## 144-Car Ferry LNG Fuel Conversion Feasibility Study

# Design Report

Prepared for
Washington State Ferries
Seattle, WA

**File No. 11030.01**
**1 July 2011**
**Rev —**

THE GLOSTEN ASSOCIATES
Consulting Engineers Serving the Marine Community

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# Revision History

| Section | Rev | Description | Date | Approved |
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| All | - | Initial release | 7/1/2011 | DWL |

# References


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# Executive Summary

Washington State Ferries (WSF) is investigating powering the new 144-Car ferries with liquefied natural gas (LNG) fuel which has potential to reduce operational costs and air emissions when compared to diesel fuel. However, converting to LNG poses technical, regulatory, and economic challenges compared to diesel. The Glosten Associates (Glosten) was tasked with conducting study to investigate both the technical and economic feasibility of such a conversion and identify regulatory risks. This study concludes that the conversion is both technically feasible and cost effective though technical and regulatory challenges remain. Capital and lifecycle costs are presented in companion report, *144-Car Ferry LNG Fuel Conversion Feasibility Study: Life Cycle Cost Analysis* (Reference 16) and design issues are presented in this report.

To support the study, Glosten has done engineering and design work culminating in a concept that has a minimum impact on vessel arrangements and operational requirements of the ferry. To convert the diesel fuelled design to LNG fuel, the diesel engines would be replaced with gas fuelled engines of similar size, power, and speed. An adequate volume of LNG fuel storage can be incorporated with the addition of a storage tank(s) on the bridge deck between the exhaust casings. All necessary gas piping and equipment, ventilation, and safety systems can be installed to support the gas fuel system without significantly affecting the general arrangements. While the conversion would require additional engineering development to be production ready, none of the design or construction modifications present a major technical risk.

One risk that has been identified is the time and cost required to obtain approval of the design by the United States Coast Guard (USCG), which does not yet have rules for gas fuelled vessels written into the Code of Federal Regulations. At the request of WSF, the USCG and Det Norske Veritas (an experienced classification society) have formally reviewed the Glosten design. Both the parties have submitted a letter to WSF with specific guidance comments to be incorporated as part of design development. No significant issues affecting feasibility were identified in the review. It is the intent that these letters establish the regulatory basis for the future review and approval of this gas fuelled vessel design. Another risk is that EPA approval of the gas engines is still in process. Though a formality, the engines cannot be sold to WSF until this approval is obtained.

A component of this study was to investigate engine exhaust gas emissions. It was found that switching to gas engines will significantly reduce emissions of nitrogen oxides ($NO_x$), sulfur oxides ($SO_x$), carbon dioxide ($CO_2$) and particulate matter (PM) but increase emissions of carbon monoxide (CO) and Methane. The decreased emissions of $CO_2$ coupled with the increase in Methane emissions result in little change to the vessel's overall Global Warming Potential. Localized air pollution would be reduced with the reduction of $NO_x$, $SO_x$, and PM.

WSF is also considering converting the *Issaquah* class vessels to LNG. Since the design of the 144-Car Ferry is very similar to the *Issaquah* class, the key elements of the Glosten design would also be applicable (LNG tanks on the top deck between the stacks, pipe routing, propulsion repowering, etc.) to those vessels and it is therefore reasonable to assume that a conversion would be feasible. The potential benefits for fuel cost savings and emissions reduction warrant that a study specifically for that class of vessels is undertaken.

# Section 1 Introduction

Washington State Ferries (WSF) is investigating powering the new 144-Car Ferries with liquefied natural gas (LNG) fuel. The use of LNG fuel has the potential of reducing fuel costs and emission when compared to diesel fuel. However, use of LNG has some technical challenges and additional equipment that contributes to a higher capital cost. In order to identify the technical challenges, design changes, and costs associated with LNG fuel use, Glosten was tasked with conducting a feasibility study for converting the existing diesel fuelled vessel design to a LNG fuelled design.

The new 144-Car Ferry class is a completed diesel fuelled vessel design that has not been built to date. The design has been carried to a production ready level, where a conversion of the existing design is more desirable than restarting the design. The design conversion would allow new vessels to be built utilizing LNG fuel, while maximizing the integrity of the current design.

An LNG design concept has been developed to retain as much of the existing design as possible while meeting the operational requirements of the ferry service as well as complying with regulatory requirements. The regulatory requirements considered for this project are the *2011 DNV Rules for Gas Fuelled Engine Installations* (Reference 1) and IMO *Interim Guidelines on Safety for Natural Gas-Fuelled Engine Installations in Ships* (Reference 2). The feasibility study considers both single fuel and dual fuel engines. This report addresses the technical feasibility of the design while a companion report, *144-Car Ferry LNG Fuel Conversion Feasibility Study: Life Cycle Cost Analysis* (Reference 16) addresses the economic feasibility.

## 1.1 Regulatory Review

Gas fueled engine installations are still an emerging into the global market and currently the Code of Federal Regulations (CFR's) do not include rules to direct the design and approval of gas fuelled vessels in the United States. However, rules and procedures for regulatory and Class review have been in place in other countries for several years now. To provide a basis for design, international rules have been used with the concurrence of the United States Coast Guard (USCG). The gas fueled concepts discussed in this report have been designed to be compliant with the DNV Gas Fuelled Engine Rules (Reference 1) and the IMO's *Interim Guidelines on Safety for Natural Gas-Fuelled Engine Installations in Ships* (Reference 2).

A dialog with USCG and DNV was established regarding the design standards for, and the review of, the gas fuelled vessel concepts discussed in this report. The purpose of this dialog was to address any concerns of the two regulatory bodies and to establish a path forward for review and approval of the gas fuelled vessel concepts. In the absence of specific federal regulations for gas fuelled engine installations in vessels, the USCG has indicated that a gas fuelled vessel may be submitted for review and approval as an alternative design under 46 CFR 50.20-30. It is pursuant to this regulation that the Glosten design was submitted to USCG.

The following documentation was submitted to both DNV and USCG.

1. Regulatory Review of Concepts Report (Reference 14)
2. Concept gas system Piping Arrangement drawing (Reference 15)
3. 3D General Arrangement Model (Reference 13).
4. DNV Rule Matrix addressing compliance of the concept design with the DNV Gas Fuelled Engine Rules. (Appendix of Reference 14)
5. IMO Rule Matrix addressing compliance of the concept design with the IMO's MSC.285 (86) *Interim Guidelines on Safety for Natural Gas-Fuelled Engine Installations in Ships* (Appendix of Reference 14).

The DNV and IMO rule matrices specifically identified how the concept design complied with each applicable rule of the subject regulations. Rules that were not applicable were identified as such.

All five submittals were provided to both USCG and DNV. Both parties reviewed items 1 through 3. Item 4 was reviewed by DNV only. Item 5 was reviewed by USCG only.

Following the reviews by DNV and USCG a WebEx phone conference was held with DNV, USCG, WSF, and Glosten to discuss comments on the reviewed submittals. Additionally USCG and DNV each supplied to WSF a letter stating that the concept design has been reviewed for compliance with the applicable rules and providing written record of their comments. These letters provide a basis for future review and approval of a gas fuelled vessel design. The letters from USCG and DNV have been included in Appendices B and C of this report.

The gas fuelled vessel concept described in this report is the concept design that was submitted for review. Necessary amendments to the concept design in response to the comments of DNV and USCG are included as footnotes to the effected sections of the report.

## 1.2 Vessel Particulars

The 144-Car Ferries will be double ended, RoRo passenger ferries for service within Puget Sound. The vessel particulars are given in Table 1.

**Table 1 Vessel Particulars**

| | |
|---|---|
| Length Overall | 362'-3" |
| Length Between Perpendiculars | 335'-3" |
| Breadth | 83'-2" |
| Depth at Amidships | 24'-0" |
| Design Draft | 16'-9" |
| Passenger Capacity | 1500 |
| Vehicle Capacity | 144 Standard Autos |
| Classification | USCG Subchapter H |

# Section 2 Vessel Design

The existing vessel design is based on a propulsion system that has already been purchased. Four ship sets of controllable pitch propellers, propeller shafting, reduction gears, high speed combining shafting, and diesel engines were purchased in 2007. A goal of the conversion is to incorporate the already purchased equipment into the LNG vessel design to the greatest extent practical. The diesel engines cannot be used as they would be replaced with the gas fueled engines. However, three of the four ship sets of engines have been repurposed to power the new class of 64 car ferries that are currently being built.

## 2.1 Route and Operating Profile

The 144-Car Ferry may be used on several different routes. The routes vary in length but the operating profile of all of the routes is similar. The vessel starts at the dock while unloading and loading passengers and vehicles. Once loading is complete, there is a short maneuvering period to undock followed by transit at a cruise speed of 17-20 knots. When the ferry arrives at the other end of the route, there is another short maneuvering period to dock the ferry and the cycle repeats. The only significant variation of the operating profile of the various routes is the duration of the transit.

WSF provided a table of historical annual fuel consumption of the various routes. As can be seen in Table 2, the Seattle – Bremerton route has by far the highest fuel consumption of the considered routes. The high fuel consumption for this route is because it has the longest crossing and the highest vessel transit speed. As a result of these factors, the Seattle-Bremerton route was used as the design route for the tank sizing and endurance calculations in this study.

**Table 2 Historical Fuel Consumption**

| Route | Description | Monthly Diesel Consumption ($m^3$) | Monthly Diesel Consumption (Gallons) |
|---|---|---|---|
| TRI | FAUNTLEROY-VASHON-SOUTHWORTH | 212.7 | 56,200 |
| MUK | MUKELTEO - CLINTON | 170.0 | 44,900 |
| BREM | SEATTLE - BREMERTON | 333.1 | 88,000 |
| SID | ANACORTES - SIDNEY | 268.8 | 71,000 |
| SJ | ANACORTES - FRIDAY HARBOR | 208.2 | 55,000 |

The durations and engine loads during the docked and maneuvering periods were taken from Reference 3 for a direct drive version of the 130-Car Ferry design. It was assumed that the docked and maneuvering loads would not be significantly different for the 144-Car Ferry. The engine load during transit was taken from Reference 4 for the 144-Car Ferry at 17 knots. The duration at transit was calculated for the route by deducting the maneuvering time from the total crossing time of 60 minutes.

**Table 3 Seattle - Bremerton Operating Profile**

| Mode | Total Propulsive Power (Brake Power) | | Duration |
|---|---|---|---|
| Docked | 379 kW | (508 HP) | 20 Minutes |
| Maneuvering | 781 kW | (1,048 HP) | 10 Minutes (Total) |
| Transit at 17 kts. | 3,441 kW | (4,615 HP) | 50 Minutes |

## 2.2 Propulsion System

The 144-Car Ferry design has a mechanically-driven, controllable pitch propeller at either end. The two main propulsion engines will be located in separate machinery spaces and will be combined through reduction gears with a high speed shaft. The reduction gears will be designed for the combined full power output of both engines, thereby allowing either propeller to be driven with both engines. During normal operation, both engines will be online and equally share the propulsive load. While transiting, the bow propeller will be fully feathered and declutched from the propulsion drive system. While maneuvering, both propellers will be used.

### 2.2.1 Gas Engine Selection

Currently there are two types of marine gas engines available on the market in the power range required for this project. These engines are dual fuel engines and single fuel (gas only) engines. The dual fuel engines can be operated on either gas fuel or liquid (diesel) fuel and can switch between fuels while in service. Additionally the dual fuel engines use a small amount (approximately 1%) of diesel fuel as a pilot fuel to ignite the gas when operating on gas fuel. The single fuel engines use only gas fuel and cannot operate on diesel fuel. Single fuel engines are spark ignition engines.

There are two safety categories of gas fuelled propulsion systems: inherently safe or not inherently safe. An inherently safe gas engine is an engine where all of the on-engine gas supply piping is double walled pipe. Engines without the double walled gas pipe are not inherently safe.

An engine that is not inherently safe must be located in an emergency shutdown (ESD) protected engine room. This means that if an abnormal condition involving a gas hazard is detected; all equipment that is not of explosion protected design, including the engine, must immediately shut down. This requires that all vital equipment located in an ESD protected engine room must be explosion proof. Because the gas piping is enclosed in a double walled pipe, in an inherently safe engine room the equipment in the engine room does not need to be explosion proof. Typically when a non-inherently safe engine is used, the engine is located in a small ESD engine room and the majority of auxiliary equipment is located in a separate machinery space so that it does not need to be explosion proof. This type of machinery arrangement is a major driver of the vessel’s arrangement and therefore structural arrangement. Because this vessel is an almost completed detailed design and a substantial amount of equipment is located in the engine rooms, ESD protected engine rooms are not practical. For this reason engines that must be located in ESD protected engine rooms were not considered in this design.

At the time of this study the only engine manufactures with gas fuelled inherently safe engines on the market and of appropriate power are Rolls Royce and Wärtsilä. Both manufacturers were considered in this study. The Rolls Royce engine considered is the single fuel Bergen C26:33 L9PG developing 2,200 kW (2,950 HP). The Wärtsilä engine that was considered is the dual fuel 6L34DF engine. The 6L34DF will need to be derated from 2,700 kW (3,620 HP) to 2,300 kW (3,084 HP). The fuel consumption was calculated to be approximately 4% higher for the 6L34DF rated at full power and operating at lower loads.

At the time of publication of this report, other manufacturers are developing inherently safe, gas fuelled engines, and there may be additional engines that will become available over the next few years. In this study however, only engines that are currently on the market and have Class approval were considered.

It should also be noted that both manufacturers have stated that they have not yet completed the process of getting EPA certification of their engines. All marine engines need to be certified by the EPA for emissions purposes. Since gas engines for marine use are still new to the US market, this process is still ongoing and a specific date for approval was not available. The EPA was not consulted for this report, but this issue will need to be resolved before either manufacturer can sell these engines in the US. While this issue is a formality, it presents a possible schedule risk to WSF.

### 2.2.2 Gears and Shafting

Replacement of the propeller, shafting, or gear due to incompatibility with the gas engine would increase cost and cause additional design changes. The existing propellers and shafting are rated for the power output of the previously purchased EMD engines ( 2,237 kW or 3,000hp). The power output of the gas engines was selected to be compatible with the purchased propellers and shafting so to that no changes are required. The reduction gears used in the current design are Falk gears with two inputs and a single output specifically designed to integrate into the drive train. The reduction ratio of the Falk gear is ~5:1 to reduce the 900 RPM EMD design engine to the 180 RPM that the propeller rotates at its optimum design point. The Falk gear geometry has both a vertical offset (44") and a horizontal offset (30") to match the engine output shaft, the combining shaft, and the propeller shafting geometry.

The Bergen engine operates at 900 RPM and no alteration to the reduction gear would be required. Slight height modifications to the engine foundation would be required to maintain vertical alignment with the gear.

The Wärtsilä engine operates at 750 RPM and to maintain the propellers 180 RPM design speed a new gear would be required. Wärtsilä cannot produce a gear with the required geometry and reduction ratio to replace the Falk gear. For this report it is assumed that Falk or a different gear manufacturer can supply the required gear. With the de-rating of the Wärtsilä engine to 2,300 kW (3,084 hp) the existing shafting will not be overloaded.

### 2.2.3 Engine Response and Maneuvering

While maneuvering and docking the engine loads change fairly quickly. Historically gas fuelled engines have slower response times than diesel fueled engines. It was necessary to look at the loading response times of the engines to see what impact engine load response might have on the maneuvering of the vessel.

At the time of publication, a load response curve was not available for the Bergen C26:33L9PG engine, however, Rolls Royce was able to provide by email an estimate of the load response performance of the engine. Rolls Royce has indicated that the C26:33L9PG engine can increase load at 3% per second. Rolls Royce recommends that the engines be loaded in steps of 0-85% and 85-100%.

Wärtsilä was able to provide the response curves for the 34DF engines. The engine loading capacity response curves can be seen in Figure 1. Based on these curves, the engine can be loaded from 20-85% at approximately 1.3% per second and from 85-100% at approximately 0.3% per second when operating on gas. Instantaneous power steps of 20% are possible from 0% power to 30% power and decreasing instantaneous power steps (down to 10%) are possible as power is increase above 30%. The response times while operating the dual fuel engine on diesel fuel are faster than when operating on gas fuel. It was assumed that the vessel will be operating on gas under normal conditions. However, in an emergency maneuver, the engine could be switched to diesel fuel to achieve a faster response time.

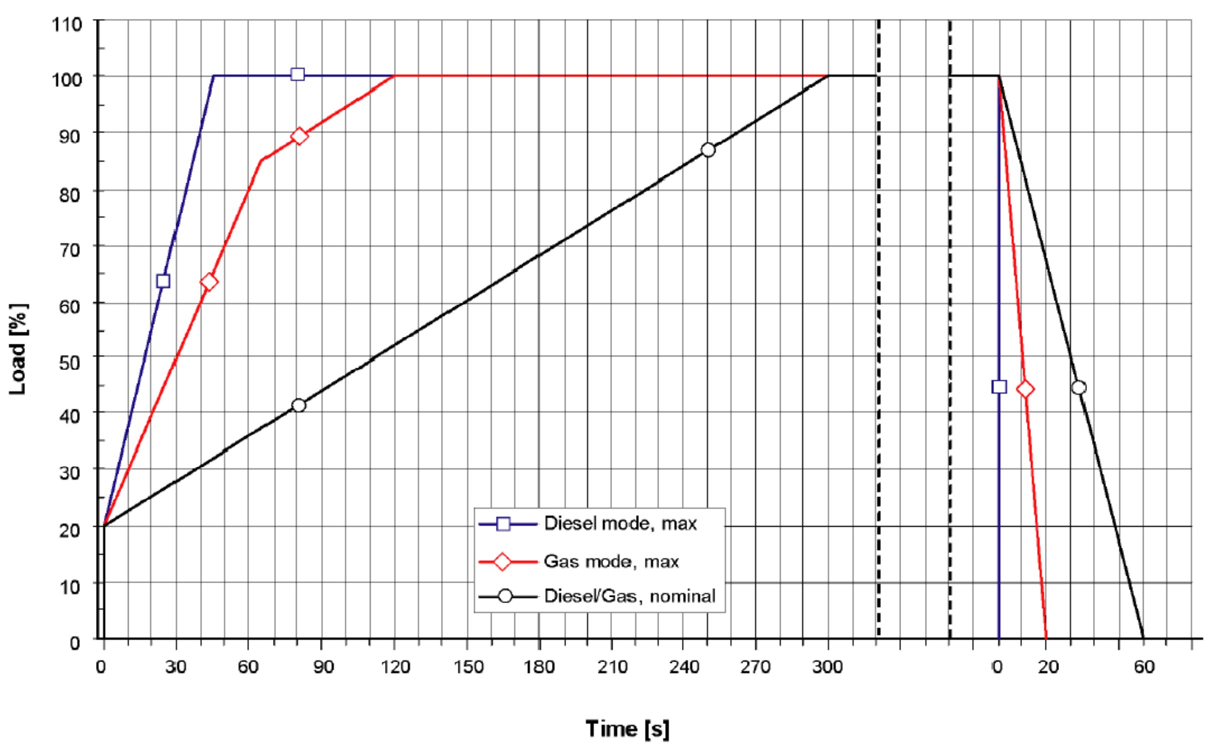


**Figure 1 Wärtsilä 34DF engine loading capacity**

The gas engine response times are slower than those of a typical two-stroke diesel engine such as the EMD engines in the existing design. The slower response times will have an effect on maneuvering and docking operations. It is likely that the operator will need to adjust their maneuvering and docking procedure to compensate for slower engine response times of the gas engines.

Rolls Royce has noted that the response of the Bergen engine and the response of the CP Propeller control system need to be reviewed in future design phases to ensure their compatibility. Some changes to the CPP control system may be necessary but it could not be fully determined due to time constraints of this study. The compatibility of the CPP control system and Wärtsilä engine should also be confirmed.

## 2.3 Gas Fuel Specification

The vessel will be fueled with liquefied natural gas (LNG). LNG is used today as a transportation fuel but the market is still small compared to most other alternative transportation fuels. LNG is typically transported by truck from liquefaction facilities to the fueling stations.

LNG is in limited use in Washington State today, but if a large enough market existed in the Puget Sound area, a supplier would build a liquefaction plant. Currently two liquefaction facilities exist on the Washington/Oregon border and another on the Canadian side of the Washington/Canada border. One LNG fueled ferry similar in size to the new 144-Car Ferry would likely consume enough LNG to justify a Puget Sound liquefaction plant. It is possible to transport LNG from the existing liquefaction facilities to supply the ferry service until a local facility is built.

The specification of the LNG that will be delivered is somewhat dependant on the liquefaction plant providing the fuel. Clean Energy Fuels, a national LNG fuel supplier has indicated that LNG supplied from the natural gas pipeline in the Puget Sound region could be produced to the fuel specification shown in Table 4.

**Table 4 Typical West Coast Pipeline LNG Fuel Specification.**

| **Gas Contents (% by Volume)** | | |
|---|---|---|
| $CH_4$ | 95.70 | % |
| $C_2H_6$ | 2.70 | % |
| $C_3H_8$ | 0.60 | % |
| $C_4H_{10}$ | 0.08 | % |
| $N_2$ | 0.90 | % |
| **Gas Properties** | | |
| Density (at 0°C & 101.325 kPa) | 0.74866 | $kg/m^3$ |
| Lower Calorific Value | 49165 | kJ/kg |

## 2.4 Range and Endurance

Initially it was intended to provide the vessel with sufficient LNG storage for 10 days of endurance on the longest route. This endurance was chosen primarily to provide a large margin in the vessel's bunkering schedule in order to accommodate any unanticipated delay in LNG fuel delivery. Late in the project one of the tank vendors and a gas supplier recommended reducing the amount of storage because they thought it may be difficult to keep the fuel cold enough with the desired bunkering schedule and endurance. As a result of these recommendations, both the Rolls Royce and the Wärtsilä designs have been updated to have 7.5 days of gas fuel endurance. This endurance will reduce the size of the tanks but still provide flexibility in the operating and bunkering schedule.

In the next phase of the design it will be necessary to revisit the vessel endurance. Working closely with the tank manufacturer(s) it will be necessary to determine the maximum endurance that can be achieved while keeping the fuel sufficiently cold. Working closely with the LNG supplier(s) it will be necessary to structure the fuel delivery such that the fuel can be delivered reliably without interruptions.

The fuel consumed for the Seattle – Bremerton route over 7.5 days was calculated for both the Rolls-Royce and the Wärtsilä engines using the operating profile and the specific fuel consumption information from the vendors. It was assumed that the vessel would make 16 crossing per day between Seattle and Bremerton, per the current schedule.

The specific fuel consumption was extrapolated using a second order polynomial curve fit to the points given in the vendor's technical information, because the specific fuel consumption data was only given for a few engine load levels.

The energy density of natural gas depends on the gas makeup and can vary significantly. Because of this, specific fuel consumption for natural gas engines is given in energy based units (mJ/kWh) rather than mass based units. The consumption of diesel oil in the dual fuel engines is given in mass based units (g/kWh).

Using the energy density of the fuel as given in Table 4, the daily fuel consumption of the two different engines was calculated. The calculated values can be seen in Table 5.

**Table 5 Daily Fuel Consumption**

| Engine | Daily LNG Consumption | Daily LNG Consumption | | Daily Diesel Oil Consumption | |
|---|---|---|---|---|---|
| | (mJ/Day) | $m^3$ | gal | l/Day | gal/Day |
| Bergen C26:33 L9PG | 385,839 | 18.98 | 5,014 | 0.0 | 0.0 |
| Wärtsilä 6L34DF* | 444,574 | 21.03 | 5,556 | 218.7 | 57.8 |

*Engine is assumed to be derated to 2,300 kW (3,084 HP)

LNG tank filling and storage must be careful calculated and controlled due some unique properties of LNG. Because LNG is cryogenic, delivered at -163°C (-262°F), the tanks must undergo a special cool down procedure before they can be filled with LNG for the first time. In the cool down procedure the tanks are slowly cooled with liquid nitrogen to bring them down to temperature. Once the tanks are filled with LNG, they need to be continuously kept cold. In order to keep the tanks cold, a minimum amount of LNG needs to remain in the tanks at all times. If the tanks are completely emptied, they will warm up and the cool down procedure is required before than can be loaded again. Typically the amount of fuel that must remain (innage) is 5-10% of the tank's volume. Based on the documentation from both tank vendors, the Rolls Royce tanks will have an innage of 10% while the Wärtsilä tank will have an innage of 5%.

Additionally, the density of LNG changes substantially with temperature which makes it necessary to account for the expansion of the liquid in the storage tank. It is theoretically possible for the LNG to reach a temperature of -130 °C (-202°F) before the tank's pressure relief valves open to vent the tank. This temperature is referred to as the reference temperature. The regulations require that the maximum fill level of the tanks is such that at the reference temperature, the tank will not be more than 98% full. Because the fuel is subcooled to -163°C (-262°F) when it is delivered from the trucks, the tanks can only be loaded to 86% full to prevent the tank from being liquid full when the gas warms up to the reference temperature.

Because of the innage and the 86% maximum filling, the amount of consumable volume in the tanks is only 76-81% of the tank's geometric volume at the delivery temperature of -163°C (-262°F). Using this information, the required geometric volumes of the tanks was calculated for both engines. The required tank volumes are given in Table 6. Note that in accordance with the regulations the dual fuel engine does not require a redundant gas fuel system; therefore a single LNG storage tank is permissible.

**Table 6 Required Tank Size**

| Engine | Total Consumable Fuel Volume | | Number of Tanks | Required Tank Volume | | Selected Tank Geometric Volume | |
|---|---|---|---|---|---|---|---|
| | $m^3$ | gal | | $m^3$ | gal | $m^3$ | gal |
| Bergen C26:33 L9PG | 142.4 | 37,618 | 2 | 93 | 24,568 | 95 | 25,096 |
| Wärtsilä 6L34DF* | 157.7 | 41,659 | 1 | 194 | 51,249 | 194 | 51,249 |

*The engine is assumed to be derated to 2,300 kW (3,084 HP)

The LNG storage tanks proposed by Rolls Royce are two 95 $m^3$ (25,096 gal) custom tanks. The storage tank proposed by Wärtsilä is 194 $m^3$ (51,249 gal) and is from a catalog of standard tank designs. Both tanks are of sufficient size to provide 7.5 days endurance on the Seattle – Bremerton route.

## 2.5 Gas Fuel System

The gas fuel system includes the LNG storage tanks, gas vaporization equipment, gas distribution system, and bunkering system. The general gas system arrangement is shown in Figure 2. Certain aspects of the gas fuel system arrangement vary slightly, depending on whether gas only or dual fuel engines will be used. Where there are differences, both configurations will be addressed specifically.

The gas system will be supplied as part of the scope of supply of the engine vendor.

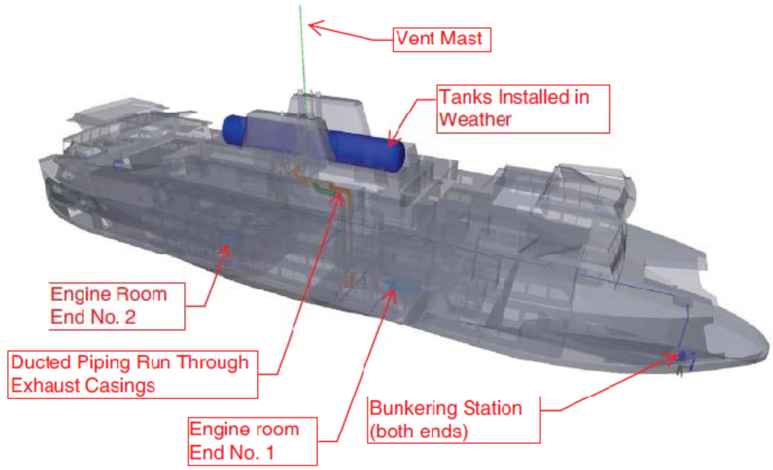


**Figure 2 Gas System Arrangement**

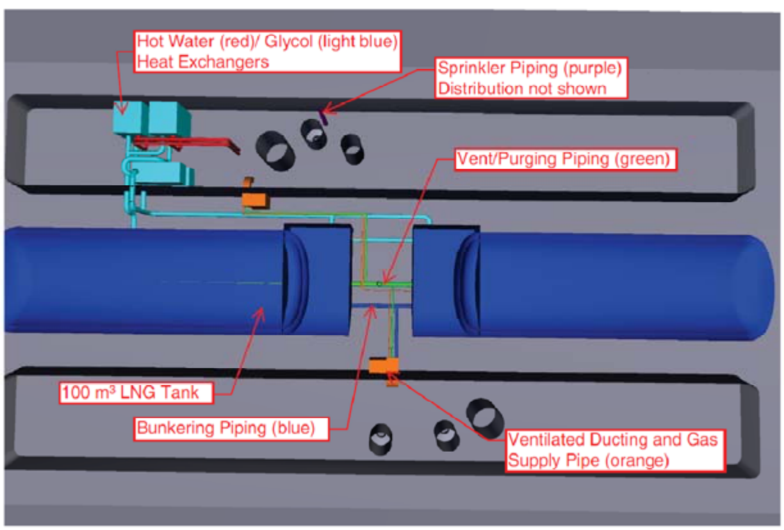


**Figure 3 Storage Tank Arrangement**

### 2.5.1 Gas Storage

The LNG will be stored in a single 194 $m^3$ (51,249 gal) tank if dual fuel engines are used or in two 95 $m^3$ (25,096 gal) tanks if single fuel engines are used. The tank sizes were determined based on the endurance of the vessel fuel consumption for the engines as well as the availability of standard tank sizes. The sizing and selection of tanks is discussed in further detail in Section 0.

The LNG storage will be located be located in the weather on the Bridge Deck of the vessel. Locating the tanks on the Bridge Deck is preferable to locating them below the main deck for several reasons.

- The vessel’s hull structure will not need to be redesigned to accommodate tanks inside the hull.
- The USCG has indicated that they prefer that the tanks be located in the weather and that they are not located beneath passenger accommodations.
- The cost of installing the tanks on an open deck is significantly less than to install them inside the hull.

Reinforcement of the deck and supporting structure will be required to support the tanks but major changes to the vessel’s structure are not required. The extent of structural modifications is further discussed in Section 2.8 of this report.

The tanks will be located on the centerline of the Bridge Deck between the exhaust casings. This places the tanks in a location such that they will be in the weather on an open deck and will not be below any passenger accommodation spaces. See Figure 3 for the location of the tanks. The tanks will be double shell vacuum-insulated pressure vessels, with a design pressure of 7.5 barg (109 psig) and an operating pressure of 5 to 6 barg (73 to 87 psig). A gas tight tank room will be integral to one end of each of the tanks, and will contain all the gasification process equipment. The tanks will be equipped with pressure relief valves to prevent over pressurization of the tank. The relief valves will vent the tank to the gas vent mast discussed in Section 2.6.2.1. The LNG storage tank vendor will be responsible for ensuring that the tanks are designed to the applicable DNV and USCG regulations and that any required certificates and documentation are provided.

The LNG storage tanks will be filled at most to 86% of the available volume. This is to allow for expansion of the LNG with changes in temperature. The space above in the liquid level in the tank will be filled with gas vapor. This space is referred as the gas cushion.

### 2.5.2 Gas Distribution System

Each tank will have an attached, gas tight tank room that will be integral with the outer shell of the tank. Each tank room will contain a pressure building unit (PBU), a LNG Vaporizer, and a Natural Gas (NG) Heater, as well as gas delivery piping and valves. All of the gas piping and equipment that processes liquefied gas will be located inside of the tank room. This does not include the bunkering pipes which also carry liquefied gas, and are located outside of the tank rooms. The bunkering system is discussed separately in this report.

In normal operation, LNG fuel is conducted to the LNG Vaporizer where it is evaporated to natural gas vapor at a temperature of approximately -140°C (-220°F). The gas is then conducted to the NG Heater where it is heated to the required temperature for the engine fuel supply between 5°C and 40°C (41°F and 68°F). The heated gas is then delivered to the engine by way of the piping and a gas supply unit (GSU) which is separately discussed in this report. When there is a need for rapid increase in engine output, fuel gas can also be taken directly from the gas cushion at the top of the storage tank. Gas taken from the gas cushion will be conducted through the NG heater where it is heated to the required temperature for the engines.

In the event that the LNG Vaporizer is inoperative, the LNG vaporizer can be isolated and the fuel gas system can use the PBU as a vaporizer. The PBU is a vaporizer used to build the pressure in the tank to the operating pressure. If the PBU is used to supply fuel gas, the vessel will be restricted to operation at reduced power due to the limited gas output of the PBU.

Each gas system is fitted with a tank valve that can be used in an emergency to shut off supply of liquefied gas. Each gas system is also fitted with a master gas valve that can be used for emergency shutdown of vaporized gas. Typically the master gas valve will be used for shutting down the gas supply unless an alarm has occurred inside the tank room. Alarms and emergency responses are further discussed in Section 2.9.

The liquefied gas will be delivered to the pressure build up unit and the fuel vaporizer by a pipe that comes off the bottom of the gas storage tank. The tank valve for shutting off the liquid line will be a remote operated valve that will be located near the tank outlet. The vaporizer and gas heater will utilize a hot water/glycol system to provide the necessary energy for vaporizing and heating the gas. Once vaporized and heated, the gas will exit the tank room through the gas supply piping that delivers the gas to the engine rooms.

The gas supply piping will be arranged with the master gas valves on the Bridge Deck close to the tank rooms. From the master gas valves onward, the piping system will be the same for both the single fuel and the dual fuel engines configurations. Because the dual fuel gas system only utilizes a single tank, the gas distribution system upstream of the master gas valves will be somewhat different for the two types of engines.

In the gas system for single fuel engines, the gas supply piping will lead from each of the tank rooms to the master gas valves located just outside of each of the tanks rooms. Between the tank rooms and the master gas valves will be a crossover pipe with a normally closed, remotely operated valve that connects the gas supply lines from both tanks. This crossover will be used to supply both engines from one of the two tanks in the event that supply from the other tank is unavailable. It should be noted that the Rolls Royce gas distribution system does not have enough capacity to supply gas to both engines at full capacity with one tank off line. This is due to the way the gasification equipment was sized. If redundancy is desired it may be possible to increase the gasification capacity. However, DNV and USCG have both indicated that the ability to operate both engines at rated power from a single tank is not required as a condition of Class or regulatory compliance.

In the gas system for the dual fuel engines, the gas distribution piping will lead from the single tank room and branch to two master gas valves, one for each engine room, located just outside of the tank room. From the master gas valves onward the gas supply piping will be identical to the single fuel gas supply piping.

From the master gas valves, the gas supply piping to the End No. 1 Engine Room will be run to the starboard exhaust casing, and the supply to the End No. 2 Engine Room will be run to the port exhaust casing. Inside the casings, the gas supply piping will be run inside ventilated ducts to the Gas Supply Unit (GSU) located in each of the engine rooms. The GSU will be located inside a gas tight enclosure in the engine room. The GSU enclosure will be integral with the ventilated duct. There will be one GSU and GSU enclosure in each of the engine rooms. The gas distribution piping will be led inside of a ventilated duct from the GSU enclosure to the engines. See Figure 2 and Figure 3 for the general arrangement of the gas system and Figure 4 for the arrangement in the engine room.

All of the gas supply piping will be low pressure piping, with the gas pressure not exceeding 7.5 barg (109 psig)and typically being 5 to 6 barg (73 to 87 psig). Pressure relief valves inside the GSU will ensure that the gas pressure does not exceed the maximum allowable pressure.

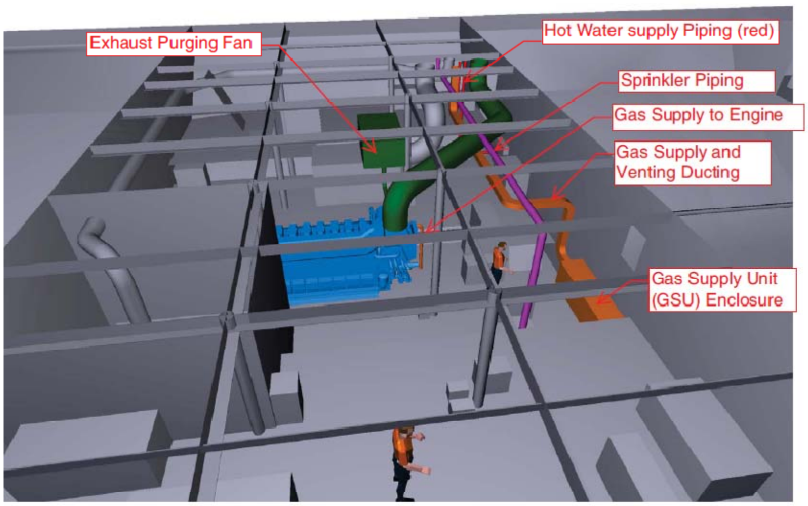


**Figure 4 Engine Room Arrangement**

### 2.5.3 Gas Supply Unit

The gas supply unit (GSU) will consist of the double block and bleed valve, gas filter, pressure control valve, and a nitrogen purging connection. On either side of the double-block-and-bleed valve will be a ventilation valve that allows the gas supply piping upstream and downstream of the double-block-and-bleed valve to be vented to the gas vent mast. The nitrogen injection valve will be located upstream of the double-block-and-bleed valve, to facilitate inerting the gas supply line between the double-block-and-bleed valve and the storage tank, as well as from the GSU to the engine.

The GSU for each engine will be installed inside a gas tight enclosure in the respective engine room. The ventilation ducting around the gas supply piping will be connected to the GSU enclosure thereby ventilating the enclosure. The GSU enclosure will be considered a *Zone 1 Hazardous Space,* per the requirements of References 1 and 2, and will not have access doors. Maintenance and service access to the enclosure will be through a bolted hatch that will only be opened when the gas supplying line has been inerted with nitrogen. After the gas supply lines are inerted, the GSU enclosure is not a hazardous space.

Wärtsilä offers a packaged GSU inside an enclosure similar to what shown in Figure 5. This packaged unit will be part of the scope of supply of the Wärtsilä system. Typically for the 34DF engines the GSU enclosure is oriented horizontally. However, Wärtsilä has indicated that it can be packaged into a vertical orientation to save space in the engine room. Rolls Royce does not offer a packaged GSU enclosure. The enclosure will need to be designed and then fabricated by the shipyard.

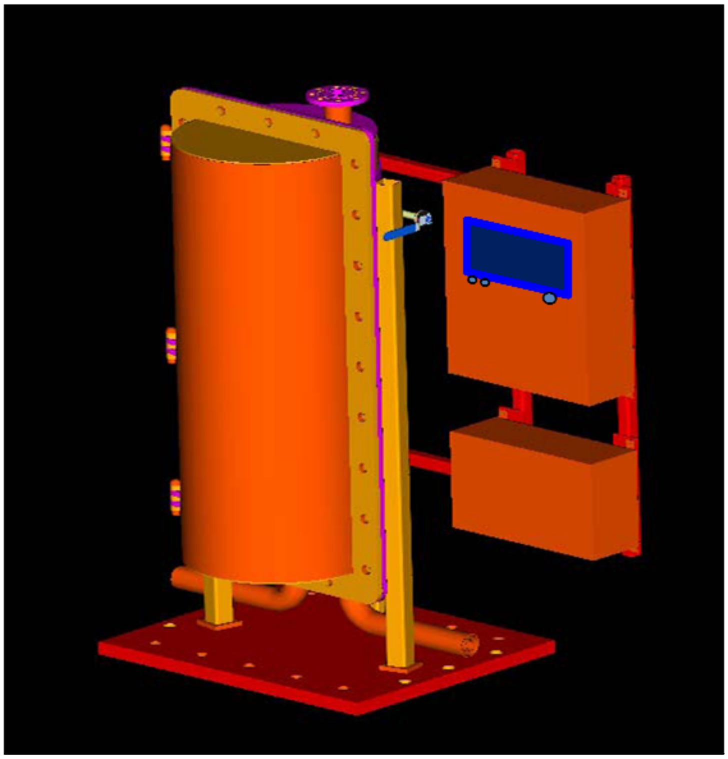

**Figure 5 Wärtsilä Packaged GSU and Enclosure**

### 2.5.4 Glycol System

The LNG vaporizer, gas heater, and pressure build up unit will be supplied with heat from a closed loop 50/50 glycol system. The glycol system heat exchangers and pumps will be located in the exhaust casing on the bridge deck as can be seen in Figure 3. The hot water heating system in the current vessel design will be used to heat the glycol through heat exchangers. Wärtsilä suggested that the low temperature jacket water system may be used to heat the glycol system, however this information was not provided in time to be included in this study. It would be worthwhile to investigate this option for both systems in the next phase of development as it would increase the waste heat utilization.

Wärtsilä offers a skid mounted glycol system consisting of a heat exchanger, two circulating pumps, and the necessary valves and piping to connect the system. The Wärtsilä gas system requires approximately 230kW of energy for the PBU and 345 kW of energy for the vaporizer to produce the required amount of gas to operate both engines at MCR. Clarification was not provided as to whether the PBU and vaporizer demands are simultaneous.

Rolls Royce does not offer a packaged glycol system. A closed loop glycol system will need to be designed and procured separately from the engine and gas system. The glycol system will consist of two hot water/glycol heat exchangers, two circulating pumps, and the necessary valves and piping to connect the system. The Rolls Royce gas system requires a total of 270 kW of energy to produce the required amount of gas to operate both engines at MCR.

Both systems will be pressurized with nitrogen to 10 barg (145 psig) in order to prevent gas from entering the glycol system in the event of a leak. Any glycol that enters the gas system will instantly freeze and will not reach the engine. A loss of pressure in the glycol system indicates a leak and will cause alarms to sound and the system with the leak to shut down.

### 2.5.5 Bunker Station and Bunkering Process

Washington State Ferries bunkers their vessels at night while they are tied up at the dock, between the last run of the day and first run of the next day. There are no passengers or vehicles on the vessel during bunkering. Bunkering with LNG will follow the same approach. The typical bunkering cycle will consist of a truckload (~10,000 gallons or ~37.8 $m^3$) of LNG fuel delivered every 2 to 3 days. The design, however, does have sufficient fuel capacity to operate at least 7.5 days without bunkering.

The vessel will have a bunkering station located at both ends of the vessel on the Main Deck at the side shell (see Figure 6). This location is open to the weather and will have good natural ventilation. The vehicle space, which is open on both ends and has large openings in the sides, will be naturally well ventilated to prevent the buildup of natural gas vapors.

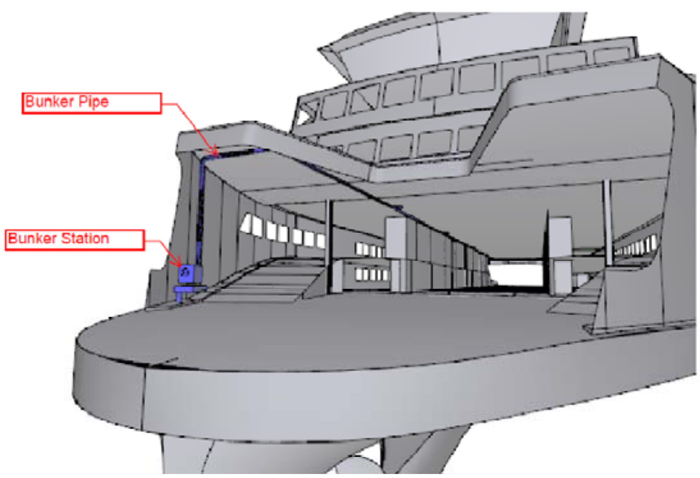


**Figure 6 Bunkering Station**

The bunker station will consist of a shore connection, a pressure gauge, a manual stop valve, and a remotely operated stop valve. Underneath the bunkering station will be a stainless steel drip tray. The drip tray will drain overboard through the Main Deck and hull plating where it overhangs the water. The drain pipe will be constructed of cold resistant stainless steel. The deck and hull penetrations will be sleeved and the drain pipe will be thermally isolated from the vessel's structure. The overboard will be installed such that any liquid discharged from the drain is directed away from the vessel's hull.

The bunker piping will be routed from the bunker station up to the overhead of the vehicle space, where it will be run to the exhaust casing at approximately amidships. Inside the casing, the piping will be routed up to the tanks alongside the gas supply piping inside a ventilated duct. The bunker piping inside the casing will be double wall vacuum jacketed pipe. Because the vehicle space is an open space, piping in the vehicle space will be single walled pipe.[1]

The bunkering station itself and the bunker piping that runs up the side shell of the vehicle space will be located less than 760 mm (29.9 in) from the side shell in apparent conflict with the applicable rules.[2] Once the bunker pipe reaches the overhead of the vehicle space, it will immediately run inboard to where it will be more than 760 mm (29.9 in) inboard of the side. Bunkering will only occur while the vessel is at the dock. While the vessel is underway, the bunker pipe will be inerted with nitrogen in accordance with the rules.

There will be over 45 m (150 ft) of bunker piping between the point where the bunker pipe reaches the vehicle space overhead and the storage tank. The piping will have sufficient flexibility that any damage to the bunker station from an accident or collision will not propagate to the tank connection. Additionally, the bunker station and the piping will be mechanically protected by the ship's structure, bollards, and/or steel cages to prevent damage by vehicles.

Bunkering will be carried out using a mobile transfer pump trailer to transfer the fuel from the tanker truck to the ship. During bunkering operations, the transfer pump trailer and the tanker truck will be located on the shore side vehicle loading ramp, and be connected to the bunkering station with a portable hose. The anticipated rate of fuel transfer is 68.1 $m^3$ per hour (300 gallons per minute). During liquid transfer, pressure will be regulated in the storage tank by spraying cold liquid into the gas space in the tank to collapse the gas pocket. No gas will be released during bunkering.

Once liquid transfer is complete, the bunkering line will be blown out with heated natural gas vapor delivered from a vaporizer on the transfer pump trailer. The heated gas will push liquid into the tanks, then vaporize any remaining liquid in the line and blow it up to the vessel's storage tanks. The vapor will be introduced into the tanks through the bottom fill lines, so that the LNG in the tanks causes the gas to condense and minimize the pressure build up in the tanks. Once the bunkering lines have been blown out, they will be purged to the vent mast with nitrogen injected at the bunkering station.

The bunkering station will be shielded from all accommodations spaces by A-60 boundaries. Because of the location of the bunkering station, it is not practical to shield the bunkering station from the vehicle space. Bunkering will only occur when the ferry is out of service, so there will be no passengers or vehicles in the vehicle space during bunkering. Additionally,

[1] DNV noted that flanges in bunkering pipes need to be protected against liquid spills onto ship structure. To accommodate this, bunker pipe joints should be welded wherever possible. Joints that cannot be welded will require spill containment. Vacuum insulation is not considered containment. These piping details should be developed in future phases of the design.

[2] DNV and USCG have stated that the short run of bunkering piping less than 760mm from the side is acceptable.

the vehicle space will be made entirely of steel decks and bulkheads of A-0 or better, and all doors to the vehicle space will be A-60. Furthermore, the vehicle space will be protected with a zonal deluge sprinkler system. As a result of these factors, it is our position that, at the time of bunkering, there will be minimal threat that a fire at the bunkering station would spread into the vehicle space or to other parts of the vessel.[3]

## 2.6 Ventilation and Bleed Vents

The ventilation and bleed systems have been designed to meet all of the applicable DNV rules (Reference 1) and IMO Resolution MSC.285 (86) (Reference 2). Although slight variation may occur between single or dual-fuel configurations, the arrangements will be very similar for both systems.

### 2.6.1 Ventilation

#### 2.6.1.1 Gas Pipes

To achieve the required ventilation, a duct will be provided around the gas supply line and the bleed vent line running to each engine room GSU as well as the portion of the bunkering line that is inside the exhaust casing. These ducts act as a secondary barrier for containment for the gas piping run through all enclosed spaces.

Each ventilation duct will be one continuous duct from the engine to the Bridge Deck. The ventilation air will be drawn into the on-engine double wall piping from the engine room. The double wall of the on-engine piping will be connected to ducting around the gas supply pipe leading from the GSU enclosure. From the GSU enclosure, the duct enclosing both the gas supply line and bleed vent line will be lead inside the exhaust casing all the way to the Bridge Deck, where it penetrates the casing. Once the gas piping exits the casing, the piping will be on open deck and ventilation ducting is not required. On the starboard side of the vessel, the bunker piping will also run inside the duct from the Upper Car Deck overhead to the Bridge Deck.[4]

On the Bridge Deck, the ventilation air will be exhausted by a fan in a non hazardous zone directly after the duct penetrates the casing. It will be exhausted on deck in a location away from any potential sources of ignition. The fans will be sized such that the air will be drawn through the GSU enclosure at a rate of 30 air changes per hour to achieve sufficient ventilation.[5]

Because the ventilation air is drawn in from the engine room, gas detectors will be installed in the engine rooms.

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[3] DNV and USCG have accepted the arrangement of the bunkering station. USCG has stated that the OCMI may put a restriction on the COI stating that bunkering may only be done with no vehicles or passengers onboard.
[4] DNV has stated that the ventilation duct around the gas distribution piping inside the machinery space must be separate from the duct around the bunker pipes outside the machinery space. A separate ventilation duct with a separate exhaust fan will need to be added for the bunker pipe to accommodate the DNV requirement.
[5] DNV has stated that redundant fans are required for the gas ventilation fans. A second fan will need to be added to each duct.

#### 2.6.1.2 Machinery Spaces

The engine rooms must also be sufficiently ventilated. Air will be drawn through a louver on the Bridge Deck and down the casing, and will be exhausted out the top of the stacks. The supply and exhaust ventilation for each engine room will each be powered by two equally sized fans (four fans total per engine room). For each engine room, one supply and one exhaust fan will be powered by a separate circuit off the main switchboard from the other two fans. This configuration provides redundancy in the event of a failure, and ensures that a minimum level of 50% of design ventilation will be maintained.[6]

#### 2.6.1.3 Tank Rooms

DNV rule Section 3/I 301 (Reference 1) states that tank rooms located below deck must be ventilated. Because the tank rooms will be located on a weather deck, we propose that the tank rooms be equipped with a ventilation system that will be secured under normal operation. The intention of securing the ventilation is to reduce the corrosion of the tank room and equipment caused by the introduction of salt air into the tank room. The ventilation system would only be operated in the event that a gas detector in the tank room alarms or to make the space safe for entry for maintenance.[7]

#### 2.6.1.4 Exhaust System Purge

A gas purging fan is also required for each engine exhaust system. Each fan will be sized to quickly purge the volume of the exhaust pipe 3 times. Purging will be done before each engine start-up or after a failed start to maintain a gas-free exhaust system and prevent ignition of any built-up gasses.

#### 2.6.1.5 Intakes and Exhausts from hazardous areas[8]

In accordance with Reference 2 hazardous area Zone 1 areas are any locations:

- Within 3m (9.8 ft) of any gas tank outlet, gas or vapor outlet, bunker manifold valve, gas valve, gas pipe flange, gas pressure relief openings
- Within 1.5m (4.9 ft)of a tank room opening
- Within 3m (9.8 ft) of the bunker station up o a height of 2.4m (7.9 ft) above the deck

Hazardous Zone 2 areas are any locations:

- Within 1.5m (4.9 ft) of a Zone 1 area.

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[6] DNV has stated the requirement for redundant engine room ventilation is intended for ESD engine rooms only. Because the engine rooms are inherently safe, the engine room ventilation system may remain as designed for the existing diesel fuelled vessel design.

[7] USCG has stated that an analysis demonstrating equivalent safety of the tank room would be required to secure the tank room ventilation system in normal operation. In light of this requirement, the tank room ventilation system would be normally on.

[8] USCG has stated that they have a slightly different definition of hazardous zones. These zones are defined in their written comments attached to this report.

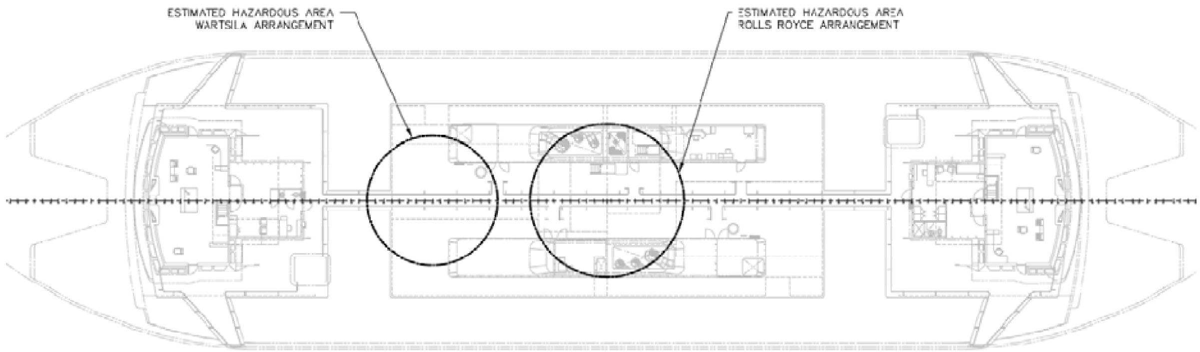


**Figure 7 Hazardous Areas on Bridge Deck**

Ventilation air intakes may only be located in non hazardous locations. Because no HVAC system drawing was available, it could not be confirmed that all ventilation intakes meet this requirement. However, the extent of hazardous areas has been minimized as much as possible. An estimation of the hazardous area on the Bridge Deck is shown in Figure 7. The actual extent of the hazardous area will depend on the detailed arrangement of the gas piping. Any ventilation intakes within the hazardous area would need to be relocated to a non hazardous area.

The engine room ventilation intakes in the existing design are located at the ends of the exhaust casings. With the arrangement of the Rolls Royce system, these intakes are not anticipated to be located in a hazardous area. In the arrangement of the Wärtsilä system the Number 2 end engine room intake will likely be affected and will require modification to ensure no intake louver will be located in the hazardous area. This may require that all the ventilation intake louvers be located on the outboard side of the casing.

All ventilation exhausts must be located in an area with a hazardous rating of no greater than the space served by the ventilation system. Again, the locations of all the ventilation exhausts could not be determined. Any ventilation exhausts located within a hazardous area would need to be relocated to a non hazardous area. Because the engine room exhausts are located in the top of the stack, they should not need to be relocated.

In addition to ventilation intakes and exhausts, openings to non hazardous spaces may not be located in a hazardous area unless they are fitted with an air lock. This may require that the spaces with access opening on the inboard side of the casings from the Bridge Deck may need to be relocated or fitted with an airlock. The extent of the effected openings will be dependent on the detailed arrangement of the gas piping system on the Bridge Deck. However, it is anticipated that no more than four opening will be affected.

### 2.6.2 Gas Vents

There are several gas vents in the gas system. The vents are either from pressure relief valves or from bleed lines for purging gas supply lines. All the gas vents are lead to a gas vent mast.

#### 2.6.2.1 Gas Mast

Because of the hazardous nature of vented gas, all gas vents are connected to a gas vent mast. The gas vent mast must be located such that the gas outlet is sufficiently far (>10m or 32.8 ft) from any potential ignition source, working deck, opening to a safe area, or a ventilation intake. To meet this requirement, the gas vent mast will be located on the centerline at amidships and will extend 12.2 m (40 feet) above the outlet of the exhaust. Because the vent mast is so tall, it will likely need to be guyed to the vessel's structure. The structural details of the mast will need to be developed in detailed design.

#### 2.6.2.2 Bleed Vents

Bleed vents will be designed for safe venting and/or purging of gas lines for engine shut down, bunkering, and in response to a gas system alarm.

The gas supply line will be vented by bleed valves in the GSU enclosure. When gas supply to the engine is stopped with the double block-and-bleed valve, the bleed valve will open to vent the pipe between the stop valves. The bleed valve will be connected to the vent pipe from the GSU enclosure to the gas vent mast on the Bridge Deck. The vent piping will run through the ventilated duct up to the Bridge Deck and will be connected to the gas mast.

In addition to the bleed line from the double block-and-bleed valve, there will also be bleed valves on either side of the double block-and-bleed valve that vent the gas supply piping in case of an automatic closure of the master gas valve. These bleed valves will be connected to the vent pipe in the GSU enclosure.

A bleed vent valve in the bunkering line will be located near the tanks. The bunkering bleed vent will be used for purging the bunkering pipe to the vent mast after the completion of the bunkering process.

The storage tanks will be connected to the vent mast by bleed valves located in the tank rooms. These valves will be normally closed, but can be opened to allow purging of the tanks for maintenance.

#### 2.6.2.3 Pressure Relief Valves

There are several pressure relief valves in the system to prevent the pressure from exceeding the maximum allowable pressure in the gas system of 7.5 barg (109 psig). There will be two pressure relief valves on the tanks, several pressure relief valves in the bunkering line, and a pressure relief valve from each GSU. If the pressure relief valves lift, the gas is vented to the gas mast through the various vent piping.

### 2.6.3 Nitrogen System

Nitrogen is used to purge and inert the bunker pipes and gas supply pipes. To supply the nitrogen, a nitrogen system would need to be installed on the vessel. The nitrogen system would use compressed nitrogen cylinders located in the fixed fire fighting room. This space was selected because it is a well ventilated space that already contains compressed gas cylinders. A pressure regulator would be installed at the nitrogen tank, and nitrogen supply piping would be led to the GSU enclosures, the tank rooms, and the bunker stations. The nitrogen distribution piping would have a maximum working pressure of 10 barg (150 psig).[9]

## 2.7 Engine Exhaust

Both wet and dry exhaust systems are being considered for this vessel. Both concepts will utilize ventilation fans to purge the exhaust piping in the event of an engine failure to start, and a rupture disk to relieve pressure due to an explosion in the piping.

The dry exhaust system would be a traditional exhaust system with spark arresting silencers fitted in the exhaust casing. The outlet of the exhaust would be at the top of the stacks.

The wet exhaust system would use water jets inside the exhaust piping to cool and condense the exhaust gasses. The wet exhaust outlet would be through the vessel's hull above the waterline. As the wet exhaust system piping requires a downward slope from the water injection point to the vessel's side, a vent pipe would be run from the highest point in the system to weather to prevent any gas buildup.

Both exhaust systems will either be designed with an explosion vent leading to weather, or will be designed such that they will be able to withstand an explosion, as required by the applicable rules.

DNV has preliminarily indicated that they have some concerns that uncombusted gas from an ignition failure could build up in the wet exhaust system and potentially cause an explosion. It will be necessary to further study a wet exhaust concept in order to allay these concerns.

## 2.8 Weights & Stability

### 2.8.1 Weight Estimate

A weight estimate has been developed for both the Rolls Royce and Wärtsilä configurations. The estimate was developed to determine change in lightship weight and center of gravity associated with the gas fuel conversion. This information was used for evaluating both the impact on the vessel's stability and structure.

Weights were broken up into either additions or subtractions. Weights associated with systems to be removed were deducted while new system components associated with the gas fuel design were added. Systems that were modified, such as exhaust, were first subtracted and then the weights of the modified system were added. All additions, removals, and modifications to the original design were documented and accounted for in the weight estimate.

[9] DNV stated that to prevent return of flammable gas to a gas safe space, a double block and bleed valve located in a non-hazardous space would be require in the nitrogen system. To address this comment, a double block and bleed valve would need to be installed in the nitrogen supply pipe just outside the fixed fire room. Additionally DNV has stated that closable non-return valves are required in the system. The non-return valves would need to be installed at every connection of the nitrogen system to a pipe or space containing a flammable gas.

When available, exact weights from vendor data were used. For systems and components that had no vendor data available, estimates were made using a combination of materials, arrangement, and routing. A five percent margin was added to both additions and subtractions to account for uncertainty in the weights.

Table 7 lists the revised lightship weight of the vessel with its corresponding longitudinal, transverse, and vertical center of gravity (LCG, TCG, VCG) for the Rolls Royce configuration. Table 8 lists the revised lightship weight of the vessel with its corresponding center of gravity for the Wärtsilä configuration.

**Table 7 Rolls Royce System Weight Estimate Summary**

| Group Description | Weight (LT) | LCG (ft Aft Fr 0) | TCG (ft Stbd CL) | VCG (ft Abv BL) |
|---:|---:|---:|---:|---:|
| Original Lightship | 3,497.30 | -0.38 | 0.32 | 28.85 |
| Subtractions | -72.90 | 6.16 | 0.33 | 21.04 |
| Additions | 220.83 | 1.70 | 0.38 | 44.04 |
| Revised Lightship | 3,645.24 | -0.38 | 0.32 | 29.93 |
| Margin (5% of Net Weight Change) | 7.40 | -0.38 | 0.32 | 29.93 |
| **Lightship (With Margins)** | **3,652.63** | **-0.38** | **0.32** | **29.93** |
| Percent Increase (%) | 4.4% | | | |

**Table 8 Wärtsilä System Weight Estimate Summary**

| Group Description | Weight (LT) | LCG (ft Aft Fr 0) | TCG (ft Stbd CL) | VCG (ft Abv BL) |
|---:|---:|---:|---:|---:|
| Original Lightship | 3,497.3 | -0.38 | 0.32 | 28.85 |
| Subtractions | -72.9 | 6.16 | 0.33 | 21.04 |
| Additions | 216.6 | 1.67 | 0.41 | 44.13 |
| Revised Lightship | 3,641.0 | -0.39 | 0.33 | 29.92 |
| Margin (5% of Net Weight Change) | 7.2 | -0.39 | 0.33 | 29.92 |
| **Lightship (With Margins)** | **3,648.2** | **-0.39** | **0.33** | **29.92** |
| Percent Increase (%) | 4.3 | | | |

### 2.8.2 Stability

It was necessary to review the stability of the gas fuelled vessel design because the addition of the LNG storage tanks on the Bridge Deck added a substantial amount of weight at a high center of gravity.

The load conditions analyzed in Reference 10 have been modified to suit the operational conditions of the vessel using LNG instead of diesel fuel. The vessel lightship has been modified to account for the weight of the LNG storage tanks, structural modifications, and miscellaneous equipment and systems modifications associated with the conversion to gas fuel. Additionally, because less diesel oil is required when the propulsion engines are gas fueled, the amount of diesel oil in each load condition has been modified to suit the new operations.

The studied load conditions will meet the stability criteria with a reasonable margin. All the load conditions have a conservative amount of free surface and there is no need to add ballast to compensate for the reduced diesel fuel. Only the Rolls Royce option was analyzed but conservative margins in weights and VCGs were used to have equivalent weights to the Wärtsilä option. Because the Wärtsilä engines revert to diesel fuel in the event of a gas supply failure, the Wärtsilä option requires extra diesel fuel to be carried onboard (~ 11.2 $m^3$ or ~2,950 gal). This extra fuel at the bottom of the vessel would lower the overall VCG which will increase the stability margins. Therefore, the Rolls Royce configuration is the limiting design case for the stability evaluation.

Per Reference 8 the driving stability criteria for the vessel operation in the 4,000 LT to 5,000 LT displacement range is the criteria found in 46CFR-170.173e1. The Maximum VCG data for that criteria found in Reference 8 is used and plotted in Figure 8 along with the modified load conditions.

Initial stability calculations were performed for storage tanks with 10 days of endurance. These calculations demonstrate that the vessel has adequate stability to meet the USCG required criterion. The design has since changed to smaller storage tanks which would reduce the VCG and increase the stability margins.

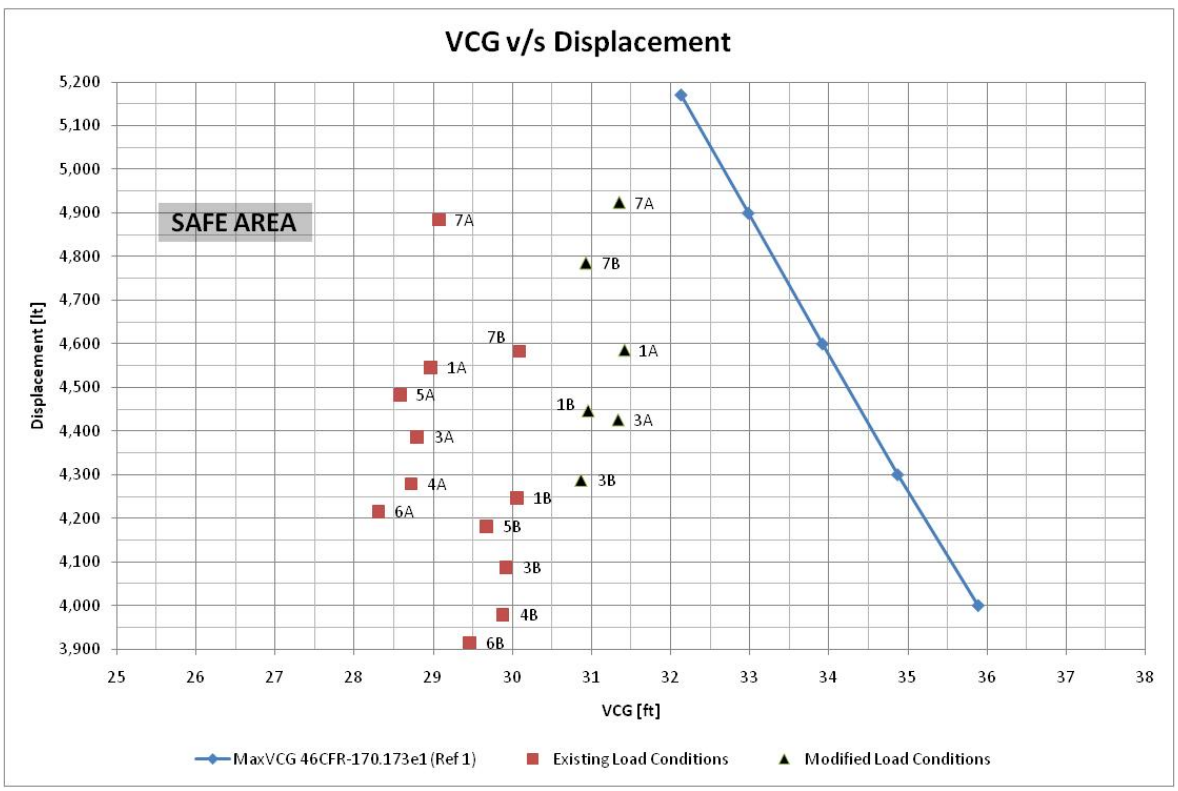


**Figure 8 VCG vs Displacement Plot**

## 2.9 Alarm, Monitoring, and Control

An alarm, monitoring, and control system will be provided by the engine and gas system supplier and will be integrated into the vessel's overall alarms, monitoring and control system. The system will provide operational monitoring and controls as well as monitoring and alarms for faults and failures, and control of valves required for automatic shutdown.

### 2.9.1 Detectors

In order to comply with the regulations, a number of specific detectors and sensors are required for gas fuelled vessels. The following detectors and sensors will be fitted.

**Table 9 Detectors and Sensors**

| Locations | Qty | Location |
|---|---|---|
| Tank Room (each) | 1 | Smoke Detector |
| | 1 | Heat Detector |
| | 1 | Bilge Low Temperature Alarm |
| | 1 | Bilge High Level Alarm |
| | 2 | Gas Detectors |
| Tanks (each) | 1 | Pressure Sensor |
| | 1 | Level Indicator |
| | 1 | High Level Alarm |
| Ventilation Duct (each) | 3 | Gas Detectors |
| Engine Room (each) | 2 | Gas Detectors |
| | 1 | Smoke Detector |
| | 1 | Heat Detector |
| GSU Enclosure (each) | 1 | Gas Detector |

In addition to the sensors and alarms listed in Table 9, the ventilated ducts around gas piping in each machinery space will be equipped with an alarm for ventilation failure.

### 2.9.2 Faults and Effects

A list of faults and effects has been compiled from both the DNV rules (Reference 1) and IMO Resolution MSC.285 (86) (Reference 2), and is included in Appendix A. This list is intended to show how the gas monitoring and alarm system provides control input to the engines and various valves in the gas system.

## 2.10 Fire Protection & Suppression

In addition to the typical fire protections and suppression systems required for a diesel fuelled passenger vessel, there are several specific fire detection and suppression systems required for gas fuelled vessels. These systems include a water spray system to protect the storage tanks, fixed fire systems to protect the bunkering stations, and additional structural fire protection.

### 2.10.1 Water Spray System

The water spray system has been designed to meet all of the applicable rules in References 1 and 2. The water spray system will be installed above the LNG storage tanks for cooling and fire prevention. The water spray system will be a branch off the deluge sprinkler system that serves the vehicle decks of the vessel.[10]

A separate suction from the seachest to a dedicated sprinkler pump is included in the current vessel design. The pump will feed the sprinkler manifold where a separate branch will be run to each zone. The tank area on the Bridge Deck will be served by an independent branch. The valve(s) in the manifold will be motor operated and the pump will be configured for remote start.

The sprinkler pump has been verified to maintain the necessary 2,400 L/min (634 gal/min) from the engine room to the Bridge Deck. This is based on full tank deck coverage at the required 10 L/min/$m^2$ (0.245 gpm/$ft^2$) horizontal and 4 L/min/$m^2$ (0.098 gpm/$ft^2$) vertical flow rates. An emergency crossover to the fire main system will also be provided.

### 2.10.2 Fixed Fire Protection

Each bunkering station will be equipped with a dry chemical fire extinguishing system. Each system will be self contained. The dry chemical will be stored under the vehicle ramp adjacent to the bunkering station. Each system will be sized to provide the required 3.5 kg/s for 45 seconds.

### 2.10.3 Structural Fire Protection

Additional Structural Fire Protection (SFP) will be required in the vicinity of the LNG storage tanks. The Bridge Deck in way of the storage tanks will need to be insulated with A-60 structural fire protection. Additionally both exhaust casings will need to be insulated with A-60 structural fire protection on the inboard side facing the storage tanks.

## 2.11 Auxiliary Generators

The existing vessel design utilizes three auxiliary diesel generators to provide the ship service power while the vessel is underway and at the dock. The generators are sized such that two generators can provide the design load and the third generator is in standby. At the time of the publication of this report, the electrical load analysis was not yet completed for the vessel. However, it was estimated that the generators will each be sized for 300 kW (402 HP) each with a maximum design load of 450 kW (603 HP).

In this study three options were considered for generation of electrical power. These options were

1) To retain the existing design with three 300 kW (402 HP) diesel generators,

[10] USCG has stated that the waterspray system must also cover any normally occupied spaces that face the storage tank. To address this requirement, the waterspray system would need to be extended to cover the two pilothouses.

2) To replace the diesel generators with three 300 kW (402 HP) gas fueled generators, or
3) To replace two of the diesel generators with two 300 kW (402 HP) shaft generators driven by the main engines and retain one diesel generator as the standby and in port generator.

The first option of retaining the three diesel generators will not result in any changes to the vessel design.

At the time of publication of this report, the authors are unaware of any inherently safe gas marine generators in the 300 kW (402 HP) size range. As was discussed in the selection of the propulsion engines, inherently safe engines are a requirement of this design. As a result of the lack of inherently safe generators, this option was not pursued further. It is worth noting that Mitsubishi does make a marine gas generator set of this size. However, it is not inherently gas safe and was therefore not considered.

The third option, using shaft generators driven by the main engines, was also considered. In the case of the Rolls Royce package the generators would need to be driven by a Power Take Off (PTO) from the front of the engine because the existing gears do not have a PTO. In the Wärtsilä package, the generators could be driven off either a front engine PTO or a gear PTO because new reduction gears are already required for the propulsion engines. Because the generators are driven by variable speed propulsion engines, the generators would need to be a variable speed generator. Power electronics would need to be used to convert the power to clean 60 Hz power to feed the main switchboard.

Both Wärtsilä and Rolls Royce have indicated that they have a generator system that could be used in this application. However, neither vendor was able to provide sufficient technical details of the generators and electronics within the timeframe required to be included in this study. There is a possibility that a significant fuel cost savings could be achieved using shaft generators, however this will need to be investigated further in a separate study, if desired.

Using shaft generators off the propulsion engines will of course increase the gas fuel consumption. This would result in either a reduction of the endurance of the vessel or an increase in required tank size to meet the 10 days endurance. It is estimated that the fuel consumption would be increased by 10-15% depending on the efficiency of the generators and electronics.

# Section 3 Impacts to Existing Design

In addition to the installation of the new equipment required for fuelling the vessel with LNG, there are several systems in the current vessel design that will require modification to support the new equipment. Additionally some modification to the existing vessel design will be necessary to comply with rules that are applicable for gas fuelled vessel. In general only substantial system modifications that have been identified are discussed in this section. Additional modifications may be necessary and will be further identified in future phases of development.

## 3.1 Machinery Arrangement

The machinery arrangement for both the Rolls Royce and Wärtsilä systems were kept as similar as possible. In order to accommodate the new machinery for the gas fuel, the arrangement of some equipment in the existing vessel design will be impacted. The affected systems for the proposed design are outlined as follows.

- Both main engine foundations will require redesign to maintain alignment of the engine output shaft and the input shaft on reduction gear.
- Exhaust piping will need to be rerouted on the hold level. If a traditional exhaust is used, deck penetrations and silencer placement will be kept as similar as possible to the original piping runs, but may be impacted slightly because of varying pipe sizes. If a wet exhaust is used, exhaust pipe routing in the engine room may affect pipes and wiring in the overhead and may impact the locations of some equipment.
- The fire pump suction and discharge manifolds in both engine rooms will need to be relocated slightly inboard and towards amidships.
- The fire pump suction strainer and the fire & sprinkler pump in both engine rooms will need to be relocated towards the ends of the vessel by a few feet to allow room for the GSU enclosure.
- Several tank access manholes will need to be relocated to avoid being blocked by new equipment.

## 3.2 Compressed Air System

The compressed air system as currently designed is for 14 barg (200 psig) starting air with the starting air receivers at 16 barg (230 psig). Both the Bergen C26:33 L9PG engine and the Wärtsilä 6LDF34 engine require the starting air to be supplied at 30 barg (435 psig). This will require different air compressors that are capable of supplying air at 31 barg (450 psig). Additionally, the starting air receivers and piping will need to be upgraded to the higher working pressure of 31 barg (450 psig). The capacity of the receivers will have to be evaluated to ensure that the receiver volume provides a sufficient number of starts to meet the applicable regulations.

## 3.3 Sprinkler and Firemain System

A new branch off the sprinkler system will need to be installed to serve the water spray system for the storage tanks. The sprinkler pump in the existing design is of sufficient size to meet the required sprinkler service. Some sprinkler system valves may need to be replaced with remotely operated valves so that the LNG storage tank water spray system can be automatically started.

The firemain system fire station locations will require evaluation to ensure there is adequate stations and isolation near the LNG storage tank.

## 3.4 Fuel Oil Storage and Transfer

The fuel oil storage, transfer and supply systems will need to be redesigned. The use of the single fuel engine eliminates all propulsion uses of diesel fuel while the duel fuel engine only requires a small amount of pilot fuel for gas operations. Unless the optional installation of PTO driven generators is implemented, diesel fuel will still be required to operate the ship service generators. For electrical generation a total of 17.4 $m^3$ (4,600 gallons) of fuel storage is required to accommodate 10 days of diesel fuel endurance. Pilot fuel for the Wärtsilä duel fuel engine will add 2.6 $m^3$ (700 gallons) to the 10 day endurance requirement. The two diesel day tanks in the existing design have a 95% capacity of 22.9 $m^3$ (6,048 gallons). The two existing day tanks have enough capacity to support 10 days of diesel fuel endurance. The existing transfer piping and pumps, purification system, and supply piping will need to be resized based on the final propulsion engine and generator selections.

The existing design had two additional diesel fuel storage tanks, the port tank is sized at 151.8 $m^3$ (40,100 gallons) and the starboard tank is sized at 87 $m^3$ (23,000 gallons). If additional diesel fuel capacity is desired these tanks could be segregated to store as much fuel as desired. If these existing tanks are not used, removal of the unused tank structure should be investigated to reduce construction cost. Removal of tank structure was not investigated in this report.

## 3.5 Hot Water Heat System

The glycol system used to vaporize and heat the LNG will be served from the existing designs hot water heat system. The glycol system heat exchangers will be served by a new branch of the hot water system that will originate at the hot water manifold in the machinery space and will be routed up the exhaust casing to the upper deck.

In the current vessel design, the hot water system provides the heat for the HVAC, hot domestic water, and various other heating demands. The current estimated design demand on the hot water system at the design condition as given in Reference 9 is 1,235 kW. The LNG vaporizer and heater will require approximately an additional 270 kW for the Rolls Royce system and 476 kW for the Wärtsilä system at rated engine power. It has been assumed that the vaporization energy for the gas system will vary directly with the engine output but the hot water heating demand will be constant.

The current hot water system utilizes waste heat from the high temperature jacket water circuit of the main engines. The waste heat is supplemented by an oil fired water heater and electric water heater. With the additional demand of the gas system, the engines do not generate enough waste heat in the high temperature cooling circuits to meet the all the demands at the design condition. The oil fired hot water heater will need to be used at times of peak heating demand or low engine loads to supplement the waste heat system. Table 10 tabulates the available waste heat from the high temperature jacket water circuits and the hot water demands.

**Table 10 Waste Heat**

| | Total Power (kW) | Total Heat Rejection (kW) | Hot Water Heat Demands (kW) | Gas System (kW) | Heat surplus (+) / Deficit (-) (kW) |
|---|---|---|---|---|---|
| **Bergen C26:33L9PG** | | | | | |
| MCR | 4400 | 1247 | -1235 | -270 | -258 |
| Transit | 3441 | 976 | -1235 | -211 | -471 |
| Docked | 379 | 107 | -1235 | -23 | -1151 |
| **Wärtsilä 34DF (Derated to 2300 kW)** | | | | | |
| MCR | 4600 | 1346 | -1235 | -490 | -379 |
| Transit | 3441 | 1007 | -1235 | -366 | -594 |
| Docked | 379 | 111 | -1235 | -40 | -1164 |

Wärtsilä has indicated that the glycol system can utilize waste heat from the low temperature (LT) cooling circuit. It may also be possible to utilize the LT circuit in the Rolls Royce system as well. Utilizing the LT circuit waste heat would reduce the deficit of waste heat during peak heating demand or low engine load. This would reduce the amount of heat required from the oil fired water heater or electric water heater. Utilizing the waste heat from the LT circuit should be further investigated in the detailed design once more specific engine and gas system performance information is available from the manufacturers.

In order for the existing hot water heat system to have the increased capacity to serve the glycol system on the Bridge Deck, some modifications will be necessary. The hot water heat system in the current design has a design temperature of 82°C (180°F) and a design flow rate of 104 $m^3$/hr (460 GPM). The system is configured with parallel primary and standby pumps each sized for 104 $m^3$/hr (460 GPM). It has been calculated that an additional 43 $m^3$/hr (190 GPM) of hot water will be required to serve the gas system for a total of 148 $m^3$/hr (650 GPM). We recommend that the two 104 $m^3$/hr (460 GPM) pumps be replaced with three 74 $m^3$/hr (325 GPM) pumps configured in parallel with one pump as a standby. In addition to changing the pumps, the waste heat recovery heat exchangers, oil heater, and electric heater will need to be resized for the increased flow rate and heat demands. A new hot water supply and return branch to the Bridge Deck will also need to be added from the supply and return manifolds in the engine room and the main system piping in the engine room will need to be increased from 5” to 6” diameter pipe.

## 3.6 Structure

The LNG storage tanks will be free standing tanks that will be mounted to the vessel through two main cradles that support the tanks at approximately the quarter points of each tank. Figure 9 depicts a typical LNG storage tank being lifted into a vessel. The cradles are welded to the outer shell of the tank. Because of the cryogenic nature of LNG, the tanks will experience thermal expansion and contraction. As a result, only one of the cradles is welded to the deck of the vessel. The other cradle is able to slide slightly to compensate for thermal expansion and contraction.

**Figure 9 Typical LNG Storage Tank**

The Bridge Deck and supporting structure was reviewed to determine the extent of modification required to support the LNG storage tanks. Both the single tank configuration and a double tank configuration were considered. Both configurations will require structural modifications however the extent of modifications for the single tank arrangement is greater. Figure 10 and Figure 11 depict the arrangement of tanks on the Bridge Deck structure.

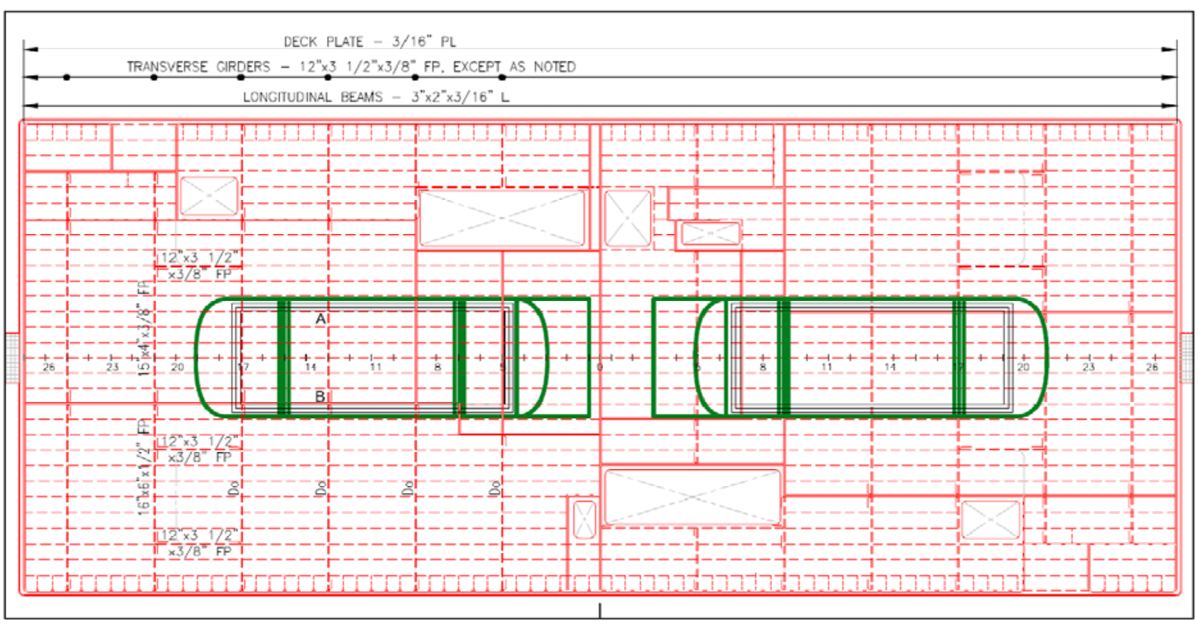


**Figure 10 Bridge Deck Structural Arrangement of Two Tanks**

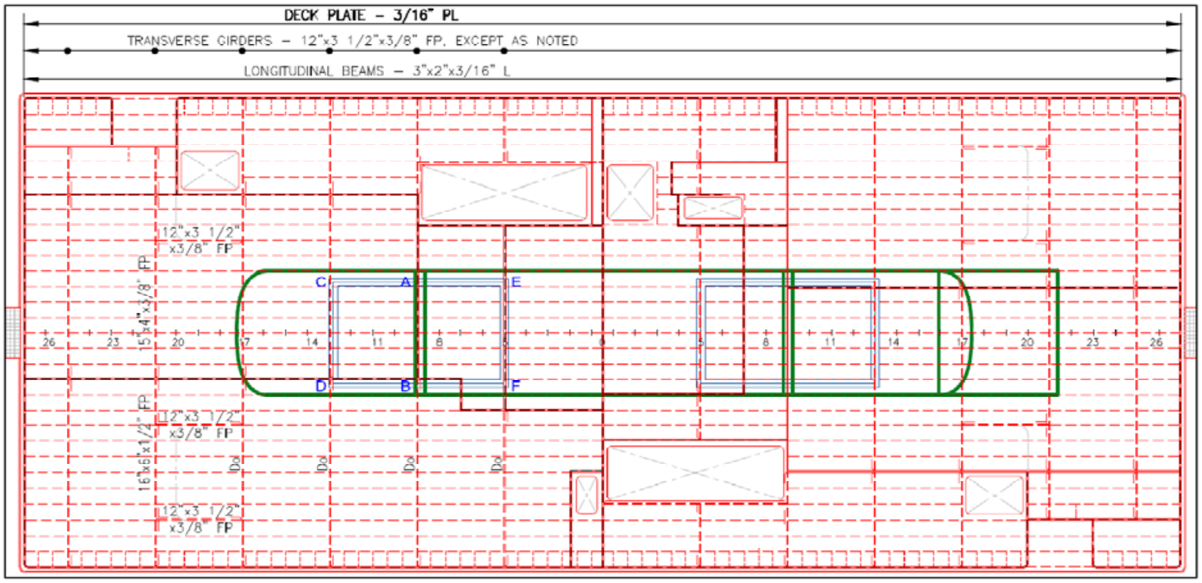


**Figure 11 Bridge Deck Structural Arrangement of Single Tank**

In order for the bridge deck to be able to support the loads imposed by the LNG tanks, the deck will need to be reinforced. It is recommended to build a skid made out of stiff I-beams (e.g. W10x100) to support the legs of the tanks and better distribute the loads to the bridge structure. The single tank configuration will require more reinforcement of the deck structure than the two tank configuration since the weight of the single tank will be transferred to the deck over a smaller area. Stanchions will have to be placed under the existing transverse girders of the deck and if the single tank option is adopted then the bulkheads in the way of the tank foundation will have to be redesigned for those loads using thicker plates and larger stiffeners. Additionally, the deck below (Sun Deck) needs to be analyzed to see if reinforcement is needed in order to support the loads of the stanchions above. Once a specific tank has been selected, a detailed design of the tank foundations will need to be done.

## 3.7 Doors and Openings

Openings to non hazardous spaces may not be located in a hazardous area unless they are fitted with an air lock. This may require that the spaces with access opening on the inboard side of the casings from the Bridge Deck may need to be relocated or fitted with an airlock. The extent of the effected openings will be dependent on the details of the arrangement of the gas piping system on the Bridge Deck. However, it is anticipated that no more than four opening will be affected.

# Section 4 Emissions

The engine emissions were analyzed to compare the relative air emissions of the existing diesel design and the Wärtsilä and Rolls Royce gas fuelled vessel designs. The purpose of this analysis was to help quantify the reduction in air emissions by converting the diesel fueled engines to gas fuel. Emissions from the ships service diesel generators were not considered for this analysis.

## 4.1 Route

The route chosen for the emissions analysis was not based on an actual route but rather on a route representing an average route. This operating profile was the same as the one used during the propulsion study for the 144-Car Ferry, Reference 3. Table 11 shows the operating profile assumed in the analysis.

**Table 11 Operating Profile**

| Power Requirements and Annual Operating Hours | | | | | | | |
|---|---|---|---|---|---|---|---|
| Condition | Engine Power | No Engines | Total Power | | Hours | Operating | |
| | kW | | kW | HP | | kWh/year | HPh/year |
| Transit | 1,721 | 2 | 3,441 | 4,614 | 3,000 | 10,323,000 | 13,842,000 |
| Maneuvering | 391 | 2 | 781 | 1,047 | 1,000 | 781,000 | 1,047,000 |
| Docked | 190 | 2 | 379 | 508 | 2,000 | 758,000 | 1,016,000 |
| Total | | | | | 6,000 | 11,862,000 | 15,905,000 |

## 4.2 Methodology

The emissions for each of the engines was computed for a year based on the operating profile, see Table 11. The required engine power was converted to a percentage of MCR and the corresponding specific emissions in grams/kilowatt-hour were determined from vendor data for each of the components of the exhaust gas. The specific emissions were multiplied by the total yearly kilowatt-hours for each operating condition then summed to determine to component emissions for the year.

Sulfur oxide ($SO_x$) emissions are only dependant on the sulfur content of the diesel fuel and the overall engine diesel consumption. An Ultra Low Sulfur Diesel (ULSD) fuel with a sulfur content of 15 parts per million was assumed for this analysis. $SO_x$ emissions are converted and reported as SO2.

## 4.3 Discussion

The results of the analysis are summarized the Table 12 and in Figure 12 through Figure 17.

Nitrogen oxides ($NO_x$) are generated when nitrogen reacts with oxygen at high temperatures and pressures. In general gas engines run at lower temperatures and pressures and lower $NO_x$ emissions would be expected.

Particulate matter (PM) and Sulfur dioxide ($SO_2$) emissions vary linearly with the quantity of diesel used. The EMD engine uses the most diesel followed by the Wärtsilä dual fuel engine and the Bergen uses no diesel. The emissions results agree with this.

Carbon monoxide (CO) is a product of incomplete fuel ignition. The higher CO emissions in the gas engines show less efficient combustion.

Carbon dioxide ($CO_2$) is a result of combustion and is proportional to the amount of energy consumed. Specific $CO_2$ emissions were not available for the EMD engine and are not shown in the chart or graphs. It is expected that the $CO_2$ emissions for EMD would be similar to although slightly higher than the gas engines.

Methane is generated in gas fuelled engine emissions when methane is left unburned in the cylinder after ignition. This unburned gas is expelled with the exhaust and contributes to the engine emissions. The diesel engines also produce a small amount of methane as a combustion byproduct. At the time of this report the specific methane emissions for the Wärtsilä engine were not available. However Wärtsilä indicated that the total hydrocarbon emissions are less than 6 g/kW-hr and that non methane hydrocarbon emissions were 1 g/kW-hr. Based on this information, the methane emissions for the Wärtsilä engine were assumed to be 5 g/kW-hr.

Non methane hydrocarbons (NMHC) are a result of unburned hydrocarbons in the exhaust gas.

The Global Warming Potential of the three engines over their lifecycle was not calculated in this report. The Global Warming Potential is a relative measure of how much heat a greenhouse gas traps in the atmosphere. If the $CO_2$ emissions are lower for the gas engines the methane emissions will offset them somewhat. Methane is a more powerful global warming gas than $CO_2$ by roughly 25 times over a 100 year period. It is expected that switching to gas engines will not have a significant impact one way or another in the vessel's overall Global Warming Potential.

**Table 12 Emissions Comparison**

| Emission | Wärtsilä | Rolls Royce | EMD |
|---|---|---|---|
| NOx (ton) | 24.7 | 15.7 | 89.0 |
| SO2 (ton) | 0.01 | none | 0.77 |
| CO (ton) | 41.3 | 20.0 | 3.4 |
| CO2 (ton) | 6,415 | 6,203 | 7,980 |
| PM (ton) | 1.13 | none | 2.33 |
| Methane (ton) | 65.38 | 59.2 | 0.32 |
| NMHC (ton) | 1,708 | not provided | 3.71 |

*ton = 2,0000 lbs

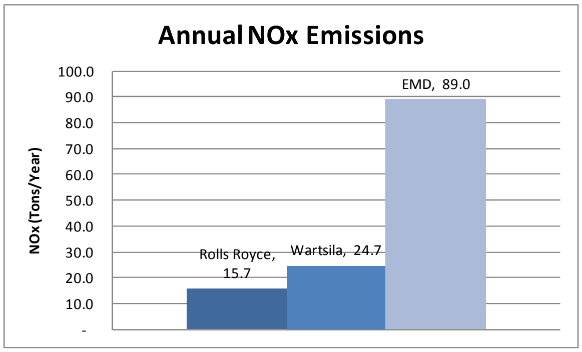


Figure 12 Annual NOx Emissions

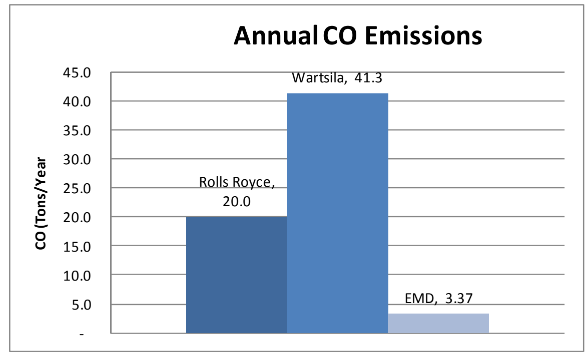


Figure 13Annual CO Emissions

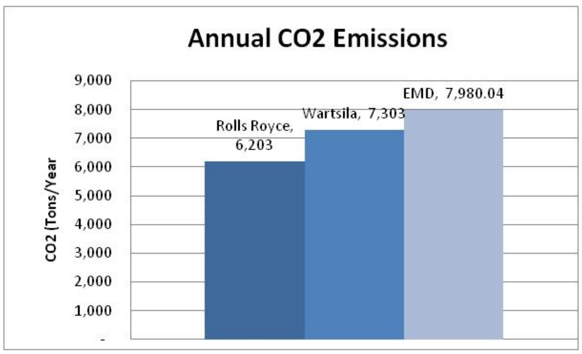


Figure 14 Annual CO2 Emissions

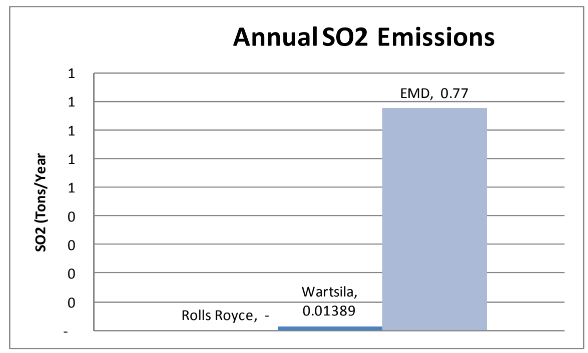


Figure 15 Annual SO2 Emissions

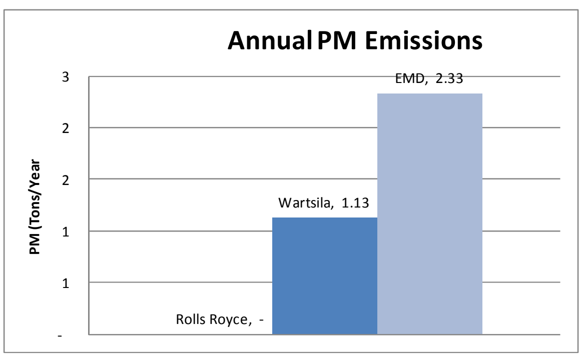


Figure 16 Annual PM Emissions

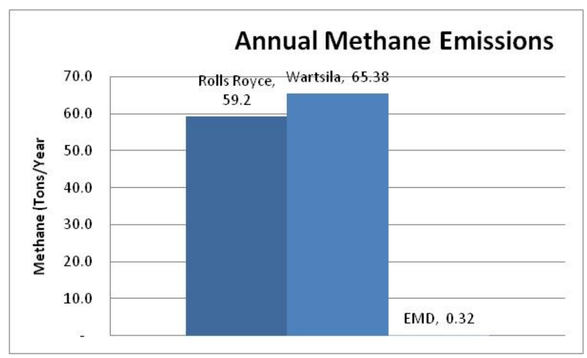


Figure 17 Annual Methane Emissions

*Ton = 2,000 lbs

# Section 5 Conclusions

This report has discussed the design of both a single fuel gas system provided by Rolls Royce and a dual fuel gas system provided by Wärtsilä. From a technical standpoint, both systems appear to be feasible to implement in the 144-Car Ferry design without any high risk impacts to the existing vessel design.

There are however, some significant changes to the design that will need to be considered. The detailed design and installation of the engines, engine foundations, gears, gas system, gas piping and gas system ventilation, and ancillary equipment will require effort. Additionally, the structure of the Bridge Deck will need to be reviewed and reinforced. The locations of the ventilation intakes and exhausts and openings to spaces in the casing will need to be reviewed and possibly modified. Several systems will require modifications including the control system, sprinkler system, hot water system, ventilation systems, and compressed air system. None of these additions or modifications, however, presents a substantial risk to the feasibility of the design.

The main focus of this study was the use of gas fuelled engines for propulsion, however ship service power generation was also considered. Gas fuelled generators were not considered due to a lack of availability. Depending on the timeframe in which additional development of the gas fuelled ferries is done, it may be worth reconsidering gas fueled generators if additional equipment becomes available. Shaft generators were considered and this concept has merit but unfortunately not enough detailed information was available to develop the concept. It is recommended that shaft generators be revisited as an option for ship service power once more information is available.

An analysis of the emissions was conducted for the two gas engines and the currently designed diesel engine. Methane emissions are increased by switching to gas. Overall $CO_2$ equivalent emissions are not expected to be reduced considerably. The Global Warming Potential of the ship is not expected to be impacted significantly by switching to gas engines. Significant reductions in $SO_x$, $NO_x$, and PM are achieved by switching from diesel to natural gas. These three gasses contribute to local air pollution and reducing them significantly should be a benefit to local air quality.

Neither the Wärtsilä system nor the Rolls Royce system has clear technical superiority. Both systems have some advantages and disadvantages. The Rolls Royce system has slightly better fuel consumption and engine response. The Wärtsilä system has more flexibility because it is dual fuel and it only requires a single storage tank. Neither system has any deficiency that makes it unsuitable for application in the 144-Car Ferry, and selection will come down to a combination of owner preference of operating characteristics, emissions, and capital and lifecycle cost (Costs are discussed separately in The Glosten Associates, Inc., Report *144-Car Ferry LNG Fuel Conversion Feasibility Study: Life Cycle Cost, reference 16*).

# Appendix A Faults and Effects Table

| Fault/Action | Alarms | Response | DNV Rule | IMO Resolution MSC.285(86) | Notes |
|---|---|---|---|---|---|
| Gas detection in Tank Room above 20% LEL | yes | none | 6/B401 | Table 1 Chap V | |
| Gas detection on 2nd detector in Tank Room above 20% LEL | yes | Automatic shutdown of main tank valve | 6/B401 | | |
| Gas detection on 2 detectors in Tank Room above 40% LEL | yes | Automatic shutdown of main tank valve | | Table 1 Chap V | |
| Fire detection in tank room | yes | Automatic shutdown of main tank valve, ventilation of space shall stop, fire damper shall close | 6/B401 | Table 1 Chap V | |
| Bilge well high level in tank room | yes | none | 6/B401 | Table 1 Chap V | |
| Bilge well low temperature in tank room | yes | Automatic shutdown of tank valve | 6/B401 | Table 1 Chap V | |
| Gas detection in duct between tank and engine room above 20% LEL | yes | none | 6/B401 | Table 1 Chap V | |
| Gas detection on second detector in duct between tank and engine room above 20% LEL | yes | Automatic shutdown of master gas valve to effected pipe | 6/B401 | | |
| | | Double block and bleed valve to close and vent | 3/E104 | | |
| | | Automatic open vent valve to gas supply between master gas valve and double block & bleed valve. | 3/E105 | | |
| Gas detection on 2 detectors in duct between tank and engine room above 40% LEL | yes | Automatic shutdown of master gas valve to mach. space containing gas engine | | Table 1 Chap V | |
| | | Double block and bleed valve to close and vent | | 5.6.3 | |
| | | Automatic open vent valve downstream of double block & bleed valve. | | 5.6.4 | |
| Gas detection in duct inside engine room above 30% LEL | yes | none | 6/B401 | Table 1 Chap V | |
| Gas detection in duct inside engine room above 60% LEL | yes | Automatic shutdown of master gas valve. | 6/B401 | | |
| | | Double block and bleed valve to close and vent | 3/E104 | | |
| | | Automatic open vent valve to gas supply between master gas valve and double block & bleed valve. | 3/E105 | | |
| Gas detection on 2 detectors in duct inside engine room above 40% LEL | yes | Automatic shutdown of master gas valve. | | Table 1 Chap V | |
| | | close and vent | | 5.6.3 | |
| | | Automatic open vent valve downstream of double block & bleed valve. | | 5.6.4 | |
| Gas detection in engine room above 20% LEL | yes | none | 6/B401 | Table 1 Chap V | Only required if duct intakes air from engine room |
| Gas detection on second detector in engine room above 20% LEL | yes | Automatic shutdown of master gas valve. | 6/B401 | | Only required if duct intakes air from engine |
| | | Double block and bleed valve to close and vent | 3/E104 | | |
| | | Automatic open vent valve to gas supply between master gas valve and double block & bleed valve. | 3/E105 | | |

| Fault/Action | Alarms | Response | DNV Rule | IMO Resolution MSC.285(86) | Notes |
|---|---|---|---|---|---|
| | | Automatic shutdown of master gas valve. | | Table 1 Chap V | Only required if duct intakes air from engine |
| | | Double block and bleed valve to close and vent | | 5.6.3 | |
| Gas detection on 2 detectors in engine room above 40% LEL | yes | Automatic open vent valve downstream of double block & bleed valve. | | 5.6.4 | |
| Loss of ventilation in duct between tank and engine Room | yes | Automatic shutdown of master gas valve. | 6/B401 | | Master Gas Valve is not shut down for single fuel engine |
| Loss of ventilation in duct between tank and engine Room | yes | Automatic shutdown of master gas valve. | | Table 1 Chap V | Master Gas Valve is not shut down for single fuel engine |
| | | Automatic shutdown of master gas valve. | 6/B401 | Table 1 Chap V | |
| | | Double block and bleed valve to close and vent | 3/E104 | 5.6.3 | |
| | | Automatic open vent valve to gas supply between master gas valve and double block & bleed valve. | 3/E105 | | |
| Fire detection in engine room | yes | Automatic open vent valve downstream of double block & bleed valve. | | 5.6.4 | |
| Abnormal gas pressure in supply pipe | yes | none | 6/B401 | Table 1 Chap V | shut down for single fuel engine |
| Failure of valve control actuating medium | yes | Close double block and bleed valve | 6/B401 | Table 1 Chap V | Time delayed as found necessary |
| Automatic shutdown of engine (engine failure) | yes | Close double block and bleed valve | 6/B401 | Table 1 Chap V | |
| | | Automatic shutdown of master gas valve. | 6/B401 | Table 1 Chap V | |
| | | Double block and bleed valve to close and vent | 3/E104 | 5.6.3 | |
| | | Automatic open vent valve to gas supply between master gas valve and double block & bleed valve. | 3/E105 | | |
| Emergency shutdown of engine manually released | yes | Automatic open vent valve downstream of double block & bleed valve. | | 5.6.4 | |
| Any loss of required ventilation capacity | yes | none | 6/B501 | 2.10.1.3 | Alarm shall sound at permanently manned location |
| Loss of ventilation in duct around bunkering line | yes | none | 6/B502 | 2.9.2.3 | Alarm shall sound at bunkering control location |
| Full stop of ventilation in an engine room | yes | Engine in room with ventilation loss shall be shut down | 6/B503 | 5.6.7 | Engine only to be shut down if 40% propulsion power is available from other engine |
| Gas detection in bunkering line ventilation | yes | none | 6/C105 | 2.9.2.4 | Audible and Visual alarm at the bunker station |

# Appendix B DNV Classification Comments

Det Norske Veritas

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| Your ref.: | Our ref.: | Date: |
|---|---|---|
| | NACNO385/GRIMS/29 Other-J-11524 | 2011-06-06 |

## WSF LNG Ferry Concept Review

Reference is made to your letter dated 2011-05-18. The following documents are reviewed 2011-06-06 and given the status as shown:

| Drawing No. | Rev. | DNV No. | Title | Code | Status |
|---|---|---|---|---|---|
| 11030.01 | 16 May 2011 | 2081 | Regulatory Review of Concept, including appendices A, B and C | | Examined w/comm |
| 11030-500-01 | P1 | 2082 | Piping Arrangement -Concept Regulatory Review (9 sheets) | | Examined |
| | | 2083 | General arrangement model -Concept Regulatory Review | | Examined |

| | | Status |
|---|---|---|
| Drawing No. 11030.01/16 May 2011, "Regulatory Review of Concept, including appendices A, B and C" is examined for compliance with DNV Rules Pt.6 Ch.13, with the following comments: | | |
| 146 | Refer to Appendix A, index #32: Please note that if the vacuum insulated pipes have flanges inside the ventilated duct, the flanges will need to be protected to avoid risk of liquid spill onto normal ship steel. If the piping system however has no flanges inside the ventilated outer duct, the vacuum insulation is accepted as a means to protect the duct from spill. | For Inf. |
| 147 | Refer to Appendix A, index #51: We can accept the location of the bunkering pipes less than 760 mm from the ship side as described in the documentation. | For Inf. |
| 148 | Refer to Appendix A, index #55: Please be informed that knock out drums are normally not needed for natural gas systems. | For Inf. |
| 149 | Refer to Appendix A, index #82: We note that the ventilated duct for the gas pipes inside the engine room are combined with the duct outside of the engine | For Inf. |

room. Since the ventilation air for the double duct in the engine room is taken from the engine room, it must be assured that a gas leakage in the duct outside the engine room can not flow to the engine room. Such a common ventilated duct can be accepted for the engine room gas pipes and for the part of the gas supply pipes between the tank room and the engine room, but this duct should not also contain bunkering pipes.

150 Refer to Appendix A, index #137: Please be informed that the requirement for redundant ventilation fans in Rules Pt.6 Ch.13 Sec.3 I 403 should not be made applicable for inherently safe engine rooms. It is however applicable to the ventilation system for the double gas duct in such an engine room. For Inf.

151 Refer to Appendix A, index #144/145: Please note that in addition to the requirements in Rules Pt.6 Ch.13 Sec.3 J100 for the nitrogen installation spaces, there are also requirements to the nitrogen system, if the nitrogen installation is in a gas safe space: For Inf.

1. To prevent the return of flammable gas to any gas safe spaces, the inert gas supply line shall be fitted with two shutoff valves in series with a venting valve in between (double block and bleed valves). In addition a closable non-return valve shall be installed between the double block and bleed arrangement and the cargo tank.
These valves shall be located outside non-hazardous spaces and must function under all normal conditions of trim, list and motion of the ship.
The following conditions apply:
a) The operation of the valves shall be automatically executed.
Signals for opening and closing shall be taken from the process directly, e.g. inert gas flow or differential pressure.
b) An alarm for faulty operation of the valves shall be provided.

2. Where the connections to the gas piping systems are non-permanent, two non-return valves may substitute the non-return devices required above.

152 Refer to Appendix A, index #153: The arrangement of the bunkering station as described and shown in documentation is found to be acceptable. For Inf.

153 Refer to Appendix A, index #242: In the next rule revision we will include the option for engine manufacturers to document that starting, stopping and low load operation on gas is possible. For Inf.

154 Refer to Appendix A, index #172: Please be informed that the dry powder extinguishers outside engine rooms are not required for natural gas fuelled ships, as the natural gas is lighter than air. For Inf.

155 Refer to Appendix C, first item on second page: Please be informed that DNV does not require shut down actions connected to the gas detection in inherently safe engine rooms, only alarm. For Inf.

**Status**

Drawing No. 11030-500-01/P1, "Piping Arrangement -Concept Regulatory Review (9 sheets)" is examined for compliance with DNV Rules Pt.6 Ch.13

Drawing No. (empty), "General arrangement model-Concept Regulatory Review" is examined for compliance with Rules Pt.6 Ch.13 **Status**

Yours faithfully
for Det Norske Veritas AS

Øivin Lorentzen
Head of Section
Cargo Handling and Piping Systems

Torill Grimstad Osberg
Contact Person

Copy To: Tony Teo; Nick Roper

# Appendix C USCG Regulatory Comments

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

Commandant
United States Coast Guard

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2011-2906
16715
July 1, 2011

Captain George A. Capacci
Deputy Chief, Operations and Construction
Washington State Ferries
2901 3rd Avenue, Suite 500
Seattle, WA 98121-3014

Dear Mr. Capacci:

Thank you for your June 2, 2011 letter concerning the use of Liquefied Natural Gas (LNG) as a propulsion fuel on passenger ferries in Puget Sound. In conjunction with your letter, we received a package from Glosten Associates, dated May 16, 2011, presenting a design concept for an LNG fueled propulsion system on the new 144-car ferry class you describe in your letter. Having reviewed and discussed the proposal with Glosten Associates, we have prepared the following response which will serve as a regulatory design basis should you choose to move forward with the LNG-fueled 144-car ferry project.

Once an application for inspection is filed with the Officer in Charge, Marine Inspection (OCMI), all required plans should be forwarded to the Marine Safety Center (MSC) for plan review. The MSC will use this regulatory design basis letter and applicable regulations and standards to complete plan review. Please note that due to your proposed use of LNG fueled propulsion systems, MSC may identify additional detailed design requirements in areas not addressed in this regulatory design basis agreement during the course of plan review. As always, the OCMI may impose additional requirements, should inspection during construction reveal the need for further safety measures or changes in construction or arrangement.

The 144-car ferry class vessels will be certificated under 46 CFR Subchapter H and must meet the applicable requirements in 46 CFR Subchapters F and J. However, as these subchapters do not address LNG fueled propulsion systems, from Glosten Associates' submission, we understand the proposed design would instead comply with IMO Resolution MSC.285(86), Interim Guidelines on Safety for Natural Gas-Fuelled Engine Installations in Ships. Glosten Associates requested clarification from the Coast Guard on how the guidelines will be applied for this application, with special emphasis on major areas listed in the executive summary of their submission.

We accept the use of the IMO Interim Guidelines subject to the additional requirements in this letter, which serves as the design basis for the LNG-fueled 144-car ferries. For any issues not specifically addressed by the IMO Interim Guidelines as modified by this letter, 46 CFR Subchapters F, H and J will apply. Clarification on the major areas Glosten Associates listed in the executive summary of their submission is provided below in the context of the IMO Interim Guidelines. The definition of "open gas sources" is addressed in item 1; the location, fire protection and isolation of bunkering stations are addressed in items 4, 6 and 11; the location of ventilation supply for gas supply piping ducts is addressed in item 7; and ventilation of the tank room is addressed in item 9.

**Design Basis**

The design of the gas-fueled propulsion system shall meet the requirements of IMO Resolution MSC.285(86) (Jun 1, 2009), except as modified below. For ease of reference, each comment is preceded by the applicable cite from IMO Resolution MSC.285(86).

1. **Section 2.1.3** For the purposes of Section 2.1.3, the term "open gas sources" has the same meaning as "source of release" defined in paragraph 1.3.32: "Source of release means any valve, detachable pipe joint, pipe packing, compressor or pump seal in the gas fuel system." This would not apply to double-wall piping systems that meet the arrangements in 2.7.1.1 or 2.9.3.1.

2. **Section 2.2** In addition to IMO Resolution MSC.285(86) section 2.2, piping for natural gas fuel must meet requirements in 46 CFR 56.60. Materials for low temperature piping (below 0 degrees F) must meet the requirements of 46 CFR 56.50-105(a)(1).

3. **Section 2.5.4** In addition to the requirements of section 2.5.4, the wall thickness of pipes must be calculated using the ASME Code for Pressure Piping (ASME B31.1-2001). This requirement does not apply to the outer wall of required double wall piping systems.

4. **Section 2.5.16** The bunkering stations and associated gas piping may be located less than 760 mm from the ship's side as proposed. This allowance is based on the piping design providing sufficient flexibility to prevent collision damage to a bunkering station from propagating to the tank connection. You must provide sufficient information to demonstrate this to the Marine Safety Center and the OCMI.

5. **Section 2.8.1** In addition to the requirements of section 2.8.1, IGC Code independent tanks used to store liquefied natural gas must either:
   a. Meet 46 CFR 154.401 through 154.476 as applicable; or
   b. Meet ASME Boiler and Pressure Vessel Code (2010), Section VIII, Division 1 or 2 if the tank is a type C independent tank.

6. **Section 2.9.1.1** We understand from Glosten Associates' proposal that bunkering will be conducted after the last run of the day and before the first run of the next day when passengers or vehicles are not onboard. These operational controls satisfy Section 2.9.1.1 provided the vessel's Certificate of Inspection (COI) has an operational restriction that at a minimum states LNG bunkering operations are not allowed while vehicles or passengers are on the vehicle deck (note: bunkering operations are not considered complete until bunkering lines are inerted per Section 2.9.2). Please note: At this time the OCMI has indicated that vehicles and passengers will not be permitted on board the ferry during bunkering.

7. **Section 2.9.3.4** Ventilation for the gas fuel supply line ducting may be drawn from the engine room provided the engine room is fitted with gas detection as required in 3/D302 of the DNV Rules for Gas Fuelled Engine Installations (Jan, 2010) as proposed by Glosten Associates. The applicable safety functions listed in Section 6, Table B3, of DNV Rules for Gas Fuelled Engine Installations must be

followed, and the detection system must meet the additional conditions listed in comments for Section 5.5 below.

8. **Section 2.10.1** The following requirements are in addition to those in Section 2.10.1:
   a. A ventilation system must:
      (1) Not recycle vapor from ventilation discharges;
      (2) Have its operational controls outside the ventilated space, if the system is mechanical; and
      (3) Have a protective metal screen of not more than 13 mm (0.512 in.) square mesh on each ventilation intake and exhaust.
   b. Where artificial ventilation is applied to spaces which are not separated by gastight boundaries, underpressure must be maintained in the hazardous enclosed spaces in relation to the less hazardous spaces, and an over-pressure must be maintained in the non-hazardous enclosed spaces in relation to the adjacent hazardous spaces.

9. **Section 2.10.2.1** For any alternate installation to be considered, you must submit a safety analysis to the MSC demonstrating that the arrangement provides a level of safety equivalent to the requirements in Section 2.10.2.1.

10. **Section 2.10.2.2** The automatic fail-safe fire dampers must be type approved by this office.

11. **Section 3.2.4** Your proposed arrangement, which provides no physical boundary separating the bunkering stations from adjacent vehicle spaces, is accepted contingent on operational restrictions mandated by the OCMI as discussed in item 6 above.

12. **Section 3.3.2** Where water spray systems are used:
   a. Coverage for on-deck storage must include all exposed parts of the gas storage tank(s) located above deck and boundaries of the superstructures, compressor rooms, pump rooms, cargo control rooms, and any other normally occupied deck houses that face the storage tank.
   b. Each pipe, fitting, and valve must meet 46 CFR Part 56.
   c. Water spray nozzles are not required to be type approved by the Coast Guard.
   d. On vertical surfaces credit may be taken for rundown if the nozzles are spaced no more than 12 feet (3.7 m) apart vertically.
   e. The coverage of nozzles protecting valves, piping and manifolds must extend at least 19 inches (0.5 m) in each direction, past the protected fittings or to the area of the drip tray, whichever is greater.
   f. The main fire pumps may be used to supply the system if they are capable of providing the required flow for both systems. The water supply for the water spray system must be adequate to supply all nozzles simultaneously.
   g. Controls to remotely start pumps supplying the water spray system and operate any normally closed valves to the systems must be located in a readily accessible position which is not likely to be cut off in case of fire in the protected areas and be outside of the protected area.
   h. Each water spray system must have a means of drainage to prevent corrosion of the system and freezing of accumulated water in subfreezing temperatures.
   i. Final installation and arrangement of the water spray system shall be to the satisfaction of the OCMI.

13. **Section 3.3.3** Where dry chemical powder fire extinguishing systems are installed as required by IMO Resolution MSC.285(86) Section 3.3.3 the system must consist of at least one hand hose line unit that:

a. Is listed for fire service by a nationally recognized testing laboratory, as defined in 29 CFR 1910.7;
b. Meets the requirements of 46 CFR 154.1155 and 154.1165 – 154.1170; and
c. Meets the requirement of MSC.1/Circ.1315 (10 June 2009).

*Note: There are no dry chemical powder fire extinguishing systems currently approved by the Coast Guard, therefore detailed manufacturer's data and a maintenance manual for the system to be installed must be provided to MSC for review as part of the detailed plan review package.*

14. **Section 3.4.1** Instead of the requirements found in IMO Resolution MSC.285(86) Section 3.4.1, fire detection systems must:

a. Be provided in tank rooms.
b. Be provided in machinery spaces containing gas-fueled engines.
c. Be approved by the Commandant in accordance with 46 CFR 161.002 and installed in accordance with 46 CFR 76.27.
d. Have fire detection cables routed such that fire or flooding in one space will not affect the ability to detect fire in another space or fire zone; and
e. Provide heat detection in addition to any other forms of detection used for the protected space.

15. **Section 4.1** Hazardous locations must meet the following requirements in lieu of IMO Resolution MSC.285(86) Section 4.1. See comments under section 4.3 for classification of hazardous areas.

a. <u>General requirements</u>.
Electrical installations should not normally be in hazardous areas. Where necessary for operational purposes, the equipment must be located in the least hazardous area practicable.

b. <u>Equipment and Installation Standards</u>
Where electrical installations are in hazardous locations, they must comply with one of the standards listed in this paragraph, but not in combination in a manner that would compromise system integrity or safety:

(1) NEC 2011 (NFPA 70) Articles 500 through 504. Equipment identified for Class I locations must meet Sections 500.7 and 500.8 of the NFPA 70 and be tested and approved or certified by an independent laboratory accepted by the Coast Guard under 46 CFR Part 159, to the current version of any of the following standards:
(i) ANSI/UL 674, ANSI/UL 823, ANSI/UL 844, ANSI/UL 913, ANSI/UL 1203, ANSI/UL 2225, and/or UL 1604 (Division 2);
(ii) FM Class Number 3600, FM Class Number 3610, FM Class Number 3611, FM Class Number 3615, and/or FM Class Number 3620; or
(iii) CSA C22.2 Nos. 0-M91, 30-M1986, 157-92, and/or 213-M1987.
*Note: See Article 501.5 of the NEC for use of Zone equipment in Division designated spaces.*

(2) NEC 2011 (NFPA 70) Article 505. Equipment identified for Class I locations must meet Sections 505.7 and 505.9 of the NPFA 70 and be tested and approved or certified by an

independent laboratory accepted by the Coast Guard under 46 CFR Part 159, to the ANSI/ISA Series standards incorporated in NFPA 70.
*Note: See Article 505.9(c)(1) of the NEC for use of Division equipment in Zone designated spaces.*

(3) IEC 60092-502 Electrical Installations in Ships, Tankers – Special Features (1999), except the following:
   (i) Paragraph d, Cable and wiring, of this section, applies in lieu of Clause 7.3.1.
   (ii) Ventilation alone may not be used as a means for reducing the classification of a hazardous space as indicated in Clauses 4.1.4, 8.3, and 8.4.
   (iii) The hazardous areas defined below under comments for Section 4.3 (Definition of hazardous area zones) apply in lieu of Clause 4.4.
   (iv) Electrical apparatus in hazardous locations must meet one or the combination of current versions of IEC 60079-1, -2, -5, -6, -7, -11, -13, -15, -18 and/or -27 in lieu of Clause 6.5.
   (v) Equipment must be certified by an IECEx System Ex Certification Body (ExCB) accepted by the Coast Guard under 46 CFR 159.010 in lieu of Clause 6.3. Certification under the European Union's (EU) ATEX Directive (94/9/EC) is not acceptable.

*Note: IECEx System means an international certification system covering equipment that meets the requirements of the IEC 60079 series of standards. The IECEx system is comprised of an Ex Certification Body and an Ex Testing Laboratory that has been accepted into the IECEx System after satisfactory assessment of their competence to ISO/IEC Standard 17025, ISO/IEC Guide 65, IECEx rules of procedures, IECEx operational documents, and IECEx technical guidance documents as part of the IECEx assessment process.*

In addition to paragraph b(1) of this section, electrical equipment that complies with NFPA 496 is acceptable for installation in Class I, Divisions 1 and 2. When this standard is used, it does not need to be identified and marked by an independent laboratory. The MSC will evaluate equipment complying with this standard during plan review. It is normally considered acceptable if a manufacturer's certification of compliance is indicated on a material list or plan.

For the standards in paragraphs b(2) and b(3) of this section, the encapsulating compound of ANSI/ISA 60079-18 and IEC 60079-18 (Ex "ma") certified equipment for installation in Class I Special Division 1 (Zone 0) hazardous locations must be compatible with LNG.

c. Lighting Systems
Lighting circuits serving flameproof or explosion proof lighting fixtures in an enclosed hazardous space or room must:
(1) Have at least two lighting branch circuits;
(2) Be arranged so that there is light for relamping any deenergized lighting circuit;
(3) Not have the switch and overcurrent device within the space for those spaces containing explosion proof or flameproof lighting fixtures.
(4) Have a switch and overcurrent protective device that must open all ungrounded conductors of the circuit simultaneously.

d. Cable and wiring

(1) Cable and wiring in hazardous areas must comply with the cable construction and testing requirements of current versions of IEEE Std 1580 (2001); UL 1309; MIL-C-24640B; MIL-C-24643A, or IEC 60092-350 (2008)/IEC 60092-353 Amendment 1, Annex A (2001), including the respective flammability tests contained therein, and must be of a copper-stranded type.
(2) For intrinsically safe systems, the wiring methods must meet Sections 504.20 and 504.30 of NEC 2011.
(3) Conduit and cable seals and sealing methods must meet Clause 6.8 of API 14F (1999).
(4) Type MC cables, when used, must meet the requirements in 46 CFR 111.60-23.

16. **Section 4.3** In lieu of IMO Resolution MSC.285(86) Section 4.3, hazardous areas are defined as noted below.

a. **4.3.1 Hazardous area zone 0**
The following are Class I Special Division 1 (Zone 0) locations:
(1) Interiors of LNG or CNG tanks, and any pipework of pressure-relief or other venting systems for the LNG or CNG tanks.
(2) A LNG or CNG pump room or compressor room*.
(3) Areas on an open deck, or semi-enclosed spaces on open deck, within 0.5 meters of any natural gas pump room or compressor room entrance, and pump room ventilation inlet or outlet.
(4) An enclosed or semi-enclosed space having an opening into a Class I Special Division 1 (Zone 0).

*The following are additional requirements related to hazardous locations for natural gas pump and compressor rooms:
(i) Providing ventilation to re-classify enclosed hazardous areas containing devices handling natural gas fuel is not allowed. These installations must comply with Clauses 6.3.1.2 of API 500 (2002) and 6.6.1.2 of ANSI API RP 505 (2002).
(ii) Where fitted, natural gas fuel pump and compressor rooms shall be isolated from all sources of vapor ignition by gastight bulkheads. The gastight bulkhead between the pump room and the pump-engine compartment may be pierced by fixed lights, drive shaft and pump-engine control rods, provided that cable bulkhead penetrations are provided with the appropriate cable sealing fittings, and the shafts and rods are fitted with fixed oil reservoir gland seals, or pressure grease seals where they pass through the gastight bulkheads. Other types of positive pressure seals must be specially approved by the Commandant (CG-521). Access to LNG or CNG pump enclosed area or room must be from the open deck.
(iii) Fixed lights in natural gas fuel pump and compressor rooms or enclosed areas must meet the arrangement and construction requirements in 46 CFR 111.105-31(g).
(iv) A natural gas fuel handling area or room that precludes the lighting arrangement of paragraph (iii) of this section, or where the lighting arrangement of paragraph (iii) of this section does not give the required light, must have explosion proof, flameproof (Ex "d") or flameproof-increased safety (Ex "de") lighting fixtures.
(v) Gas fuel pumps and compressors must shut-down automatically when the quick-closing shut-off valves are closed as required under IMO Resolution MSC.285(86) Section 5.6.

b. **4.3.2 Hazardous area zone 1**
The following are Class I Division 1 (Zone 1) locations:
(1) A tank room.
(2) A zone on the weather deck or a semi-enclosed space on the weather deck within 3.0 m (10 feet) of any LNG or CNG tank outlet, gas or vapor outlet, gas fuel pipe flange, valve, manifold, and machinery room ventilation hood or gas fuel piping ventilated pipe or duct outlet.
(3) Areas on an open deck, or semi-enclosed spaces on open deck, 1.0 meter beyond the areas in item (3) of the Class I Special Division 1 (Zone 0) locations listed above.
(4) Areas on the open deck within spillage coamings surrounding gas bunker manifold valves and 3 meters beyond these, up to a height of 2.4 meters above the deck.
(5) An enclosed space or semi-enclosed space having an opening into any Class I Division 1 (Zone 1).

c. **4.3.3 Hazardous area zone 2**
The following are Class I Division 2 (Zone 2) locations:
(1) Enclosed or semi-enclosed spaces, immediately above the tank room (for example between decks) or having bulkheads above and in line with gas-fuel tank room bulkheads.
(2) A zone on the weather deck or a semi-enclosed space on the weather deck within 1.5 m (5 ft) of the areas in items (2) through (4) of the Class I Division 1 (Zone 1) locations listed above.
(3) A zone within 2.4 m (8 ft) of the outer surface of a LNG or CNG tank where the surface is exposed to the weather.
(4) An enclosed space that shares a boundary with a tank room.

17. **Section 5.5** Gas detection systems must meet the following requirements in addition to IMO Resolution MSC.285(86) Section 5.5:

a. Portable Gas Detectors
Each vessel must have at least two portable gas detectors meeting the applicable equipment testing standards listed under paragraph f below.

b. Gas detector certification
All gas detection systems, including associated devices, and portable detectors must be certified by an independent laboratory accepted by the Coast Guard under 46 CFR Part 159, as meeting the requirements of 46 CFR 113.15-30 and certified for use in the appropriate hazardous area classification as described in 46 CFR 111.105. Where the fire and gas detection systems are combined, the system must also comply with 46 CFR 161.002.

c. Plan Submittal

In addition to the submission of typical new construction drawings, including such drawings reflecting the installation of an LNG fueled propulsion system, he following gas detection system plans must be submitted for review in accordance with 46 CFR 110.25-3:

(1) Arrangement and layout of system;
(2) Operational description of system;
(3) System block diagrams;
(4) User manual(s);
(5) Power supply arrangements;
(6) Equipment list;
(7) Circuit diagrams; and
(8) Independent laboratory certification and applicable test reports of the gas detection system.

d. Functional requirements for gas detection systems

(1) Gas detection systems must 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 must have an indicator panel in each wheelhouse.
(2) Gas detection cables must be routed such that a fire or flooding in one space will not affect the ability to detect gas in another space or zone.
(3) Gas detection system shall be designed such that failure of one component or sub-system will not unduly affect any other system, sub-system or component and, as far as practicable, shall be detectable.
(4) Safety function shall be independent of control and monitoring (alarm) functions.
(5) Must provide two sources of power. Main power and emergency power are to be supplied to the gas detection system(s) from independent cabling systems.
(6) Power supplies and electric circuits necessary for the operation of the system shall be designed with self-monitoring properties for the loss of power.
(7) Simultaneous activation of gas detectors shall not impair the operation of the system.
(8) Provision of portable gas detection devices will be to the OCMI's satisfaction.

e. Required standards, testing and certification for gas detection systems and portable detectors

Portable gas detection equipment must be suitably marked for use in the hazardous (classified) location. The gas detection equipment should be listed by an independent laboratory accepted by the Coast Guard under 46 CFR Part 159, as meeting the following requirements:

f. Equipment Testing Standards

(1) Fixed oxygen analysis and gas detection equipment
    IEC 60945 (2002)
    IEC 60533 (1999)
    IEC 60079-29-1 (2007)
(2) Portable oxygen analysis and gas detection equipment
    IEC 60945 (2002)
    IEC 60533 (1999)
    IEC 60079-29-1 (2007)
    IEC 60079-0 (2004)
    IEC 60079-1 (2007)

IEC 60079-10 (2002)
IEC 60079-11 (2006)
IEC 60079-15 (2005)
IEC 60079-26 (2006)

18. **Section 5.6** Table 1, in Section 5.6 Safety functions of gas supply systems, is replaced with the table included as enclosure (1) to this letter.

This design basis is applicable to the Glosten Associates' May 16, 2011 proposal for the new 144-car ferry class of vessels. Any major departure will require reevaluation by this office.

As mentioned in your letter, we anticipate receipt of a similar conceptual design package for your existing Issaquah Class ferries. Although the gas-fueled system proposal for the Issaquah Class may be similar, it will require a separate review to ensure any issues unique to its design are adequately addressed.

For further clarification on any of these issues, please feel free to contact Mr. Tim Meyers of my staff at (202) 372-1365.

Sincerely,

J. D. REYNOLDS
Commander, U.S. Coast Guard
Acting Chief, Office of Design and Engineering Standards
By direction

Encl: (1) Safety Functions of Gas Supply Systems

Copy: USCG Marine Safety Center (MSC-2)
USCG Sector Puget Sound
USCG Liquefied Gas Carrier National Center of Expertise
Glosten Associates