Recent Acceptance of Natural Gas as Fuel on U.S. Flag Vessels

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Abstract:

The use of natural gas as fuel onboard ships is a leading alternative for meeting current and future air emission requirements, including the limits for Emission Control Areas adopted in recent amendments to MARPOL Annex VI. Because of this, a number of companies have submitted design proposals to the U.S. Coast Guard for ships utilizing this fuel. The use of natural gas onboard ships does pose certain unique technical challenges due to its intrinsic properties that warrant careful consideration to ensure vessels are designed for safe operation.

The U.S. Coast Guard has conducted a systematic review of rules and guidelines concerning the design and construction of natural gas-fueled vessels. The International Gas Carrier Code and experience with liquefied natural gas (LNG) carriers form the basis of the Coast Guard's knowledge on gas-fueled engine arrangements. Additionally, specific attention has been given to the International Maritime Organization's Interim Guidelines on Gas-Fueled Ships, IMO Resolution MSC.285(86), as well as to the satisfactory service of existing applications.

Several important topics concerning design philosophy are discussed in this paper. They include: the use of inherently gas safe versus emergency shutdown concepts in system design, natural gas fuel tank location, considerations for hazardous locations, as well as the current review and approval process for U.S. natural gas-fueled vessel designs.

1. Background

Air pollution prevention requirements are driving the marine industry to seek advanced technologies to reduce the air emissions from ships. Many of the new air emission reduction systems being considered for use onboard vessels have been proven in land based applications, and are now being adapted to the marine environment. One such technology is the use of natural gas as fuel.

Although gas-fueled ships are not commonplace in the U.S., the use of natural gas as a transportation fuel is not new. Natural gas has been successfully used to power cars and busses in the U.S. for over twenty years. For over 45 years, liquefied natural gas (LNG) cargo ships have used cargo boil-off to fuel their propulsion boilers, and more recently in specially designed dual-fuel gas and diesel engines. Used as a transportation fuel, natural gas is stored as either LNG or compressed natural gas (CNG). When burned in internal combustion engines, it provides a significant reduction in air emissions compared to diesel fuel.

The U.S. Coast Guard has recently received numerous inquiries from vessel designers, operators, and engine manufacturers considering the use of this technology on commercial vessels. Interest in gas-fueled marine applications has spanned a full range of vessel types including passenger vessels, offshore supply vessels, container RO/RO ships, and towing vessels. With more stringent air emission reduction mandates on the horizon, and the proven performance of natural gas as a means of compliance, it is expected that the U.S. marine industry will continue its pursuit of natural gas as a marine fuel. In order to address this trend, the U.S. Coast Guard is reviewing concept proposals for vessel designs that incorporate this technology. Although existing U.S. regulations do not address natural gas fuel for vessels other than LNG cargo ships, such proposals are being reviewed on a case-by-case basis as equivalency requests to existing requirements under Title 46 of the Code of Federal Regulations (CFR).

2. Upcoming Air Emission Requirements - A Major Driver for Shifting to Natural Gas

Under Annex VI to the International Convention for the Prevention of Pollution from Ships (MARPOL), progressively more stringent limits for nitrogen oxide (NO_x) and sulfur oxide (SO_x) emissions are being placed on the global shipping industry over the next decade. Within the U.S., these requirements are implemented through the Act to Prevent Pollution from Ships (APPS)[i]. NO_x emissions limits are being imposed in a tiered approach based on engine speed, and SO_x is being limited primarily by regulating sulfur content in fuel. Details of these standards are shown in Tables 1 and 2.

Table 1. *NO_x Standard (g/kW-hr)*

NO_x Tier	Area of applicability	Model Year	Maximum in-use engine speed		
			Less than 130 RPM	130-2000 RPM	Over 2000 RPM
Tier 1	All U.S. navigable waters and EEZ	2004-2010	17.0	$45.0 * n^{-0.20}$	9.8
Tier 2	All U.S. navigable waters and EEZ	2011-2015	14.4	$44.0 * n^{-0.23}$	7.7
Tier 2	All U.S. navigable waters and EEZ, excluding ECA and ECA associated areas	2016 and later	14.4	$44.0 * n^{-0.23}$	7.7
Tier 3	ECA and ECA associated areas	2016 and later	3.4	$9.0 * n^{-0.20}$	2.0

n is maximum in-use engine speed, in RPM, rounded to one decimal place

Table 2. *Sulfur Standard in Fuel (max % by weight)*

Calendar years	Sulfur limit in all U.S. navigable waters and EEZ	Sulfur limit in ECA and ECA associated areas
2010-2011	4.50%	1.00%
2012-2015	3.50%	1.00%
2016-2019	3.50%	0.10%
2020 and later	0.50%	0.10%

The most stringent requirements come into play within Emission Control Areas (ECA) which encompass a 200 nautical mile band around most of North America and the Hawaiian Islands, and roughly 40-50 nautical miles around Puerto Rico and the U.S. Virgin Islands[ii] as depicted in Figure 1. Once fully in place, vessels operating within these areas will be subject to the most stringent emission requirements.

Several technologies are being considered to address these limits, including advanced diesel engine design, exhaust after-treatment, alternative fuels, and alternative power sources. One of the most promising methods for meeting the new emission standards is the use of natural gas as fuel. The conversion from burning diesel to natural gas within an internal combustion engine significantly reduces emissions. Some engine manufacturers report reductions as high as 85% for NO_x, and the total elimination of SO_x since natural gas does not contain sulfur.[iii] Accordingly, a gas-fueled engine can be compliant with even the strictest emissions requirements. Therefore, natural gas seems an ideal solution in meeting the increasingly stringent air emissions mandates, especially for those vessels operating within U.S. ECAs.

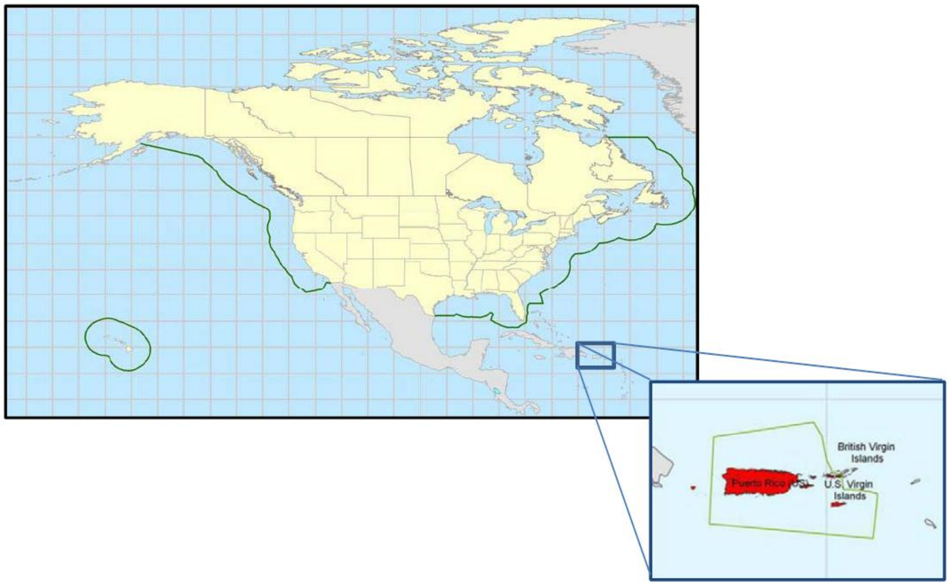

Figure 1. *North American and Caribbean Environmental Control Areas*

3. The Scandinavian Experience

Since 2000, Norway has authorized LNG fueled ships to operate within their waters. As a result, ship operators and regulators have acquired significant expertise and experience in the design, construction, operation, and inspection of these vessels. LNG has proven to be a viable fuel for coastal applications on a variety of ships and propulsion arrangements.

In the Scandinavian region, natural gas fuel systems have been installed on vessels ranging from small coast guard patrol vessels to larger offshore supply vessels. The engine designs vary; some engines are spark ignited, others use a diesel fuel pilot light, and some are dual-fuel engines that can operate on either natural gas or diesel fuel. The engineering plants are often natural gas electric hybrids; these are considered more efficient since they match power production with power demand.

In addition, Norway has created a reliable natural gas distribution system supplied from substantial offshore natural gas reserves. In general terms, the LNG distribution system is comprised of small-scale liquefaction facilities that use barges or trucks to fill pier-side storage tanks located near a vessel's berth. Vessels generally bunker at night without passengers onboard. Of course, the handling of cryogenic liquids does require specialized training and personal protective equipment; however, transferring LNG is a relatively simple process and has been done safely by implementing engineering and administrative safety controls.

The use of LNG has been economically viable in Norway for several reasons. One reason is that Norway taxes NO_x and CO_2 emissions. Natural gas produces much less NO_x and CO_2 compared to diesel, and therefore owners who use natural gas are taxed less. Also, natural gas is cheaper than diesel based on energy content, which provides substantial savings to the owner as well. However, there are certain limitations. One is that the capital and normal operating costs of an LNG fueled ship have tended to be higher than a conventional ship. Another limitation is that the energy density of LNG is about 60% of diesel, and the amount of space required to install LNG tanks and associated systems further reduces the amount of fuel that can be stored on a vessel. Essentially, the range of a vessel will be reduced if it uses LNG instead of diesel fuel, and will limit its applications to coastal zones. Due to its technical limitations, LNG is currently only economically viable for use on ferrys, coast guard vessels, offshore supply vessels, fishing vessels, and cargo ships engaged in short sea shipping.

Overall, Norway has found that the use of natural gas onboard ships is safe, reliable, and cost effective. Because of these factors, Norway has seen an increase in the use of natural gas as fuel and has experienced a corresponding reduction in air emissions from its maritime fleet.

4. Current International Safety Standards for Gas-Fueled Ships

The International Maritime Organization (IMO) is in the process of developing an International Code on safety for ships using natural gas and other low-flashpoint fuels. Work on this standard began in 2005. The Coast Guard is the primary U.S. representative to the IMO for all policy development, including the continued development of this new code. With the code still under development, it was decided that interim guidance was needed. As a result, in June of 2009 the IMO published Resolution MSC.285(86), Interim Guidelines on Safety for Natural Gas-Fuelled Engine Installations in Ships.

In addition to the IMO Interim Guidelines, several classification societies have published rules or guides for gas-fueled ships. Among them are Det Norske Veritas (DNV), Germanischer Lloyd (GL), and the American Bureau of Shipping (ABS). Each of these classification society standards are closely aligned with the IMO Interim Guidelines, and in some cases provide more comprehensive requirements.

5. Safety Considerations for U.S. Gas-Fueled Vessels

The U.S. Coast Guard is continually developing its knowledge, experience, and expertise in the use of natural gas as a marine fuel. The majority of the Coast Guard's experience is based on the development and application of the International Gas Carrier (IGC) Code to LNG carriers, and the Coast Guard's own domestic requirements for gas carriers in 46 CFR Part 154. The Coast Guard has been actively involved in the development of the IMO's Interim Guidelines on Safety for Natural Gas-Fuelled Ships, and the ongoing development of its IGF Code. The Coast Guard has also reviewed various class society rules on gas-fueled engine installations as well as conducted site visits onboard existing gas-fueled vessels to enhance awareness of how the current technology is being implemented.

The Coast Guard has recently reviewed and accepted several concept proposals for vessel designs that incorporate the use of LNG fuel systems. These concept reviews were conducted on a case-by-case basis where an equivalent level of safety was established to the requirements of existing regulations. So far, each of these designs incorporated the IMO Interim Guidelines as a baseline standard. The following discussion highlights some important issues to be considered in gas-fueled ship design, and provides some insight into the Coast Guard's approach in determining safety equivalency as it pertains to LNG fuel system designs.

Fuel System

Machinery Space Configuration

The IMO Interim Guidelines provide two basic design concepts for engineering plant arrangements on natural gas-fueled ships: the inherently gas safe concept, and the emergency shutdown (ESD) concept. Both designs employ safety strategies to mitigate the risks posed by running a natural gas distribution system within a machinery space.

For the inherently gas safe concept, machinery spaces are considered gas safe under all conditions. This arrangement requires natural gas fuel piping within engine room boundaries to be fitted in a gastight enclosure. This is accomplished by using double-walled pipe, or single walled piping within a gastight duct. The space between the inner pipe and outer pipe or duct must be either pressurized with inert gas, or ventilated. The machinery space is considered a non-hazardous area, and there are no restrictions placed on electrical equipment installations. This is very similar to the gas fuel distribution system on existing LNG carriers that use cargo boil-off as fuel.

For the ESD concept, machinery spaces are considered gas safe under normal conditions, but have the potential to become gas-dangerous spaces under certain abnormal conditions. This concept allows single-walled piping inside the engine room without an external gastight enclosure. In the event gas is detected at low levels within the space, all electrical equipment not certified safe for hazardous locations is automatically shut down. The ESD concept was developed at a time when engine manufacturers had yet to engineer a proper solution for fitting double-walled piping to the fuel manifolds on internal combustion engines. With current advances in technology this is no longer an issue for the majority of engine sizes. A significant element to the ESD concept is that it relies heavily on active safety measures. Specific concerns with this method are that gas detection sensors require careful upkeep and maintenance, and the automation systems that translate sensor signals into alarms and shutdowns contain multiple components that are subject to failure. This concept may require additional maintenance costs and further testing requirements.

Currently, the systems that have been accepted as meeting an equivalent level of safety to that of existing regulations have been of the inherently gas safe type.

Tank Placement

There is some debate among IMO members developing the IGF Code on the placement of fuel tanks below accommodation spaces, service spaces, and control stations. Although the current IMO Interim Guidelines do not prohibit this arrangement, it goes against the longstanding safety practice applied to gas carriers. Specifically, there is a clear separation between LNG storage tanks within the cargo block of the vessel, and other areas of the vessel not related to cargo operations. Concern is especially heightened in the case of a vessel carrying passengers.

It is recognized that the configuration of ship types other than gas tankers may not lend themselves to providing a well-defined area dedicated exclusively to storage and transfer of natural gas since the primary purpose of the vessel is not the carriage of this commodity. Acknowledging this, the IMO Interim Guidelines provide several layers of protection to address the additional risks presented when tanks are stored below deck or in an enclosed space or tank room. These include gas detection with associated alarms and shutdowns, continuous negative-pressure ventilation of the tank room at 30 air changes per hour, and liquid level and temperature monitoring systems in the tank room bilge. Additionally, the tank room is considered a Zone 1 hazardous space prohibiting the installation of non-certified electrical equipment, and tank room boundaries must be constructed of cold-resistant material and thermally insulated from the hull structure. Various class societies have further considered additional requirements for tanks under accommodation areas on passenger vessels. These include providing a cofferdam between the tank compartment and adjacent machinery or accommodation space. Also, under the Interim Guidelines tanks should be placed at a distance of B/5 from the hull, where B is the vessel's beam. Additional technical analysis will be required to ensure the risk of placing a natural gas fuel tank underneath an accommodation, control, or service space is sufficiently mitigated.

Tank placement relative to other areas on a gas-fueled ship will require considerable thought. The various risks to the tank and their consequences must be weighed, and careful consideration given to the measures in place to prevent or mitigate these consequences.

Compressor Rooms

Existing U.S. federal regulations require compressor rooms on chemical and gas carriers to be located above the freeboard deck, with the entrance leading from the weather. Section 3.2.2 of the IMO Guidelines also require compressor rooms to be located above the freeboard deck, however there is an allowance for locating them below decks if they meet the provisions in place for tank rooms.

Tank Requirements

In Section 2.8.1 of the IMO Interim Guidelines, a storage tank for LNG fuel should be an independent tank designed in accordance with Chapter 4 of the ICG Code. The domestic equivalent of this standard for U.S. vessels is found in 46 CFR §154.401 through §154.476. With regard to recent concept approvals, the Coast Guard has required the use of either this equivalent domestic standard, or alternatively, has allowed type C independent fuel tanks to be designed to the ASME Boiler and Pressure Vessel Code Section VIII Division 1 or 2. In either case, recent equivalency determinations were also based on the fact that the containment system met the additional provisions in Section 2.8.1 of the Guidelines specific to gas-fueled installations.

In consideration of CNG storage tanks, the IMO Interim Guidelines do not provide a design standard, but state that they should be approved by the Administration. For U.S. vessels, the Coast Guard will consider storage tank designs on a case-by-case basis. The tank should be designed to an established standard suitable for the service intended.

Piping Requirements

In addition to meeting the provisions of Section 2.5 of the IMO Interim Guidelines, piping for natural gas fuel, as with other piping systems on a U.S. vessel, must meet ASME B31.1 Power Piping standards as modified by 46 CFR Subchapter F.

Hazardous Locations

Classification of Hazardous Areas

Section 4.3 of the IMO Interim Guidelines uses the International Electrotechnical Comission's (IEC) zone-based system for classifying hazardous locations, and provides a listing of those spaces and areas on a gas-fueled ship that should be classified as Zone 0, Zone 1, or Zone 2. Over the past several years, the U.S. Coast Guard has been transitioning from the division-based system of classification used under the National Electric Code (NEC), to the IEC zone-based system; however, there is not a direct correlation between area classifications under the two regimes.

In order to be consistent in classifying hazardous areas on a gas-fueled ship in comparison with similar areas on other U.S. vessels, a good starting point is to consider the definitions for "gas safe" and "gas dangerous" spaces given in the gas carrier regulations under 46 CFR 154.7, and the corresponding hazardous area requirements for gas carriers under 46 CFR 111.105-32. While these requirements apply to flammable gas cargoes, and are not divided into Zone categories, they do provide insight into how the Coast Guard may classify hazardous areas around similar functional components of a gas-fueled system.

Electrical Equipment Selection and Certification

In selecting electrical equipment that may be located in the hazardous areas described above, the Coast Guard under 46 CFR 111.105, currently recognizes certification of electrical equipment to either NEC or IEC based standards. Currently accepted protection techniques are listed in 46 CFR 111.105-9, 11 & 15. Any electrical equipment installed in a hazardous location must comply with one of these standards listed in 46 CFR 111.105, but not in combination in a manner that would compromise system integrity or safety. The regulations in 46 CFR 111.105 further state that electrical equipment required by these standards to be tested and approved must be certified by an independent laboratory recognized by the U.S. Coast Guard under 46 CFR 159.010. To date, the Coast Guard has not accepted certification under the European Union's ATEX Directive as proof of having met this requirement.

Gas Detection

Section 5.5 of the IMO Interim Guidelines contains requirements for gas detection on gas-fueled ships; however certification of these systems is not addressed. On currently approved gas-fueled vessel concepts, the Coast Guard has required fixed gas detection systems, including associated devices, and portable detectors to be listed or certified by an independent laboratory, accepted by the U.S. Coast Guard under 46 CFR Part 159.

Fire Protection

Installed Fire Fighting Systems

Under the IMO Interim Guidelines, a water spray system must be installed to protect exposed surfaces of a fuel tank if it is on the weather deck. On currently approved gas-fueled vessel concepts, the Coast Guard has required the boundaries of the superstructures, compressor rooms, pump rooms, cargo control rooms, and any other normally occupied deck houses that face the storage tank to also be protected by a water spray system.

The IMO Interim Guidelines require bunkering stations to be protected by a dry chemical powder fire extinguishing system. On currently approved gas-fueled vessel concepts, the Coast Guard has required such a system to consist of a hand hose line unit that is listed for fire service by a nationally recognized testing laboratory, as defined in 29 CFR 1910.7, and meets the requirements of 46 CFR 154.1155 and 154.1165 – 154.1170 as well as the provisions of MSC.1/Circ.1315.

Fire Detection

Under the IMO Interim Guidelines fire detectors must be provided in tank rooms, ventilation trunks for tank rooms below decks, and machinery spaces containing gas-fueled engines. On currently approved gas-fueled vessel concepts, the Coast Guard has required fire detection systems to be approved by the Coast Guard in accordance with 46 CFR 161.002 and installed in accordance with 46 CFR 76.27.

6. Approval Process for Gas-Fueled Ship Designs

Design Basis Agreement

Since existing U.S. regulations do not address the use of natural gas as fuel on commercial vessels, a company seeking approval generally submits a request to the Coast Guard's Office of Design and Engineering Standards for an alternative design under 46 CFR 50.20-30. To date, successful concept approvals for gas-fueled vessels have included general arrangements, a layout of the gas-fueled system components, and a list of standards proposed for system design. Proposals that the Coast Guard has accepted have used the IMO Interim Guidelines as a baseline standard and provided details on how each provision of the IMO Interim Guidelines will be met and how any deviations are to be addressed.

The Coast Guard's response to these proposals has taken the form of a Design Basis Agreement which lays the framework of requirements that need to be met for plan approval and vessel certification. So far, this process has proved successful in identifying significant issues early on in the design phase which should avoid major changes in the later stages of design and construction.

Detailed Plan Review

Once a Design Basis Agreement has been obtained, detailed plan review can be conducted by the Coast Guard's Marine Safety Center (MSC). Procedures for submitting plans for approval can be found in 46 CFR Subpart 50.20. The MSC will conduct a full review of drawings, equipment selection, and automation ensuring that plans are in line with the Design Basis Agreement.

Inspection

During construction, Coast Guard marine inspectors ensure that a vessel is built according to approved plans. For the construction of a gas-fueled ship, members from the Marine Safety Center and the Coast Guard's Liquefied Gas Carrier National Center of Expertise may also accompany local marine inspectors during initial inspection. To avoid unnecessary construction delays, it is crucial that work not be started until plans have been approved.

7. Conclusion

The use of natural gas as fuel is a promising technology for complying with upcoming air emission limits in the U.S. which has had a long history of proven success in Scandinavia. The U.S. Coast Guard is currently reviewing concepts for gas-fueled vessel design on a case-by-case basis. Recently approved concepts have been determined to provide an equivalent level of safety to the Code of Federal Regulations by using the IMO Interim Guidelines as a baseline standard.

This paper has provided insight into specific design issues, and described the current process for obtaining approval of gas-fueled systems on U.S. Flag vessels. It is hoped that shipowners and designers will benefit from reviewing these considerations when developing conceptual designs for gas-fueled ships, and highly recommended that they start discussions with the Coast Guard early in the design process.

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[i] Cook, Kevin, Cynthia Giles, and Gina McCarthy. "Memorandum of Understanding Between USCG and EPA Regarding Enforcement of Annex VI as Implemented by the Act to Prevent Pollution from Ships." Letter. 27 June 2011. Coast Guard Headquarters, Washington, DC

[ii] International Maritime Organization. "Date of Taking Effect of the Amendments to Regulations 13 and 14 of MARPOL Annex VI Adopted by Resolution MEPC.202(62)." MEPC.1/Circ. 756, 10 August 2011

[iii]Wärtsilä Corporation and Shell Sign Co-operative Agreement to Promote LNG as Marine Fuel. Wartsila.com, 8 Sept. 2011. Web. 2 Oct. 2011.

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