THE SHEARER GROUP INC.

3118 Harrisburg Blvd.
Suite 100
Houston, TX 77003

281.532.2080 phone
281.326.1615 fax

shearer-group.com

December 14, 2017

Commanding Officer (MSC)
Attn: Marine Safety Center
United States Coast Guard Stop 7430
2703 Martin Luther King Jr Ave SE
Washington, DC 20593-7430

via email: msc@uscg.mil

Attn: Chief, Machinery Branch

Corr. No: 0315-002-SUBMIT004

Subject: 65-0" x 24'-0 x 6'-0" Twin Screw Inland Towboat
Principio, O.N. 240091, Sturgeon Bay (Wis.) Shipbuilding & Dry Dock Co.
Drawing Package and Equivalency Letters

Reference: (a) USCG Project Number: P020484
(b) USCG Letter: E1-1703885
(c) ANSUL Wheeled Unit Data Sheet "F-2002046 SEMIPORTABLE UNITS"

Enclosures: (1) TSGI Drawing: 0315-002-190R1 "Waterspray System" 14 Dec 2017
(2) TSGI Drawing: 0315-002-192R0 "Fire and Safety Plan" 14 Dec 2017

Sir/Ma'am;

As technical support agents for Pittsburgh Region Clean Cities, we are submitting herein electronic copies of enclosures (1) and (2) your review. Enclosures (1) and (2) were revised/produced per reference (b). References (c) is intended to aid in your review of enclosure (2).

If any additional information is required, please advise us and we will answer your comments accordingly.

Respectfully,

The Shearer Group, Inc.

Alex Ediger

Alex Ediger
Naval Architect

Appendix K (TSGI Submission to USCG) *M/V PRINCIPIO*, Drawing Package and Equivalency Letters (3 of 3)

THE SHEARER GROUP INC.

3118 Harrisburg Blvd.
Suite 100
Houston, TX 77003

281.532.2080 phone
281.326.1615 fax

shearer-group.com

January 05, 2018

Commanding Officer (MSC)
Attn: Marine Safety Center
United States Coast Guard Stop 7430
2703 Martin Luther King Jr Ave SE
Washington, DC 20593-7430

via email: msc@uscg.mil

Attn: Chief, Machinery Branch

Corr. No: 0315-002-SUBMIT005

Subject: 65-0" x 24'-0 x 6'-0" Twin Screw Inland Towboat
Principio, O.N. 240091, Sturgeon Bay (Wis.) Shipbuilding & Dry Dock Co.
Drawing Package and Equivalency Letters

Reference: (a) USCG Project Number: P020484
(b) USCG Letter: E1-1703885
(c) D.W.P. fan cut sheets

Enclosures: (1) TSGI Drawing: 0315-002-511R1 "Gas Fuel System Schematic" 05 Jan 2018
(2) TSGI Drawing: 0315-002-701R1 "Gas Train Ventilation System" 05 Jan 2018

Sir/Ma'am;

As technical support agents for Pittsburgh Region Clean Cities, we are submitting herein electronic copies of enclosures (1) and (2) your review. Enclosures (1) and (2) were revised per reference (b). References (c) is intended to aid in your review of enclosure (2).

If any additional information is required, please advise us and we will answer your comments accordingly.

Respectfully,

The Shearer Group, Inc.

Alex Ediger

Alex Ediger
Naval Architect

NAVAL ARCHITECTS : MARINE ENGINEERS : MARINE SURVEYORS
Member, THE AMERICAN WATERWAYS OPERATORS

Appendix L (TSGI Submission to USCG) *M/V PRINCIPIO*, Altronic GTI Bi-Fuel System: FMEA and PSTP

THE SHEARER GROUP INC.

3118 Harrisburg Blvd.
Suite 100
Houston, TX 77003

281.532.2080 phone
281.326.1615 fax

shearer-group.com

March 15, 2018

Commanding Officer (MSC)
Attn: Marine Safety Center
United States Coast Guard Stop 7430
2703 Martin Luther King Jr Ave SE
Washington, DC 20593-7430

Via email: msc@uscg.mil

Attn: Chief, Machinery Branch

Corr. No: 0315-002-SUBMIT006

Subject: 65-0" x 24'-0 x 6'-0" Twin Screw Inland Towboat
Principio, O.N. 240091, Sturgeon Bay (Wis.) Shipbuilding & Dry Dock Co.
Altronic GTI Bi-Fuel System: FMEA and PSTP

Reference: (a) USCG Project Number: P020484
(b) MSC Letter: E2-1703960, 25 Oct 2017

Enclosures: (1) ALTRONIC Doc: "GTI+ FMEA", Jan 2014
(2) ALTRONIC Doc: "GTI SN127 Recommended Annual Check" 23 Feb 2018

Sir/Ma'am;

As technical support agents for Pittsburgh Region Clean Cities, we are submitting herein electronic copies of enclosures (1) and (2), both documents produced by Altronic, LLC, for your review per the request of Reference (2). Enclosures (1) and (2) are the FMEA and PSTP, respectively, for the bi-fuel system.

If any additional information is required, please advise us and we will answer your comments accordingly.

Respectfully,

The Shearer Group, Inc.

Alex Ediger

Alex Ediger
Naval Architect

Appendix M (USCG Response to TSGI) *M/V RON-CHRIS,* LNG Conversion Project Regulatory Assessment

U.S. Department of Homeland Security
United States Coast Guard

Commanding Officer
United States Coast Guard
Marine Safety Center

US Coast Guard Stop 7430
2703 Martin Luther King Jr. Ave SE
Washington, DC 20593-7430
Staff Symbol: MSC-2
Phone: (202) 795-6729
Email: msc@uscg.mil

16710/P020484/wjc
Serial: E1-1603079
October 3, 2016

The Shearer Group, Inc. (TSGI)
Attn: Mr. Alex Ediger
3101 NASA Parkway
Suite I
Seabrook, TX 77586
aediger@shearer-group.com

Subj: RON-CHRIS, O.N. 263103
49′ x 20′ x 6′ Twin Screw Inland Towboat (C)
LNG Conversion Project Regulatory Assessment

Ref: (a) TSGI Corr. No. 0315-002-900R0, Rev. -, "Dual Fuel Inland Towboat: Basis of Design," 22 sheets, dated July 28, 2016
(b) TSGI Corr. No. 0315-002-903R0, Rev. -, "Dual Fuel Inland Towboat: Preliminary Risk Analysis," 26 sheets, dated July 28, 2016
(c) TSGI Corr. No. 0315-002-SUBMIT001, Rev. -, "Basis of Design and Preliminary Risk Assessment," 2 sheets, dated July 28, 2016
(d) Commandant (CG-521) Policy Letter No. 01-12, "Equivalency Determination – Design Criteria for Natural Gas Fuel Systems"
(e) IMO Resolution MSC.285(86), "Interim Guidelines on Safety for Natural Gas-Fuelled Engine Installations in Ships"
(f) IMO Resolution MSC.391(95), "International Code of Safety for Ships Using Gases or Other Low-Flashpoint Fuels (IGF Code)"

Dear Mr. Ediger:

We reviewed references (a) and (b), submitted by your letter, reference (c) (MSC Document No. 1615977), for compliance with 46 CFR Subchapter C and references (d) and (e). This letter establishes the regulatory regime applicable to the vessel which you reference in your letter, and provides comments regarding our review.

The Commandant's Office of Design and Engineering Standards (CG-ENG-1) has determined that conversion of an existing Towing Vessel's propulsion system to use LNG as fuel constitutes a *material alteration* to the vessel, as defined in 46 CFR 24.05-5(a). Therefore, Part 27.211(c), which requires Commandant (CG-ENG) acceptance of alternative fuels, applies. Reference (d) outlines the regulatory standard established by Commandant (CG-ENG) for the use of LNG as fuel, in addition to those requirements which already apply to the vessel.

In reviewing the documents you submitted for compliance with the applicable regulations, we noted areas that must be addressed before we enter the plan review phase. These areas are as follows:

Subj: RON-CHRIS, O. N. 263103
LNG Conversion Project Regulatory Assessment

16710/P020484/wjc
Serial: E1-1603079
October 3, 2016

Reference (a)

1. We note the intention to comply with the "gas safe" configuration as described in reference 2.6.1.1.1 of reference (e). The system configuration shown on page 7 of reference (a) which utilizes an LNG fumigation arrangement for gas injection into the existing propulsion engine, is not compliant with the requirements for gas safe machinery spaces. The current configuration shows double ducting only to the point where the gas is mixed with the air in the air intake for the engine, presumably in accordance with Section 2.7.1.2, footnote 7 of reference (e). Footnote 7 requires injection of the LNG gas at the individual cylinder intake as opposed to the air intake manifold as depicted. Reference (f) section 9.6.2, footnote 18 is an updated version of reference (e) section 2.7.1.2 footnote 7. In the updated version, the intention of section 2.7.1.2 footnote 7 in reference (e) is more clearly stated clarifying that a fumigation system injecting gas as depicted is not compliant. However, we may be able to accept the current arrangement based on an 'equivalent level of safety' if it can be shown that the risk of explosion within the manifold is negligible or suitable pressure release systems are installed. Additionally, any release of gas into the machinery space must not result in an explosive atmosphere. This may be shown through mitigation of gas release via the use of alarms, detectors, mechanical ventilation, or a combination thereof.

2. There is no discussion of explosion protection required by Section 6.2.1.1 through 6.2.1.3 of reference (e) in reference (a) or reference (b). A fumigation system would require either explosion relief venting or demonstration of system strength, through documentation.

Please note that reference (e) has been superseded by reference (f) and will enter into force internationally on January 1, 2017. Commandant (CG-ENG) is currently drafting policy superseding references (d) and (e) and establishing reference (f) as the equivalent standard to that provided for traditional fuel systems by existing regulations. Accordingly, the design basis used for this vessel may not be available for use on future projects.

Our Project Number for this vessel is P020484. Please ensure that all future correspondence includes the Project Number and the Official Number that appears in the subject line. If you would like to further discuss this matter please contact us to arrange a meeting. Please contact LT William Cotta at (202) 795-6757 with questions concerning our review.

Sincerely,

S. T. BRADY
Commander, U. S. Coast Guard
Chief, Engineering Division
By direction

Copy: Commanding Officer, Marine Safety Unit Pittsburgh

U.S. Department of Homeland Security
United States Coast Guard

Commanding Officer
United States Coast Guard
Marine Safety Center

US Coast Guard Stop 7430
2703 Martin Luther King Jr. Ave SE
Washington, DC 20593-7430
Staff Symbol: MSC-2
Phone: (202) 795-6729
Email: msc@uscg.mil

16710/P020484/wjc
Serial: E1-1702073
June 20, 2017

The Shearer Group, Inc. (TSGI)
Attn: Mr. Alex Ediger
3118 Harrisburg Blvd
Houston, TX 77003
aediger@shearer-group.com

Subj: PRINCIPIO, O.N. 240091
65′ x 24′ x 6′ Towing Vessel (C)
LNG Fuel System

Ref: (a) TSGI Doc. No. 0315-002-900R1, Rev. -, "Dual Fuel Inland Towboat: Basis of Design," 32 sheets, dated May 5, 2017
(b) TSGI Doc. No. 0315-002-903R1, Rev. -, "Dual Fuel Inland Towboat: Preliminary Risk Analysis," 29 sheets, dated May 5, 2017
(c) TSGI Letter, Corr. No. 0315-002-SUBMIT002, "Basis of Design & Preliminary Risk Assessment," 2 sheets, dated May 5, 2017
(d) Commandant (CG-521) Policy Letter No. 01-12 "Equivalency Determination Design for Natural Gas Fuel Systems"
(e) IMO Resolution MSC.285(86) "Interim Guidelines on Safety for Natural Gas-Fuelled Engine Installations in Ships"
(f) Marine Safety Center Letter E1-1603079, "RON-CHRIS, O.N. 263103, LNG Conversion Project Regulatory Assessment," dated October 3, 2016

Dear Mr. Ediger:

We reviewed references (a) and (b), submitted by your letter reference (c), (MSC Document No. 1713491), for compliance with 46 CFR Subchapter C and references (d) and (e). We note the change of vessel from the RON-CHRIS (O.N. 263103) to the PRINCIPIO (O.N. 240091), this change does not affect our comments in reference (f).

As stated in reference (f), the regulatory requirements for the conversion to the use of LNG as fuel are references (d) and (e). The requirements of reference (e) will be applied as stated in reference (e) and interpreted in reference (d), with no additional requirements applied based on future regulations. The design concept presented in reference (a) is acceptable in principle, and detailed plans may now be submitted for review and approval. Please note the comments and requirements for additional information we require for plan review and approval:

1. The proposal requests that the system be considered as compliant with the gas safe system configuration requirements of Section 2.6.2 of reference (e). Section 2.7.1.2 of reference

(e) requires double ducting on the gas piping all the way until the gas is injected into the chamber. Note 7 of reference (e) allows low pressure engines to omit double ducting on the air inlet piping of the engine if a gas detector is fitted above the engine. Therefore the system as designed is compliant with reference (e).

2. The methodology for determining the location of the gas detectors above the engines is not discussed in section 9.2 of reference (a). Please note the arrangement of gas detectors must be based on the requirements of section 5.5 of reference (e). In addition you must submit the results of the gas dispersal analysis or physical smoke testing, as discussed in section 5.5.3. This analysis is an acceptable measure to reduce the risk of an explosive environment being created in the engine room as a result of a gas leak in air intake downstream of the double wall piping.

3. We note your intention to install ventilation capacity in excess of the requirements for gas safe machinery spaces, section 2.10.3.1 of reference (e), as a mitigating safety measure. You indicate in section 6.9 of reference (a) your intention to meet the requirements for emergency shutdown systems, section 2.10.3.2 and 2.10.3.3 of reference (e). You must submit detailed ventilation plans showing the capacity and location of all installed ventilation equipment and ducting to demonstrate compliance with the requirements of reference (e).

4. The proposal submitted shows hazardous classified zones 1 & 2 which appear to intersect openings in the aft main deckhouse. In accordance with section 4.3.2 of reference (d) an enclosed or semi-enclosed having an opening into a Zone 1 location would be classified as a Zone 1 location and all electrical equipment would be required to meet section 4.1 of reference (d).

You must provide the OCMI with a copy of this letter and references (a) through (c). Additionally we recommend you engage the OCMI prior to initiating the plan review process in order to determine any operational requirements that may be imposed on the vessel, and ensure these requirements are feasible for your project.

Our Project Number for this vessel is P020484. Please ensure that all future correspondence includes the Project Number and the Official Number that appears in the subject line.

Please contact LT William Cotta at (202) 795-6757 with questions concerning our review.

Sincerely,

C. J. ROBUCK
Lieutenant Commander, U. S. Coast Guard
Chief, Engineering Division
By direction

Copy: Commanding Officer, Marine Safety Unit Pittsburgh

Appendix O (USCG Response to TSGI) *M/V PRINCIPIO,* LNG Piping Systems

U.S. Department of Homeland Security
United States Coast Guard

Commanding Officer
United States Coast Guard
Marine Safety Center

US Coast Guard Stop 7430
2703 Martin Luther King Jr. Ave SE
Washington, DC 20593-7430
Staff Symbol: MSC-2
Phone: (202) 795-6729
Email: msc@uscg.mil

16710/P020484/wjc
Serial: E1-1703885
October 25, 2017

The Shearer Group, Inc. (TSGI)
Attn: Mr. Alex Ediger
3118 Harrisburg Blvd
Houston, TX 77003
aediger@shearer-group.com

Subj: PRINCIPIO, O.N. 240091
53.2′ x 24′ x 5.6′ Towing Vessel (C)
LNG Piping Systems

Ref: (a) TSGI Dwg. No. 0315-002-190, Rev. 0, "Waterspray System," 2 sheets, dated September 26, 2017
(b) TSGI Dwg. No. 0315-002-511, Rev. 0, "Gas Fuel System Schematic," 1 sheet, dated September 26, 2017
(c) TSGI Dwg. No. 0315-002-512, Rev. 0, "LNG Storage Details," 1 sheet, dated September 26, 2017
(d) TSGI Dwg. No. 0315-002-701, Rev. 0, "Gas Train Ventilation System," 1 sheet, dated September 26, 2017
(e) Your letter Corr. No. 0315-002-LETTER001 dated September 26, 2017
(f) Your letter Corr. No. 0315-002-LETTER002 dated September 26, 2017
(g) Your letter Corr. No. 0315-002-LETTER004 dated September 26, 2017
(h) Your letter Corr. No. 0315-002-SUBMIT003 dated September 27, 2017
(i) Commandant (CG-521) Policy Letter No. 01-12 "Equivalency Determination Design for Natural Gas Fuel Systems"
(j) IMO Resolution MSC.285(86) "Interim Guidelines on Safety for Natural Gas-Fuelled Engine Installations in Ships"

Dear Mr. Ediger:

We reviewed references (a) through (g), submitted by your letter (reference (h), MSC Document No. 1721260), for compliance with 46 CFR Subchapter C and references (i) and (j). References (a) through (d) are **Returned for Revision**. Plans so considered are not approved and must be resubmitted for review after revision. References (e) through (h) are **Examined**. Specific approval of these references is not required; however, they contain information that is needed to verify compliance and subsequent approval of required plans. Other plans submitted with your letter, not specifically addressed herein, will be the subject of separate correspondence from the Marine Safety Center. The following comments apply:

References (a) through (d)

1. The plans submitted lack sufficient detail to demonstrate compliance with 46 CFR Subchapter C and references (i) and (j). More information is required in the following areas:

a. Detailed piping plans including material specifications and piping dimensions which demonstrate compliance with ASME B31.3, as required by reference (i), section 2.5.
b. Detailed component lists including manufacturer name and part number, material specifications, maximum pressure ratings, and minimum design temperatures of all components must be submitted. This includes all valves, filters, gauges, and relief valves.

2. References (e) through (h) contain equivalency considerations for specific requirements pertaining to references (a) through (d). Please note that we do not approve designs offering an equivalent level of safety in concept. Instead, we approve plans noting the specific equivalencies demonstrated in that plan. Therefore without detailed plans including all the information required to demonstrate compliance with Subchapter C and references (i) and (j), we cannot offer approval of the design concepts at this time.

Reference (c)

3. As required by references (i) and (j), storage tanks must meet the requirements of section 2.8. As an alternative, the storage tank may be designed to meet ASME Boiler and Pressure Vessel Code, Section VIII, Division 1 or 2. You must submit calculations demonstrating the tank meets these requirements or an equivalent level of safety.

Reference (f)

4. As noted in reference (i), section 3.3.3, no dry chemical powder fire extinguishing systems are currently approved by the Coast Guard. To demonstrate compliance, detailed manufacturer's data and maintenance manual should be submitted. In addition, a fire safety plan showing the location of the portable fire extinguishers should be submitted to demonstrate compliance with the unit's listing limitation for coverage distance.

Our Project Number for this vessel is P020484. Please ensure that all future correspondence includes the Project Number and the Official Number that appears in the subject line.

Please contact LT William Cotta at (202) 795-6757 with questions concerning our review.

Sincerely,

J. J. MIN
Lieutenant Commander, U. S. Coast Guard
Chief, Machinery Branch
By direction

Copy: Commanding Officer, Marine Safety Unit Pittsburgh

Appendix P (USCG Response to TSGI) *M/V PRINCIPIO*, Hazardous Area Plan, Gas Detection System, Alarm and Monitoring System

U.S. Department of Homeland Security
United States Coast Guard

Commanding Officer
United States Coast Guard
Marine Safety Center

US Coast Guard Stop 7430
2703 Martin Luther King Jr. Ave SE
Washington, DC 20593-7430
Staff Symbol: MSC-2
Phone: (202) 795-6729
Email: msc@uscg.mil

16710/P020484/lnf
Serial: E2-1703960
October 25, 2017

The Shearer Group, Inc. (TSGI)
Attn: Mr. Alex Ediger
3118 Harrisburg Blvd
Houston, TX 77003
aediger@shearer-group.com

Subj: PRINCIPIO, O.N. 240091
65′ x 24′ x 6′ Towing Vessel (C)
Hazardous Area Plan, Gas Detection System,
Alarm and Monitoring System

Ref: (a) TSGI Dwg. No. 0315-002-150, Rev. 0, "Hazardous Zone Plan," 2 sheets, dated September 26, 2017
(b) TSGI Dwg. No. 0315-002-106, Rev. 0, "Gas Detector Locations," 2 sheets, dated September 26, 2017
(c) TSGI Dwg. No. 0315-002-691, Rev. 0, "Alarm Logic Diagram," 1 sheet, dated September 26, 2017
(d) Your letter Corr. No. 0315-002-LETTER003 dated September 26, 2017
(e) Your letter Corr. No. 0315-002-SUBMIT003 dated September 27, 2017
(f) Commandant (CG-521) Policy Letter No. 01-12 "Equivalency Determination Design for Natural Gas Fuel Systems"
(g) IMO Resolution MSC.285(86) "Interim Guidelines on Safety for Natural Gas-Fuelled Engine Installations in Ships"

Dear Mr. Ediger:

We reviewed references (a) through (d), submitted by your letter reference (e) (MSC Document No. 1721260), for compliance with 46 CFR Subchapter C and references (f) and (g). References (a) through (c) are **Returned for Revision**. Plans so considered are not approved and must be resubmitted for review after revision. References (e) is **Examined**. Specific approval of these references is not required; however, they contain information that is needed to verify compliance and subsequent approval of required plans. Other plans submitted with your letter, not specifically addressed herein, will be the subject of separate correspondence from the Marine Safety Center. The following comments apply:

<u>Reference (a)</u>

1. Enclosure (1) Section 4.3 of reference (f) outlines requirements for hazardous zones. There are numerous openings to unlabeled spaces which have openings into hazardous locations. In accordance with 4.3.1, 4.3.2, and 4.3.3 (where applicable) these enclosed or semi-enclosed spaces with openings into hazardous locations are required to meet the requirements of the zone into which they open. Please revise the drawing to demonstrate compliance.

Subj: PRINCIPIO, O.N. 240091
Hazardous Area Plan, Gas Detection System,
Alarm and Monitoring System

16710/ P020484/lnf
Serial: E2-1703960
October 25, 2017

2. Please provide detailed component lists including manufacturer name, part number, and applicable certification to meet the requirements of enclosure (1) section 4.1 of reference (f) must be provided in order demonstrate compliance.

<u>Reference (b)</u>

3. Please provide all plans and certifications required by enclosure (1) section 5.5 (3) of reference (f). These plans should demonstrate compliance with all applicable requirements of enclosure (1) section 5.5 of reference (f).

<u>Reference (c)</u>

4. Plan provides insufficient details to demonstrate compliance with enclosure (1) sections 5.1 and 5.3 of reference (f). Please provide Failure Modes and Effects Analysis (FMEA), Design Verification Test Procedures (DVTP), and Periodic Safety Test Procedures (PSTP) as required by 46 CFR 61.40.

<u>Reference (d)</u>

5. Please note we do not approve designs offering an equivalent level of safety in concept. Instead we approve plans noting the specific equivalencies demonstrated in that plan. Therefore without detailed plans including all the information required to demonstrate compliance with Subchapter C and references (f) and (g), we cannot offer approval of the design concepts at this time.

Our Project Number for this vessel is P020484. Please ensure that all future correspondence includes the Project Number and the Official Number that appears in the subject line.

Please contact Mr. Lee Franklin at (202) 795-6757 with questions concerning our review.

Sincerely,

mahossain

M. A. HOSSAIN
Chief, Electrical Branch
U.S. Coast Guard
By direction

Copy: Commanding Officer, Marine Safety Unit Pittsburgh

Appendix Q **(USCG Response to TSGI) *M/V PRINCIPIO*, General Arrangement, Structural Fire Protection and Structures**

U.S. Department of Homeland Security
United States Coast Guard

Commanding Officer
United States Coast Guard
Marine Safety Center

US Coast Guard Stop 7430
2703 Martin Luther King Jr. Ave SE
Washington, DC 20593-7430
Staff Symbol: MSC-2
Phone: (202) 795-6729
Email: msc@uscg.mil

16710/P020484/tjw
Serial: H2-1703966
October 30, 2017

The Shearer Group, Inc. (TSGI)
Attn: Mr. Alex Ediger
3118 Harrisburg Blvd
Houston, TX 77003
aediger@shearer-group.com

Subj: PRINCIPIO, O.N. 240091
65′ x 24′ x 6′ Towing Vessel (C)
General Arrangement, Structural Fire Protection and Structures

Ref: (a) TSGI Dwg. No. 0315-002-100, Rev. 0, "General Arrangement," 3 sheets, dated September 26, 2017
(b) TSGI Dwg. No. 0315-002-191, Rev. 0, "Fire Boundary Plan," 1 sheet, dated September 26, 2017
(c) TSGI Dwg. No. 0315-002-290, Rev. 0, "Vessel Structural Modifications," 2 sheets, dated September 26, 2017
(d) Commandant (CG-521) Policy Letter No. 01-12 "Equivalency Determination Design for Natural Gas Fuel Systems"
(e) IMO Resolution MSC.285(86) "Interim Guidelines on Safety for Natural Gas-Fuelled Engine Installations in Ships"

Dear Mr. Ediger:

We reviewed references (a) through (c), submitted with your e-mail dated September 27, 2017 (MSC Document No. 1721260), for compliance with 46 CFR Subchapter C and references (d) and (e). References (a) and (b) are **Approved**. The installation, workmanship and testing shall be accomplished to the satisfaction of the cognizant Officer in Charge, Marine Inspection (OCMI). No action was taken on reference (c) which was provided for reference only.
As an agreed-upon condition of your participation in the Marine Safety Center's electronic commerce program, you must provide the OCMI with a copy of this letter and identical paper copies of references (a) through (c).

Our Project Number for this vessel is P020484. Please ensure that all future correspondence includes the Project Number and the Official Number that appears in the subject line.

Subj: PRINCIPIO, O.N. 240091
General Arrangement, Structural Fire Protection
and Structures

16710/P020484/tjw
Serial: H2-1703966
October 30, 2017

Please contact Mr. Tom Woodford at (202) 795-6753 with questions concerning our review.

Sincerely,

J.M. Walsh

J. M. WALSH
Lieutenant, U. S. Coast Guard
Chief, Major Vessel Branch
By direction

Copy: Commanding Officer, Marine Safety Unit Pittsburgh

Appendix R (USCG Response to LCE) *M/V PRINCIPIO*, LNG Tank Equivalency

U.S. Department of Homeland Security
United States Coast Guard

Commanding Officer
United States Coast Guard
Marine Safety Center

US Coast Guard Stop 7430
2703 Martin Luther King Jr. Ave SE
Washington, DC 20593-7430
Staff Symbol: MSC-2
Phone: (202) 795-6729
Email: msc@uscg.mil

16710/P020484/wjc
Serial: E1-1704571
December 15, 2017

Life Cycle Engineering
Attn: Mr. Kenneth Siegman
859 Missionary Drive Suite 210
Pittsburgh, PA 15236
ksiegman@lce.com

Subj: PRINCIPIO, O.N. 240091
53.2′ x 24′ x 5.6′ Towing Vessel (C)
LNG Tank Equivalency

Ref: (a) Your letter, "LNG Storage Tank Requirements for LNG Conversion of M/V PRINCIPIO," dated December 1, 2017
(b) Your letter, "Equivalency consideration for LNG storage tank and tank pipe connections," dated December 5, 2017
(c) Commandant (CG-521) Policy Letter No. 01-12 "Equivalency Determination Design for Natural Gas Fuel Systems"
(d) IMO Resolution MSC.285(86) "Interim Guidelines on Safety for Natural Gas-Fuelled Engine Installations in Ships"

Dear Mr. Siegman:

We reviewed references (a) and (b), submitted by your email dated December 5, 2017 (MSC Document No. 1723088), for compliance with 46 CFR Subchapter C and references (c) and (d). References (a) and (b) are being held in abeyance pending resolution of the following comment:

As discussed in our phone call on December 11, 2017, detailed drawings, dimensions and materials of all components of the LNG tank must be provided. Once received, we can review all information, including the gap analysis (submitted in references (a) and (b)), to evaluate the equivalency request for the LNG tank.

Our Project Number for this vessel is P020484. Please ensure that all future correspondence includes the Project Number and the Official Number that appears in the subject line.

Please contact LT William Cotta at (202) 795-6757 with questions concerning our review.

Sincerely,

Jodi Min

J. J. MIN
Lieutenant Commander, U. S. Coast Guard
Chief, Machinery Branch
By direction

Copy: Commanding Officer, Marine Safety Unit Pittsburgh

Appendix S (USCG Response to TSGI) *M/V PRINCIPIO*, Fire Suppression and Water Spray Systems

U.S. Department of Homeland Security
United States Coast Guard

Commanding Officer
United States Coast Guard
Marine Safety Center

US Coast Guard Stop 7430
2703 Martin Luther King Jr. Ave SE
Washington, DC 20593-7430
Staff Symbol: MSC-2
Phone: (202) 795-6729
Email: msc@uscg.mil

16710/P020484/wjc
Serial: E1-1704713
January 11, 2018

The Shearer Group, Inc. (TSGI)
Attn: Mr. Alex Ediger
3118 Harrisburg Blvd.
Houston, TX 77003
aediger@shearer-group.com

Subj: PRINCIPIO, O.N. 240091
53.2′ x 24′ x 5.6′ Towing Vessel (C)
Fire Suppression and Water Spray Systems

Ref: (a) TSGI Dwg. No. 0315-002-192, Rev. 0, "Fire and Safety Plan," 2 sheets, dated December 14, 2017
(b) Your letter, "Equivalency consideration for dry chemical fire protection," dated September 26, 2017
(c) Ansul Data Sheet, "Red Line Wheeled Extinguisher Models 150-D, 350-D"
(d) TSGI Dwg. No. 0315-002-190, Rev. 1, "Waterspray System," 2 sheets, dated December 14, 2017
(e) Your letter, "Drawing Package and Equivalency Letters," dated December 14, 2017
(f) Commandant (CG-521) Policy Letter No. 01-12, "Equivalency Determination Design for Natural Gas Fuel Systems"
(g) IMO Resolution MSC.285(86) "Interim Guidelines on Safety for Natural Gas-Fuelled Engine Installations in Ships"

Dear Mr. Ediger:

We reviewed references (a) through (d), submitted by reference (e), (MSC Document Nos. 1721260 and 1723088), for compliance with 46 CFR Subchapter C and references (f) and (g). References (a) through (c) are being held in abeyance pending resolution of the following comments. Reference (d) is **Returned for Revision**. Plan so considered are not approved and must be resubmitted for review after revision. The following comments apply:

References (a) through (c)

1. Held in abeyance pending the submission and approval of the fire detection and gas detection systems.

Reference (d)

2. This plan contains insufficient information for review and approval of the water spray system. No calculations are provided to show that all nozzles will be supplied with sufficient pressure to meet the requirements of section 3.3.2.2 of reference (g), which requires an application rate of at least 10 $l/min/m^2$. To demonstrate compliance with reference (g), you must submit revised plans and calculations showing that the pump capacity can overcome all pressure losses due to friction and height to supply adequate flow to all nozzles simultaneously.

3. The water spray system does not cover the aft deck and aft bulkhead of the deck house. As required by reference (f), Enclosure (1), Section 3.3.2(1), coverage for on-deck storage should include all boundaries of the superstructures, compressor rooms, pump rooms, cargo control rooms, and any other normally occupied deck houses that face the storage tank. You must submit revised plans showing coverage to all required surfaces to demonstrate compliance with reference (f).

Our Project Number for this vessel is P020484. Please ensure that all future correspondence includes the Project Number and the Official Number that appears in the subject line.

Please contact LT William Cotta at (202) 795-6757 with questions concerning our review.

Sincerely,

Jodi Min

J. J. MIN
Lieutenant Commander, U. S. Coast Guard
Chief, Machinery Branch
By direction

Copy: Commanding Officer, Marine Safety Unit Pittsburgh

Appendix T (USCG Response to TSGI) *M/V PRINCIPIO,* Natural Gas Fuel Piping and Ventilation Systems

U.S. Department of Homeland Security
United States Coast Guard

Commanding Officer
United States Coast Guard
Marine Safety Center

US Coast Guard Stop 7430
2703 Martin Luther King Jr. Ave SE
Washington, DC 20593-7430
Staff Symbol: MSC-2
Phone: (202) 795-6729
Email: msc@uscg.mil

16710/P020484/wjc
Serial: E1-1800992
March 20, 2018

The Shearer Group, Inc. (TSGI)
Attn: Mr. Alex Ediger
3118 Harrisburg Blvd.
Houston, TX 77003
aediger@shearer-group.com

Subj: PRINCIPIO, O.N. 240091
53.2′ x 24′ x 5.6′ Towing Vessel (C)
Natural Gas Fuel Piping and Ventilation Systems

Ref: (a) TSGI Dwg. No. 0315-002-511, Rev. 1, "Gas Fuel System Schematic," 2 sheets, dated January 5, 2018
(b) TSGI Dwg. No. 0315-002-701, Rev. 1, "Gas Train Ventilation System," 1 sheet, dated January 5, 2018
(c) Delta T Systems Specifications Sheets "DWP Fan Cut Sheets," 3 sheets
(d) Your letter, "Drawing Package and Equivalency Letters," dated January 5, 2018
(e) Commandant (CG-521) Policy Letter No. 01-12, "Equivalency Determination Design for Natural Gas Fuel Systems"
(f) IMO Resolution MSC.285(86) "Interim Guidelines on Safety for Natural Gas-Fuelled Engine Installations in Ships"

Dear Mr. Ediger:

We reviewed references (a) through (c), submitted by reference (d), (MSC Document No. 1813807), for compliance with 46 CFR Subchapter C and references (e) and (f). References (a) and (b) are **Returned for Revision**. Plans so considered are not approved and must be resubmitted for review after revision. Reference (c) is being held in abeyance pending resolution of the following comments:

References (a) and (b)

1. The fuel supply system contains flexible hose connections that are listed as JIC threaded connections. Screwed couplings are addressed in section 2.5.11.3 of reference (f), and should only be used for accessory lines and instrumentation lines with external diameter of 25 mm (0.98 in) or less. You must submit revised plans.

2. No information is provided on the flexible hose in the fuel supply system. Please note that flexible hose meeting SAE J1942 is not acceptable for this application, as natural gas vapor

service is outside the scope of testing and approval in SAE J1942. Expansion bellows must meet the requirements of section 7.6 in reference (f). Also, please note that the use of non-metallic materials in piping systems must meet the requirements of the IGC Code, Chapter 6 and Appendix 4, as required by reference (f) section 2.2.1. If an alternative standard is used, please provide information on the standard, so our office can determine if the connection offers an equivalent level of safety.

3. The tank, tank connections, and liquefied gas system were not reviewed. As discussed over the phone, this information will be provided by the system manufacturer.

Reference (c)

4. All electrical equipment located within the hazardous area must be explosion-proof or intrinsically safe, as certified by an independent testing laboratory recognized by the Coast Guard as required by 46 CFR 111.105-7 and references (e) and (f).

Our Project Number for this vessel is P020484. Please ensure that all future correspondence includes the Project Number and the Official Number that appears in the subject line.

Please contact LT William Cotta at (202) 795-6757 with questions concerning our review.

Sincerely,

Jodi Min

J. J. MIN
Lieutenant Commander, U. S. Coast Guard
Chief, Machinery Branch
By direction

Copy: Commanding Officer, Marine Safety Unit Pittsburgh

Appendix U (USCG Response to TSGI) *M/V PRINCIPIO*, Failure Modes and Effects Analysis, Periodic Safety Test Procedures

U.S. Department of Homeland Security
United States Coast Guard

Commanding Officer
United States Coast Guard
Marine Safety Center

US Coast Guard Stop 7430
2703 Martin Luther King Jr. Ave SE
Washington, DC 20593-7430
Staff Symbol: MSC-2
Phone: (202) 795-6729
Email: msc@uscg.mil

16710/P020484/lnf
Serial: E2-1801291
April 5, 2018

The Shearer Group, Inc. (TSGI)
Attn: Mr. Alex Ediger
3118 Harrisburg Blvd
Houston, TX 77003
aediger@shearer-group.com

Subj: PRINCIPIO, O.N. 240091
65′ x 24′ x 6′ Towing Vessel (C)
Failure Modes and Effects Analysis,
Periodic Safety Test Procedures

Ref: (a) Altronic Doc., "GTI+ Bi-Fuel Fumigation," 10 sheets, dated January 2014
(b) Altronic Doc., "GTI SN127 Recommended Annual Check," 1 sheet, dated February 23, 2018
(c) Commandant (CG-521) Policy Letter No. 01-12 "Equivalency Determination Design for Natural Gas Fuel Systems"
(d) IMO Resolution MSC.285(86) "Interim Guidelines on Safety for Natural Gas-Fuelled Engine Installations in Ships"
(e) Marine Safety Center Technical Note 02-11, dated December 15, 2011
(f) Our letter E2-1703960 dated October 25, 2017

Dear Mr. Ediger:

We reviewed references (a) and (b), submitted by your letter dated March 15, 2018 (MSC Document No. 1814070), for compliance with 46 CFR Subchapter C and references (c) and (d). References (a) and (b) are **Returned for Revision** and must be resubmitted for approval. The following comments apply:

Reference (a)

1. This document is a quantitative failure analysis of the operation of the Bi-Fuel system. The FMEA for alarm, monitoring, and control system should be a qualitative failure analysis (QFA) in accordance with 46 CFR 62.20-3. The QFA should include the following: objectives (of the QFA), assumptions made in performing the QFA, description of the equipment addressed in the QFA, description of the mode(s) of operation, description of failure modes and cause and effect relationships, acceptable deviations from required function, and evaluation of local and total system effect(s). Please see reference (e) for further guidance.

2. Please provide control system drawings in order to verify the assumptions in the QFA.

3. As noted in comment 4 of reference (f), please provide a Design Verification Test Procedure (DVTP) for our review as required by 46 CFR 61.40. The DVTP should be a detailed

procedure to verify each failure mode identified in the QFA. Please see reference (e) for further guidance.

Reference (b)

4. It is noted that this document was submitted to serve as the Periodic Safety Test Procedure to address comment 4 of reference (f). The document should be revised to test all required alarms and safety systems as noted in enclosure (1) sections 5.1 and 5.3 of reference (d). Please see reference (e) for further guidance.

Our Project Number for this vessel is P020484. Please ensure that all future correspondence includes the Project Number and the Official Number that appears in the subject line.

Please contact Mr. Lee Franklin at (202) 795-6757 with questions concerning our review.

Sincerely,

mahossain

M. A. HOSSAIN
Chief, Electrical Branch
U.S. Coast Guard
By direction

Copy: Commanding Officer, Marine Safety Unit Pittsburgh

Appendix V Design Concept Details

Due to the innovative nature of this system in the inland marine environment and the available systems, the intent was to request special considerations from the USCG while demonstrating that the design accomplishes an equal or equivalent level of safety, and meets the intent of the corresponding regulations. This section discusses some of the design challenges that the PRCC Team faced for this project

The biggest obstacle in obtaining USCG approval to move forward was that MSC and CG-ENG mostly held gas-system drawings and requests for special considerations in abeyance until they received a full design package; this included reaching a few milestones such as a regulatory review of the tanks and fumigation systems. Obtaining a go-ahead to use highway tanks quickly became the bottleneck to obtaining any sort of ruling on other key elements to the design.

Receiving tank approval from Coast Guard was a major challenge for this project. The intent was to use approved highway tanks. While these tanks held multiple classification society approvals (SAE J2343, DOT 4L, NFPA 52), they were not specified as being designed to the standards of the ASME Pressure Vessel Code, or the applicable portions of 46 CFR 154. Without intimate knowledge of the tank design, the only way to get approval to use approved highway tanks was either to work with the tank vendor, convince the tank vendor to work directly with USCG, or to conduct a gap analysis on the regulations themselves. The goal of this was to show that the tanks are designed an equivalent level of safety, or meet the intent of the regulations to an adequate level as determined by USCG. Even though our studies showed that the approved highway tanks were fundamentally sound, tank approval was never received from USCG.

Fumigation System

Concerning fumigation systems, standard land-based systems do not need to meet the same level of stringency as marine systems. This presented the team with obstacles when using an already proven system. While the team believed it was safer to use a tried-and-true and all-incorporated system, USCG regulations required certain modifications to the system (such as changing the solenoid valves in class 1 / div 1 and div 2 locations) that proved difficult.

The fumigation system, which receives natural gas from the LNG containment system, consists of a few integral systems: Simply, the gas train monitors and controls the gas supply, the supply piping delivers to gas to the engines. Both of these systems had unique challenges. The gas train needed an enclosure due to the hazardous zones, and this enclosure was required to be ventilated. The supply piping was also required to be enclosed by ventilated piping, referred to as double wall piping. This double wall piping started at the gas trains on the aft deck, and continued all the way to the engine. At the engine, the entire injection point on the turbocharger’s air intake was completely encased by an airtight enclosure that was still ventilated. The ventilation outlets were themselves hazardous zone emitters and those locations presented yet another challenge. As mentioned in Section 4.4 in this report, the applicable regulations for the *M/V RON-CHRIS* and *M/V PRINCIPIO* allowed for this arrangement, provided that gas was supplied at low pressure and gas detectors were fitted above the engines. When looking at newer vessels, newer regulations did not provide this flexibility. Instead, the double ducting would be required for gas pipes on the engine itself, all the way until gas is injected into the chamber. This means new engines would be required, and the core purpose of this dual fuel conversion project related to retrofitting existing engines with an air fumigation system.

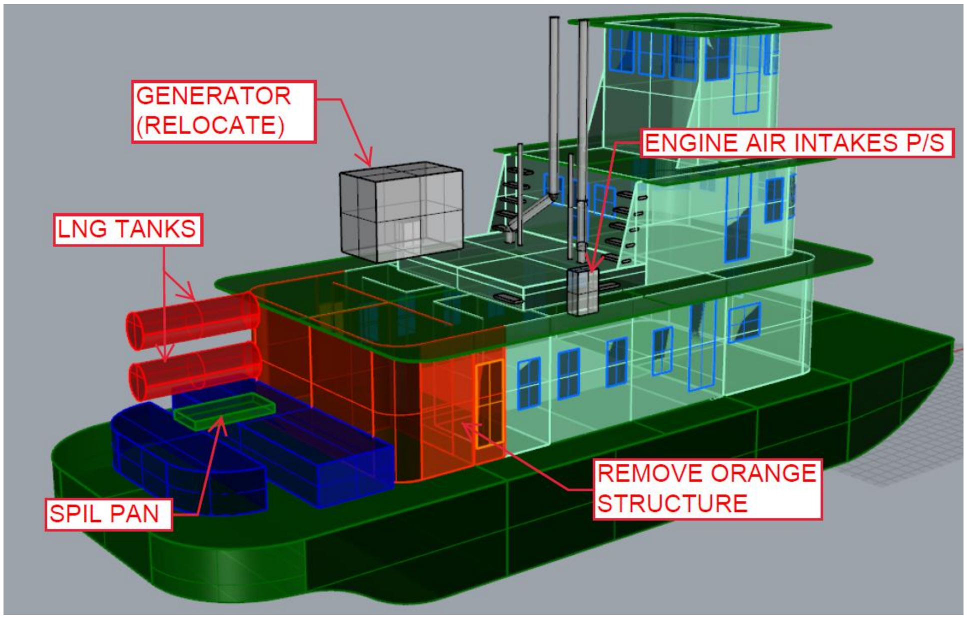
Firefighting System

For firefighting, the vessel was required to have a water spray system and a dry chemical powder system. The water spray system was intended for use against accidental flammable gas releases, which create LNG vapor clouds. The water spray acts to directly contact the LNG vapor and disperse the gas cloud. The vapor cloud becomes diluted and warmed, allowing it to mix more readily with the surrounding air. The water spray system is not used to fight LNG fires. The water spray system also acts to provide thermal shielding and cooling for LNG storage tanks and surrounding structure when a fire is present. As it can be seen, this fire protection is vital for safe operations. The vessel as currently designed however, did not have a fire main nor a sea chest. Adding a sea chest would likely require the vessel be docked for the install. There were understandable economic challenges to installing an appropriate fire protection system.

In addition to the water spray, a dry chemical system was also required for firefighting. The rules for dry chemical systems specify flow rates and times. These rates and times however are not dependent on the quantity of LNG carried, meaning the required flow rates for a large tanker are the same as the rates for a 58' towboat carrying less than 300 gallons of LNG. There exists an off-the-shelf 300# semi-potable unit, from a well-established vendor widely used by the industry in this application that meets the required flow rate, yet comes up seven seconds shy on flow time. Considering the size of the vessel and small quantity of LNG, the design team believed this system was more than adequate to meet the intent of the safety regulations. Otherwise, larger units simply would not fit on this small vessel, and a custom system would have been either cost or time prohibitive, or both. The team submitted a letter to USCG requesting special consideration on this matter, thinking this would be a relatively simple decision, however it was held in abeyance pending the submission and approval of the fire and gas detection systems. The fire and gas detection would have been completed by another vendor, and likely would not have received approval until the status of the tanks and fumigation systems were approved.

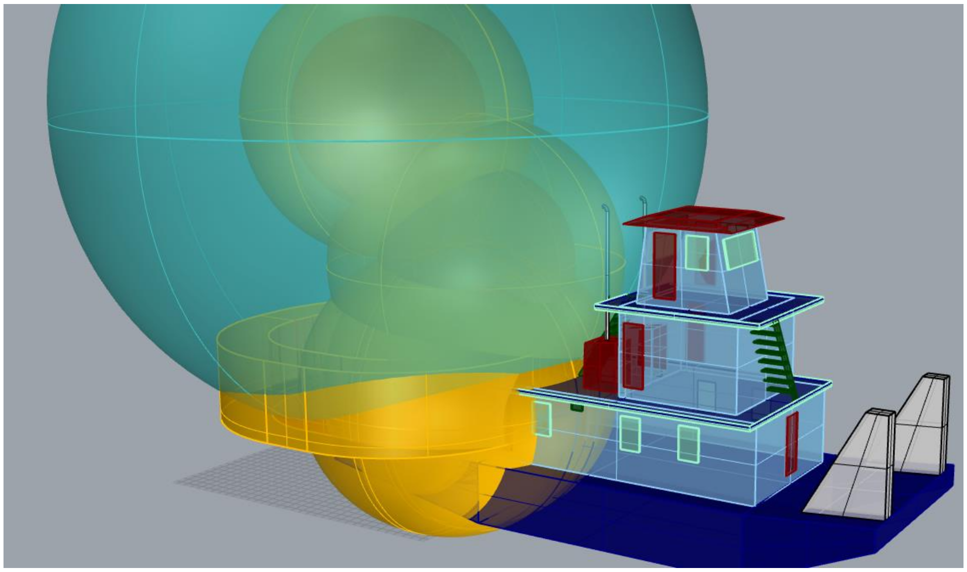
There were other design challenges due to hazardous zones such as rerouting engine exhaust outlets, moving /closing engine room windows and modifying bulkheads and decks to be of the appropriate A class. The design team did receive MSC approval for the fire boundary plan on the *M/V PRINCIPIO*.

The *M/V PRINCIPIO* required quite a bit more modifications as it would relate to the hazardous zones. Specifically, the air-intakes for the port engine needed to be rerouted to the starboard side, and the entire aft portion of the deckhouse needed to be removed. In addition, the *M/V PRINCIPIO's* generator sets in the engine room are not functioning; a "temporary" generator set was located on deck. The temporary generator needed to be removed, and the generator situation needed to be resolved. See the figure below for an example of some changes the *M/V PRINCIPIO* for illustrative purposes.

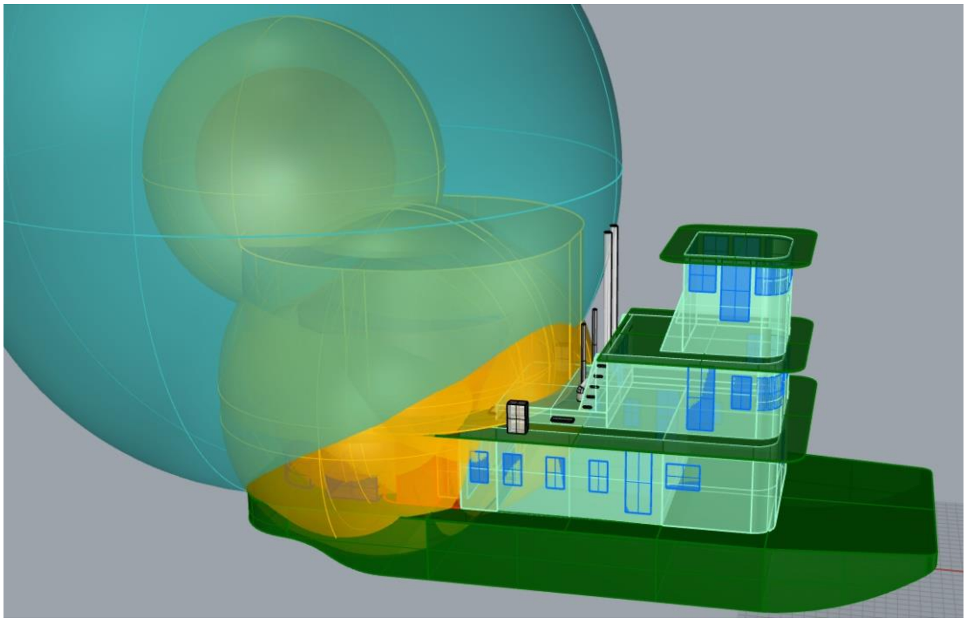


Proposed changes to have been completed onboard the *M/V PRINCIPIO*

The figures below provide a couple images of the hazardous zones for both the *M/V RON-CHRIS* and the *M/V PRINCIPIO*, respectively.



Hazardous zones of the *M/V RON-CHRIS*



Hazardous zones of the *M/V PRINCIPIO*

While the *M/V PRINCIPIO* is 7 feet longer than the *M/V RON-CHRIS*, the *M/V RON-CHRIS* was much more receptive to receiving the modification due to the arrangement of the vessel as well as the condition of the equipment onboard. A significant amount of work, such as structural modifications, and rerouting of systems, would be necessary on the *M/V PRINCIPIO*, here are some challenges specific to the *M/V PRINCIPIO*: In addition to removing the whole aft section of the deckhouse, the engine room bulkhead and 01 deck were teeming with holes, cracks, non-tight cable and unused pipe penetrations, and a steering-pole penetration that would require quite a lot of work. Additionally, there was a soft patch on the 01 deck that would need to be closed up. Finally, there was an electric motor in the steering gear box on the stern that must be relocated. The arrangement of *M/V PRINCIPIO's* stern required the LNG tanks to be supported at the 01 deck level, but supported by structure built over the aft main deck and steering box.

The *M/V RON-CHRIS* was not short of challenges either. On both vessels, in addition to the items mentioned earlier, many electric receptacles, lights, light stands and other electrical equipment needed to be replaced or removed. Both vessels required significant structure additions for the tanks and especially the vent pipe, the outlet of which needed to be approximately 28 feet above the main deck.

The *M/V RON-CHRIS*, shown in the figure below, may help to provide a better understanding of the differences between the arrangements of the two vessels.

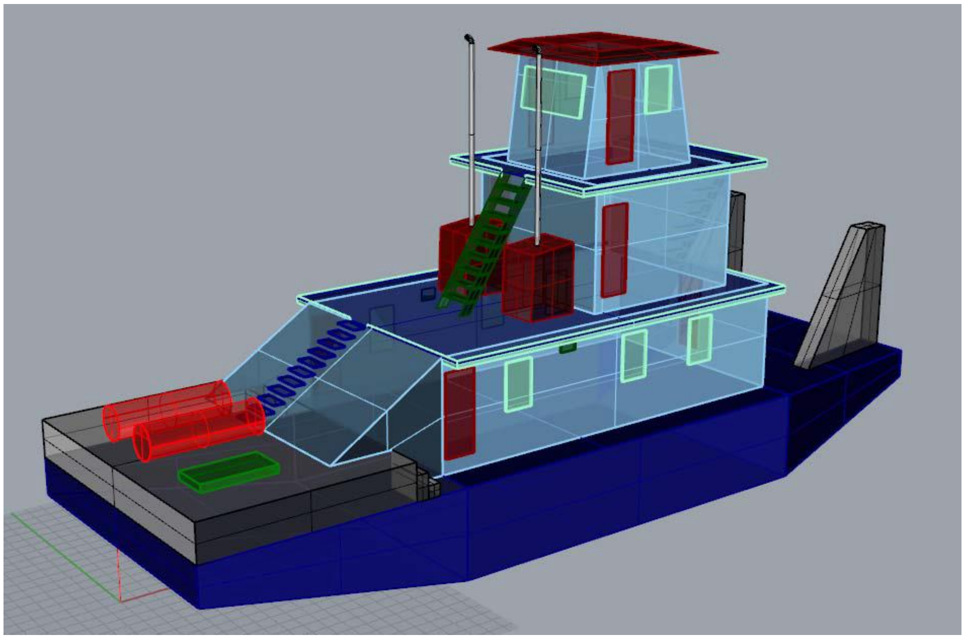


Illustration of the *M/V RON-CHRIS*

Appendix W Technology Insertion Discussion – CNG Tank Gap Analysis

As part of the project to install a liquefied natural gas system on the towboat *M/V PRINCIPIO*, the design required a number of LNG tanks. In the desired tank size, manufacturers use SAE specification J2343 that meets the requirements of DOT 4L for the tank design. International Code of the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (ICG) compliant tanks were not commercially available in 2017 in the required size. Coast Guard rules on LNG tanks requires the use of the ICG code, which then specifies the ASME Boiler Code. The Coast Guard requested that LCE prepare a gap analysis to highlight the differences between the two sets of specifications.

The findings of the gap analysis were:

- Areas Where the ASME and SAE/DOT Tank Requirements are Similar
  - The minimum and maximum temperatures allowed by SAE/DOT 4L were compliant with the ASME tank requirements.
  - The pressure relief requirements of each set of specifications are essentially identical.
  - The ullage requirements of each set of specifications are essentially identical.
  - The piping requirements of each set of specifications are essentially identical.

- Areas Where the SAE/DOT Tank Requirements are Superior to the ASME Code
  - The ASME Boiler Code permits materials that are not allowable per the SAE/DOT 4L tank requirements. ASME permits aluminum, which is a poor choice for a fuel tank that can be exposed to high temperatures in a fire.
  - Fuel hold times are not covered by the ASME Boiler Code. The SAE/DOT requirements are appropriate and restrict the design, where the ASME Code is silent.
  - Tank shut off requirements are not covered by the ASME Boiler Code. The SAE/DOT requirements are appropriate and restrict the design, where the ASME Code is silent.
  - Fueling connection requirements are not covered by the ASME Boiler Code. Therefore, in this area the SAE/DOT requirements are better than the ASME Code.
  - Vaporizer requirements are not covered by the ASME Boiler Code. Therefore, in this area the SAE/DOT requirements are better than the ASME Code.
  - The SEA/DOT tanks are required to have a drop (impact) test. ASME requires seismic calculations. The seismic calculations are not appropriate for this application, where the impact test is appropriate. In this area, the SAE/DOT requirements are better than the ASME Code.
  - Operators and maintenance manuals are required for the SAE/DOT tanks. ASME has no requirements in this area.
  - A gas detection system is required for SAE/DOT tanks. The ASME Boiler Code has no requirements in this area.

- The ASME Boiler Code does not cover excess flow devices, backflow preventers, automatic shut-off devices, or vaporizer warning devices. Therefore, in these areas the SAE/DOT requirements are better than the ASME Code.
- The SAE/DOT specifications require a flame test to ensure tank integrity. There is no ASME Boiler Code requirement covering this.

- Area Where the ASME Requirements are More Stringent Than The SAE/DOT Requirements
  - The main negative finding in the gap analysis was the factor of safety for ASME tanks is about 10% higher than in the SAE/DOT 4L tanks. The minimum factor of safety was about 2.94 for the SAE/DOT compliant tank, and about 3.24 for the ASME Boiler Code compliant design. Either specification should be adequate in service, especially since the stainless steel specified for the SAE/DOT compliant tanks requires little corrosion allowance, versus the ASME allowed carbon steel pressure vessels.

LCE prepared the GAP analysis, and delivered it in early December 2017. In early January 2019, the Coast Guard rejected the analysis. The Coast Guard letter stated that the SAE/DOT tank was not equivalent to the IGF code. After the Coast Guard rejection was received, LCE prepared and submitted a revised GAP analysis. At the publish of this report, no response has been received from the Coast Guard.

Appendix X M/V RON-CHRIS Conversion Equipment Quotes

DeltaT System	
SYSTEM	Quote w/ Installation
DeltaT	$28,735
Total	$28,735

RelTek System	
SYSTEM	Quote w/ Installation
Fire Detection	$6,263
Extra Sensors	$11,331
Gas/Leak Detection	$46,249
Install & Testing	$28,262
Zero & Span Gas Tank	$570
Total	$92,675

PIC (Altronics & Chart) System	
SYSTEM	Quote w/ Installation
Fumigation System	$68,000
Oxidation Catalyst	$28,600
Installation & Testing; Fumigation System	$26,700
Install & Testing; Oxidation Catalyst	$15,100
Total	$138,400

ABCO System	
SYSTEM	Quote w/ Installation
Dry Chemical Units	$8,780
Total	$8,780

Engines	
SYSTEM	Quote w/ Installation
Replacement Engines	$80,000
Engines	**$80,000**

Total Equipment (Less Engines)	**$268,590**

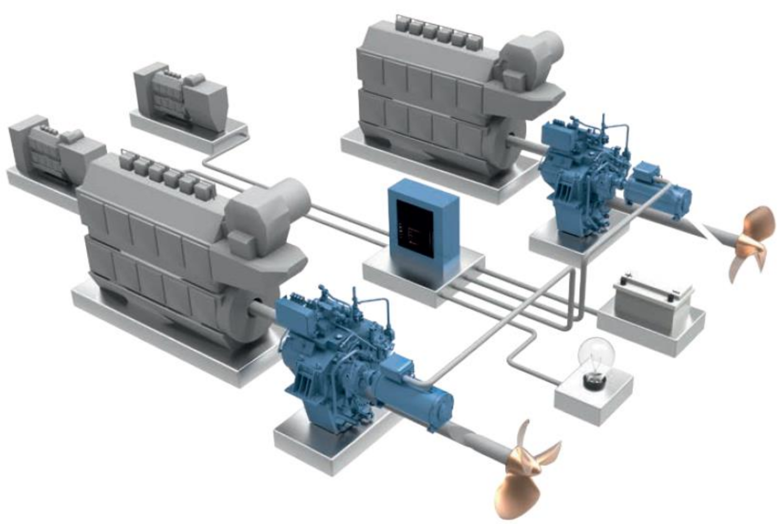
Overall Modifications	
SYSTEM	Quote w/ Installation
Controls Modifications	$5,000
Installation & Hook-Up of New Main Engines	$20,000
HVAC Modifications	$17,425
HVAC Double Wall Pipe	$33,315
Structural Modifications	$41,277
Water Spray Nozzles	$6,240
Total Mods	**$123,257**

Total Materials, Engines & Mods	**$471,847**

Appendix Y Hybrid Design Concept

When the project team was faced with the prospect of switching from *M/V PRINCIPIO* to a boat that required the main propulsion engines to be changed out in order to convert to natural gas, other conversion concepts were discussed as options. One such option was to convert the boat to a hybrid electric propulsion system. The hybrid propulsion concept is starting to become popular in the marine industry and is even making its way into the Inland Waterways. Hybrid-Electric vessel propulsion towboat designs are more widely accepted in Europe than North America, but this was considered a real possibility as well.

The principle of operation changes the use of natural gas from the main engines to the generator sets. In theory, the generator sets would run on natural gas to provide ships service power to the craft while also providing hybrid-electric propulsive power to the vessel. The main engines would have their reduction gearboxes replaced with a hybrid-design gear set that can couple with a motor. Depending on the configuration, this motor could provide the vessel with a sole source of power, or could provide assistive, load-sharing power.



Reintjes Hybrid Drive System

Reintjes Power Train Solutions is a German reduction gear company that has been in operation for over 140 years. Since 1955, they have been producing marine gearboxes for the international and have established themselves as an industry leader. The company has developed hybrid drive systems and offer tiers of options depending on horsepower and duty cycle requirements. Despite having a focus on larger craft, both in the commercial and pleasure craft industries, they produce an option that is able to fit in Ohio River towboats.

The options they provide typically have three modes available: electric motor only, diesel engine for propulsion and shaft generation, and boost mode. The electric motor only mode is simply how the name defines it: the vessel can be operated solely by the connected electric motor. In boost mode, both the main engines and the generator engines are capable of providing power to the shafts. In diesel engine for propulsion and shaft generation mode, the main engines use the motors as shaft generators while the engines also provide propulsive power for the craft.

This setup is ideal for operators due to its low level of risk and commitment; however, it also yields the lowest yield of results for the natural gas conversion study. As previously stated, this would require the generator sets to either be converted or replaced with natural gas fueled options. Either way, the generators inherently use less fuel that the main engines during normal operation of the vessel. For a terminal boat, however, this may be an excellent design choice since a large amount of time for these boats is spend at low power levels to support fleeting activity.

In addition to the engine and main hybrid drive electrical components that would need to be added, the ship's electrical distribution would also need to be altered. A setup like this has more flexibility than a conventional towboat design, but also requires that the vessel's electrical distribution can handle the changes in load profiles.

Storage solutions of the LNG would not be changed. They would still need to be placed in proper locations approved by USCG regulations.

The table below shows the price quotes of equipment required for installation on a terminal size towboat.

Quote of Hybrid Drive Equipment

Electronic Power Design, Inc.		
Item	**Qty**	**Price**
Main Propulsion Switchboard	2	$ 54,000.00
600HP VFD Drives	2	$262,000.00
600HP AC Motors	1	$118,000.00
Studies Conducted for Installation	N/A	$ 5,000.00
	Total	**$439,000.00**
Reintjes Hybrid Drive Gearboxes		
Item	**Qty**	**Price**
WAF 364 / 5.590:1	2	$ 98,300.00
	Grand Total	**$537,300.00**

Appendix Z Replacement Boat Surveys

During the June visit, the subject matter experts (SMEs) boarded the vessel and talked to the owner to get a general sense of the vessel condition. As with the previous vessel, considerations towards engines, generators, exhaust stacks, pilothouse controls, and LNG tank design were investigated. Preliminary dimensions were taken in addition to the overall condition assessment to get a sense of what equipment would be needed for installation.

M/V TIMMY Main Engines

M/V TIMMY Generators

After it was concluded that the *M/V TIMMY* would be the vessel of choice, another visit was made to take more detailed measurements of the spaces, as well as record essential machinery information. In addition to the nameplate data of the engines, generator sets, reduction gears, and other essential equipment, regulatory requirements needed to be investigated as well. For example, investigation into the fire detection system, fire pump installation, engine room ventilation, and adjacent spaces were taken into effect this time around. Dimensions were taken by the LCE SMEs and given to the marine engineering and naval architecture SMEs at TSGI for review and application into design.