ABS ADVISORY ON GAS AND OTHER LOW FLASHPOINT FUELS

ABS

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SUMMARY

The marine industry faces a number of substantive challenges, mostly driven by increasingly stricter gaseous air emission and global warming legislation, and also from the shift in global energy markets towards renewable energy and non-traditional oil and gas supply sources triggered by the development of North American tight oil sources. Globalization uncertainties, geo-political influences, digitalization and cyber threats add to the increasing complexities faced by the shipping industry in determining the most effective ship propulsion arrangements and fuel strategies.

The advent of the IMO MARPOL Annex VI Regulation 14 global fuel sulphur limit of 0.5% from 1 January 2020 is driving the development of new conventional marine fuels, but also the use of alternative technologies such as exhaust gas cleaning systems and a switch to inherently low sulphur low flashpoint fuels such as LNG. The marine industry is at an unprecedented marine fuels crossroads, similar only to historic ship fuel and propulsion technology shifts from wind to coal and coal to oil.

The commitment and ambition from the IMO MEPC in April 2018 to act upon the Paris Agreement and reduce GHG emissions from shipping, notably to reduce total annual GHG emissions by at least 50% by 2050 compared to 2008, signals a longer-term marine industry shift towards zero carbon and low carbon fuels.

Shipping will therefore see advancements in ship technologies to further improve efficiency, an increase in batteries and hybridization and a broad range of fuel options that will be driven by availability, price and suitability for specific ship types, sizes and operational areas.

This advisory focuses on LNG and other low flashpoint fuels that can provide solutions to the fuel sulphur regulations in the short and mid-term, and in some cases viable solutions for the longer-term transition to low and zero carbon fuels. The regulatory requirements for all options are broadly in place, but each of the fuels possess specific benefits and technical challenges.

Information is provided on the regulatory background for the use of LNG and other low flashpoint fuels, and an overview of the technologies and operational impacts is also given that can support the decision making process for future ship propulsion arrangements and fuel strategies. While providing some additional challenges to conventional fuels, both on the technology and fuel infrastructure sides, it is clear that equipment manufacturers and fuel suppliers are meeting the challenge of providing effective and environmentally friendly solutions for the future. The increasing use of automation and sophisticated control systems for fuel containment, fuel gas supply and prime movers also makes the management of this transition simpler.

INTRODUCTION

International, regional, national and local air emissions legislation is driving the development of alternative fuels, primary engine technologies and secondary exhaust emissions abatement systems to reduce exhaust emissions from ships. These techniques are primarily aimed at meeting IMO MARPOL Annex VI[1] Regulations 13 and 14 requirements for nitrogen oxide (NOx) emissions from diesel engines and sulfur oxide (SOx) emissions from all fuel-burning equipment on board.

A means of complying with the SOx emissions limits of MARPOL Annex VI Regulation 14 and potentially (for certain engine types) the NOx limits of Regulation 13 is the use of natural gas as a fuel and other low flashpoint fuels which are inherently low in sulfur.

For almost 60 years the gas carrier fleet has developed technologies, technical requirements and operational practices for the safe handling and burning of liquified natural gas (LNG). The technologies for consuming boil-off gas (BOG) have provided the basis for the use of LNG as fuel on other ship types and are an essential part of LNG cargo temperature and pressure management. In 2005 the LNG carrier fleet transitioned from steam turbines to more efficient 4-stroke medium speed dual fuel (DF) diesel electric engines, and more recently, to 2-stroke DF engines with direct drive.

Historically the gas carrier regulations for the use of cargo as fuel, IMO's *International Code for the Construction and Equipment of Ships Carrying Liquified Gases in Bulk* (IGC Code), only permitted the burning of natural gas as fuel. However, the adoption of the revised (2016) IGC Code by IMO Resolution MSC.370(93)[2] in May 2014 introduced the option to burn other non-toxic cargoes as fuel. Furthermore, the adoption of the *International Code of Safety for Ships Using Gases or Other Low-Flashpoint Fuels* (IGF Code) by IMO Resolution MSC.391(95)[3] in June 2015 provided the IMO regulatory safety requirements and framework for the use of natural gas and other low flashpoint fuels on all ship types.

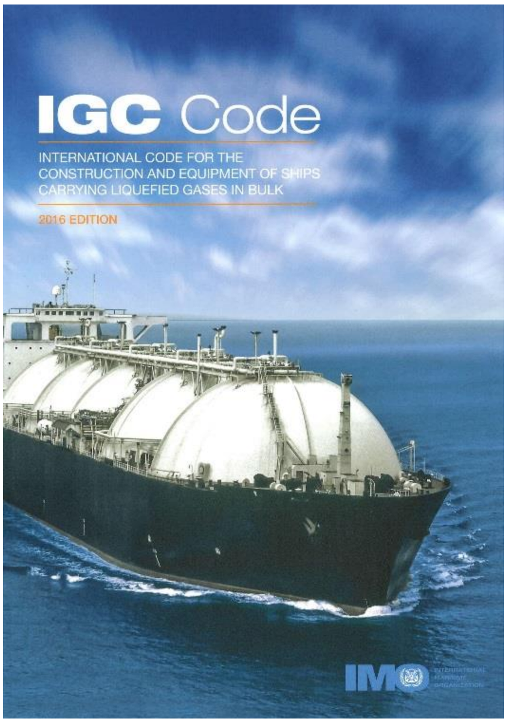
While the contribution of shipping to global CO_2 emissions is relatively low at approximately 3%, the adoption of the initial IMO GHG reduction strategy by IMO Resolution MEPC.304(72)[4] in April 2018 demonstrates the IMO commitment to support the Paris Agreement[5]. The IMO strategy includes an ambition to reduce the total annual GHG emissions from shipping by at least 50% of 2008 levels by 2050, which means a game changing move to zero and low carbon marine fuels in the longer term.

The majority of the deep-sea shipping fleet will be using conventional and emerging lower sulfur residual and distillate fuels to meet the 1 January 2020 IMO global fuel sulfur limit of 0.5%. However, in the short and mid-term, new types of conventional fuels will emerge, and also shipping will trend towards a reduction in conventional fuels in favor of alternative fuels such as low flashpoint fuels and biofuels. This advisory provides an overview of the regulatory, technical and operational background for assisting the decision-making process for application of LNG and other low flashpoint fuels, such as ethane, LPG and methanol, to shipping. For more information on conventional marine fuels and exhaust emission abatement (EEA) technologies refer to the ABS *Marine Fuel Advisory* and the ABS *Advisory on Exhaust Gas Scrubber Systems*.

The industry continues to work on innovative projects using hydrogen, ammonia, bio-fuels, and other zero carbon technologies, additional guidance on these is provided in the ABS *2019 Low Carbon Shipping Outlook* [6].

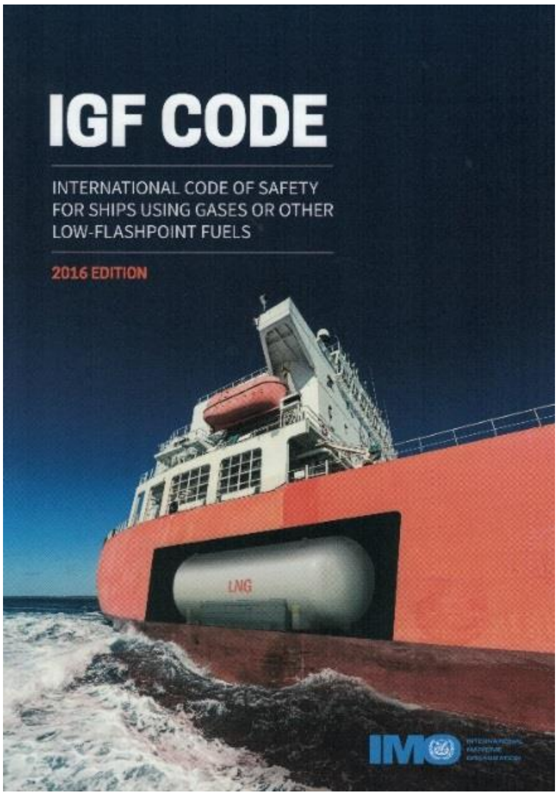
REGULATORY BACKGROUND

IMO SAFETY



SOLAS has historically prohibited the use of low-flashpoint fuel oils less than 60˚C, except for emergency generator use, where the limit is 43˚C and subject to a number of additional requirements detailed under SOLAS II-2 Regulation 4.2.1. At the same time IMO adopted the IGF Code, the amendments to SOLAS making the IGF Code mandatory (by including a new Part G to SOLAS II-1) were also adopted by IMO Resolution MSC.392(95)[7]. Prior to this the only guidance from IMO for the use of natural gas as fuel was that detailed in the 'Interim Guidelines', IMO Resolution MSC.285(86)[8], 'Interim Guidelines on Safety for Natural Gas-fuelled Engine Installations in Ships', which were adopted on 1 June 2009. The adoption of the IGF Code therefore introduced a framework and requirements under SOLAS for burning fuels with a flashpoint less than 60˚C.

Under the 'one ship, one code' policy, IMO clarified that with the exception of ships subject to the IGC Code burning cargo as fuel, the IGF Code is applicable to all new ships, and ship conversions, over 500GT using low flashpoint fuels for which the building contract is placed on or after 1 January 2017. In the absence of a building contract, the IGF Code is applicable to those ships with a keel laid on or after 1 July 2017, or the delivery of which is on or after the 1 January 2021.



The adopted IGF Code includes detailed prescriptive requirements for natural gas under Part A-1. The IGF Code also includes requirements for risk assessment, but for natural gas this need only be applied to the specific sections of Part A-1 of the IGF Code referenced by 4.2.2 of the IGF Code, such as sizing of drip trays and general fuel containment assessment. This reflected the greater maturity of experience with natural gas as fuel at the time the IGF Code was adopted; with the first gas as fuel ferry conversion undertaken in the year 2000 and approximately 70 gas fueled ships in operation in 2015. Further details on the IGF Code risk assessment requirements are given under the 'Risk Assessment' section of this advisory.

Other low flashpoint fuels may also be used as marine fuels, provided they meet the intent of the goals and functional requirements of the IGF Code and provide an equivalent level of safety. This approval process is by application of the 'Alternative design' criteria under 2.3 of the IGF Code and equivalency shall be demonstrated as specified in SOLAS II-1/55, which refers to the engineering analyses submitted for approval (by the Administration) to be based on the MSC.1/Circ.1212[9] guidelines.

In the longer term it is understood that additional parts will be added to the IGF Code (Parts A-2, A-3, etc.) to cover other low flashpoint fuels as industry applications and experience grows. Prior to that it is anticipated that IMO will issue further 'Interim Guidelines', such as the 'Draft Interim Guidelines for the Safety of Ships Using Methyl/ethyl Alcohol as Fuel' which were approved in principle by IMO at the Carriage of Cargoes and Containers (CCC) 5 sub-committee meeting held 10-14 September 2018.

For gas carriers, the use of natural gas as a fuel is permitted by application of Chapter 16 of the IGC Code. With the adoption of the revised IGC Code in 2014, a new section 16.9 for 'Alternative fuels and technologies' was introduced permitting the burning of cargoes other than natural gas, provided they are not identified as toxic products. In a similar manner to the approach of the IGF Code, the 2016 IGC Code permits the burning of these alternative fuels subject to agreement with the Administration and requires that the same level of safety as natural gas is ensured. Projects considering this approach need to engage in dialogue with the Administration to clarify the roadmap to approval, but it is understood this also requires a risk assessment approach to be applied, and application of the 'Equivalents' criteria given under 1.3 of the 2016 IGC Code. Successful completion of this process would require the Administration to notify IMO of the equivalent arrangements through the IMO GISIS database.

With the adoption of the IGF Code and 2016 IGC Code, IMO has established the regulatory safety requirements and framework for the use of natural gas and other low flashpoint fuels on all ship types. In all cases, the prescriptive and goal-based objectives apply the following three safety principles, and general arrangements, to mitigate the risks of using low flashpoint fuels:

- Prevention of leakage, e.g. double barriers, sealing systems, protective locations, cofferdams, air locks;
- Prevention of explosive or toxic atmosphere, e.g. ventilation, gas detection, hazardous area classification, master gas fuel valves, fuel block and bleed valves, inert gas barriers, and fuel purge systems; and
- Explosion mitigation, e.g. explosion relief valves, pressure vent systems, design for worst case pressure rise, specialized fire detection and firefighting equipment.

IMO EMISSIONS

GASEOUS EMISSIONS

In 1997, an IMO international conference of parties to MARPOL adopted the 1997 Protocol to the MARPOL Convention which added a new Annex VI, Regulations for the Prevention of Air Pollution from Ships, based on the regulatory text developed by the IMO Marine Environment Protection Committee (MEPC). This Annex entered into force on 19 May 2005. The conference also adopted the Technical Code on Control of Emission of Nitrogen Oxides from Marine Diesel Engines (NOx Technical Code – NTC).

To reduce the harmful effects of NOx and SOx emissions on human health and the environment, Regulation 13 of this new Annex detailed the limits for NOx emissions from diesel engines and Regulation 14 the SOx emissions limits from all fuel-burning equipment on board. The 58th IMO MEPC session in October 2008 adopted further significant changes to Annex VI and the NTC under Resolutions MEPC.176(58)[10] and MEPC.177(58)[11] respectively.

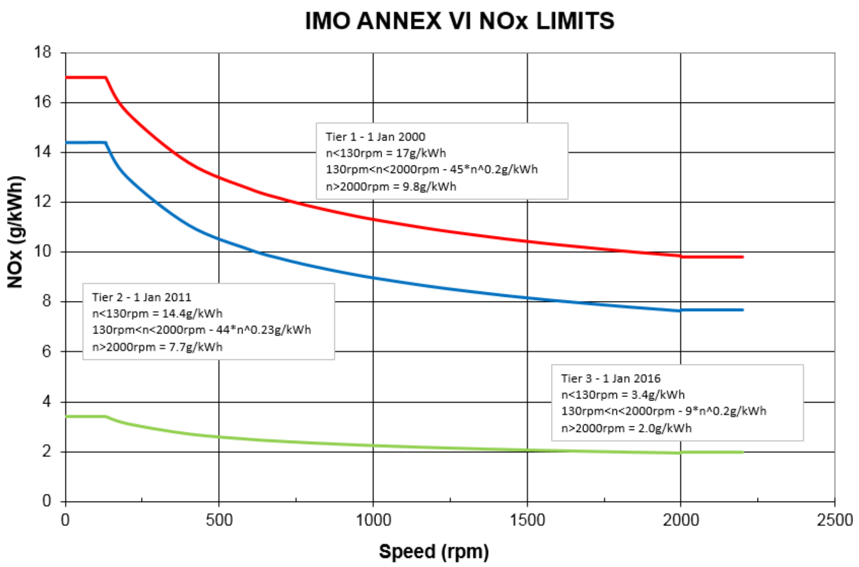


Figure 1: IMO MARPOL ANNEX VI Regulation 13 NOx Limits

The IMO engine NOx limits are based on engine rated speed (see Figure 1), with the lowest limits applicable to medium and high-speed engines. The application date of the Regulation 13 NOx emission limits is tied to the ship construction date. The IMO NOx limits apply to all installed engines with a rated output of more than 130kW, except emergency generators. The Tier I NOx limit was retrospectively applicable to engines fitted to ships with keels laid on or after 1 January 2000 once Annex VI entered into force on 19 May 2005. The 2008 amendments progressively reduced the NOx limits, with the Tier II limit entering into force on 1 January 2011. The amendments also introduced the Tier III limit, which is only applicable in Emission Control Areas (ECA), and represents a NOx reduction of approximately 80% from the Tier I limit. Currently the only NOx ECAs in force are the North American (see Figure 3) and United States Caribbean Sea ECAs (see Figure 4), which entered into force on 1 January 2016. The existing Baltic and North Sea SOx ECAs (see Figure 2) will also become NOx ECAs from 1 January 2021.

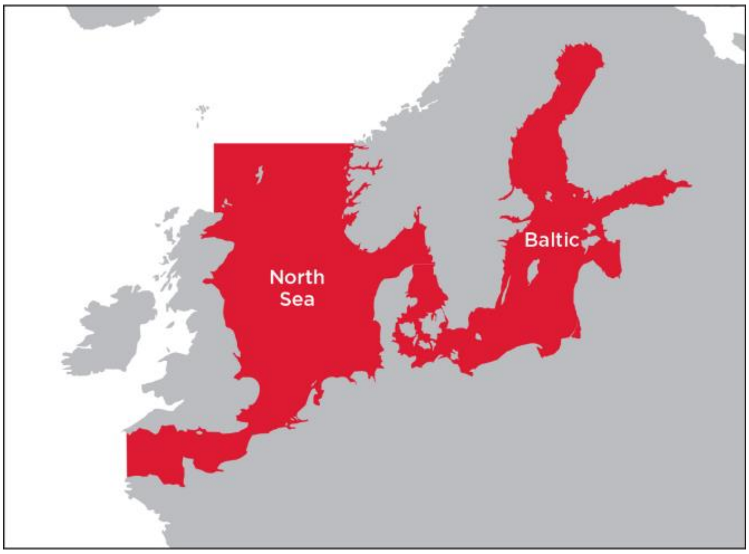


Figure 2: Baltic and North Sea SECA

The IMO SOx regulation limits sulfur oxide emissions, and therefore the sulfate portion of the particulate matter (PM), by controlling the sulfur content of the fuel. Similar to the NOx emissions limits, IMO prescribes limits for SOx at global and local ECA levels – see Table 1. However, these are applicable to all fuel burning equipment onboard from the date of application of the regulation. The Baltic Sea was the inaugural SOx Emission Control Area (SECA), followed by the North Sea in November 2007. The revised Annex VI included a change to the terminology and regulations associated with coastal air emission control areas with the revision from SECAs to ECAs. This added the provision to designate areas as NOx, SOx and PM Emission Control Areas.

Figure 3: North American ECA

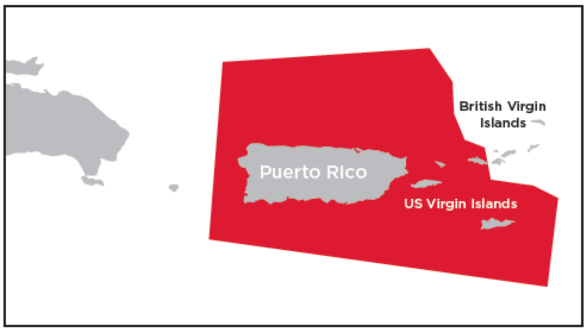


Figure 4: United States Caribbean Sea ECA

IMO Global		SECA/ECA	
Date	Sulfur %	Date	Sulfur %
Initial limits	4.5	Initial limits	1.5
Jan 1, 2012	3.5	Jul 1, 2010	1.0
Jan 1, 2020	0.5	Jan 1, 2015	0.1

Table 1: IMO Global and ECA Fuel Oil Sulfur Limits

The use of natural gas as a fuel, and other low flashpoint fuels which are inherently low in sulfur, is a means of complying with the SOx emissions limits of MARPOL Annex VI Regulation 14. NOx formation is linked to peak combustion temperatures, and therefore natural gas burning engines that use the Otto combustion process in gas mode can meet the NOx limits of Regulation 13 without exhaust emissions aftertreatment equipment. For more information on dual fuel and gas engines see the ‘Prime Movers’ section of this Advisory.

ENERGY EFFICIENCY AND GHG

At the IMO MEPC 62nd session in July 2011 further amendments to MARPOL Annex VI were made with the adoption of resolution MEPC.203(62)[12] which introduced a new Chapter 4 for the inclusion of energy efficiency measures for ships. These new requirements were adopted as applicable to new ships of 400GT and above for ships with a building contract placed on or after 1 January 2013, in the absence of a building contract to ships with a keel laid on or after 1 July 2013, and regardless of building contract or keel laying dates delivered on or after 1 July 2015.

This new chapter introduced design and operational requirements for energy efficiency through the Energy Efficiency Design Index (EEDI) and Ship Energy Efficiency Management Plan (SEEMP), together with introducing a requirement for ships to be issued with an International Energy Efficiency Certificate (IEEC) after demonstrating that the attained EEDI of the ship does not exceed a maximum allowable 'Required EEDI'. The required EEDI differs for ship type, size, and construction date, and the regulations included a plan to progressively reduce from the reference EEDI (Phase 0) introduced in 2013 through further phases to the 2025 time horizon (see Figure 5). Currently IMO is in the process of revising these criteria by bringing the Phase 3 2025 requirements forward to 2022 and considering further EEDI reductions as part of the initial IMO GHG reduction strategy. At MEPC 73 in October 2018 IMO agreed, in principle, to bring the Phase 3 requirements, for certain ship types and sizes, forward to 2022 These proposed amendments were further considered by MEPC 74, where it was agreed to bring the Phase 3 application date forward to 2022 for general cargo carriers, container ships, LNG carriers of 10,000 DWT and above, gas carriers of 15,000 DWT and above and cruise passenger ships with non-conventional propulsion systems. Please see the ABS website for the latest regulatory information.

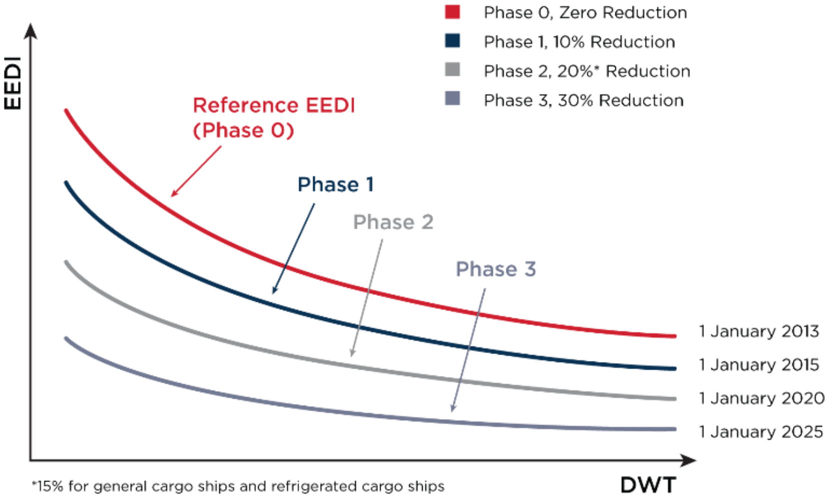


Figure 5: IMO EEDI Phases

The GHG reduction ambition from IMO aims to reduce CO_2 emissions per transport work by at least 40% by 2030, and pursue efforts towards 70% reduction by 2050, compared to 2008. Furthermore, the ambition aims to peak GHG emissions from international shipping as soon as possible, to reduce the total annual GHG emissions by at least 50% by 2050 compared to 2008, and to pursue efforts towards phasing GHG emissions out. As called for in the vision on a pathway of CO_2 emissions reduction that is consistent with the Paris Agreement global temperature goals.

Of note amongst the short-term candidate measures identified in the IMO strategy is the plan to consider measures to address emissions of methane, which is particularly significant for the use of LNG as a marine fuel. Also, to develop robust lifecycle GHG/carbon intensity guidelines for all fuel types in order to prepare for an implementation program for uptake of low-carbon and zero-carbon fuels.

Efficiency improvements alone will not meet these objectives, and while the contribution of shipping to global CO_2 emissions is relatively low, at approximately 3%, the adoption of the initial IMO GHG reduction strategy demonstrates that IMO has ambitions consistent with the Paris Agreement and which effectively means a game changing move to zero and low carbon marine fuels towards the 2050 timeline.

ISO

Several ISO standards and technical specifications have been developed to support the application of LNG and other low flashpoint fuels to the marine sector. Notable amongst these are the ISO 20519:2017[13] standard covering the LNG bunkering transfer systems and the ISO/TS 18683:2015[14] technical specification for systems and installations that supply LNG as fuel to ships. These documents address the LNG bunkering interface between LNG supply and LNG receiving ship for shoreside tank-to-ship, truck-to-ship and ship-to-ship scenarios (see Figure 6). Incorporating risk assessment and operational aspects they assist operators in selecting LNG fuel providers that meet defined safety and fuel quality standards and support the permitting of LNG bunkering infrastructure within port and terminal areas.

To support standardization on LNG fuel quality and LNG bunkering dry-disconnect/connect couplings, ISO has also developed the 'Specification of liquified natural gas as a fuel for marine applications' and 'Technical requirements for liquified natural gas bunkering dry-disconnect/connect coupling' standards currently under development.

Furthermore, to support the uptake of methanol and ethanol as marine fuels, at the 99th session of the IMO Maritime Safety Committee (MSC) meeting, held 16-25 May 2018, the IMO invited ISO to develop standards for methyl/ethyl alcohol as a fuel and methyl/ethyl alcohol fuel couplings in a similar manner to those under development for LNG. Some concerns on lack of sufficient experience as a marine fuel were expressed, however ISO is willing to develop such standards, so we can expect this work to initiate in due course.

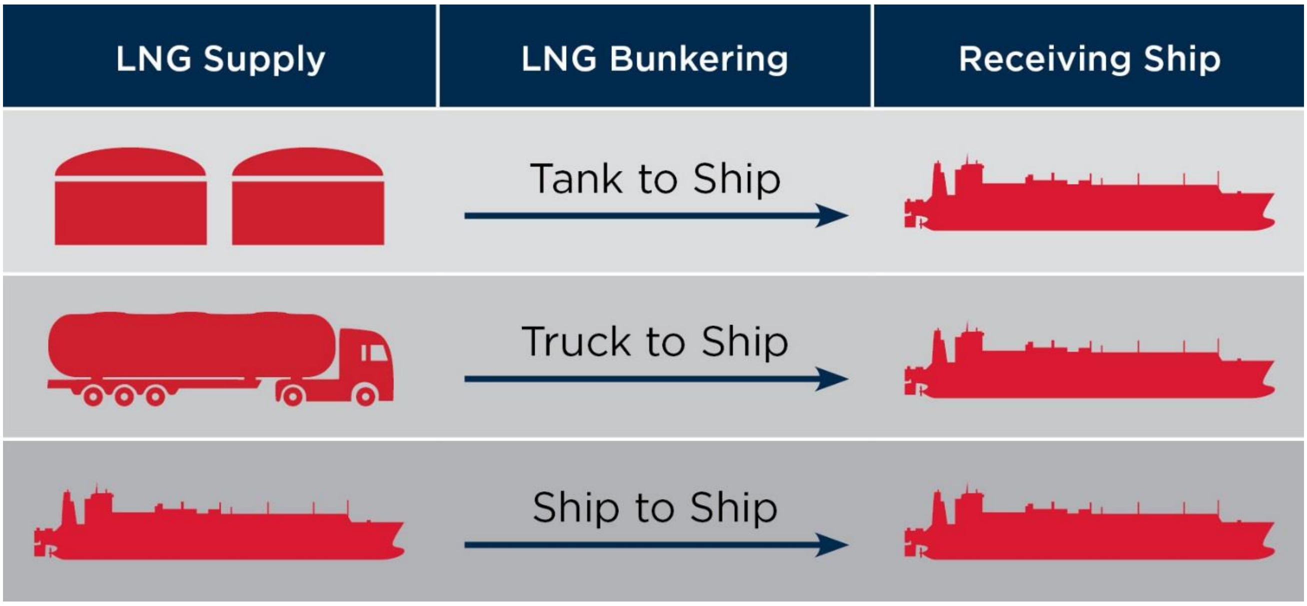


Figure 6: LNG Bunkering Scenarios

IACS

IACS members verify compliance with the IGC and IGF Codes, acting as Recognized Organizations (RO) for the flag Administration of the ship. Some IACS members have incorporated these IMO codes within their rules and have also developed further requirements for LNG and other low flashpoint fueled ships; see also the “ABS Rules” section of this advisory for more information on how ABS has incorporated the IGC and IGF Codes within the ABS Rules.

To assist uniform application of requirements that may be outside the scope of the IMO approved Codes or fall within traditional Classification requirements, IACS members work together to develop Unified Requirements (UR). All IACS members apply these requirements in a consistent manner. The URs are publicly available on the IACS website and cover a wide range of ship and machinery topics. Of particular interest for equipment associated with gas and low flashpoint fuels are the applicable URs detailed in the “G” series, for Gas Tankers, the “M” series for Machinery Installations, the “P” series for Pipes and Pressure Vessels and the “Z” series for Survey and Certification.

IACS are also active at IMO in the support of further development and application of the IGF Code under the IMO CCC sub-committee. The sub-committee work includes developing new low flashpoint fuel requirements, such as those for methyl/ethyl alcohol fuels currently under development as interim guidelines, but also has the mandate to develop amendments to the IGF Code to incorporate new requirements and further refine the existing text. An example of such an amendment is IMO circular MSC.1/Circ.1568[15], which details the amendment to 11.3.2 of the IGF Code to clarify bridge window fire ratings.

To support harmonized application of the IGC and IGF Codes, IACS also develops Unified Interpretations (UI). These are submitted to IMO for agreement before being incorporated as IACS UIs and available from the publicly available publications section of the IACS website. IMO circulars MSC.1/Circ.1558[16] and MSC.1/Circ.1591[17] detail such UIs for the IGF Code. IACS publishes these IGF Code interpretations to individual code requirements as “GF” UIs on the IACS website. The IACS UIs to the IGC Code are published as “GC” UIs.

Where needed, IACS is also active in developing general marine recommendations to facilitate harmonized interpretation and implementation. A number of such recommendations have been developed specifically to assist application of the IGC and IGF codes and the uptake of LNG or other low flashpoint fuels. For IGC Code ships IACS has developed recommendations on tank filling criteria higher than 98%, ESD valves and sampling connections and vapor pockets not in communication with vapor/liquid domes, under recommendation numbers 109[18], 114[19] and 150[20] respectively. At the time of publication of this document there were also three published IACS recommendations for IGF code ships in place, covering LNG bunkering, risk assessment and survey of cryogenic fuel containment systems, under recommendation numbers 142[21], 146[22] and 148[23] respectively.

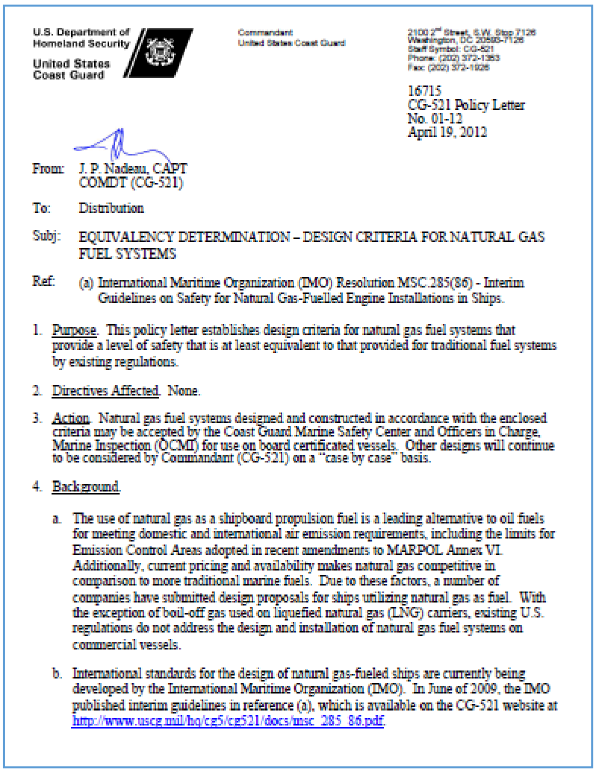
FLAG ADMINISTRATIONS

USCG

In the United States the combination of the first IMO NOx and SOx ECA, and the potential for relatively cheap LNG, has inspired a number of LNG fueled projects. With the ABS classed Harvey Gulf OSVs becoming the first LNG fueled ships in operation in North America in 2015 and the ABS classed Tote container ships introducing some more firsts, i.e. the world's first order for the MAN Energy Solutions ME-GI high pressure DF engine and the first LNG fueled container ships, the U.S. is moving forward with developing LNG fueled ships and LNG bunkering infrastructure.

The U.S. administration has long been active in the development of the IGF Code at IMO, but to further support this developing market for LNG as fuel in the U.S., the USCG was also instrumental in developing flag Administration requirements for gas fueled ships, LNG bunkering and crew training. The USCG CG-521 No. 01-12[24] Policy Letter provided equivalency determination criteria for U.S. flagged ships using natural gas fuel systems based on the IMO 'Interim Guidelines' MSC.285(86) in 2012 and which has been superseded with the CH-1[25] update and alignment to the IGF Code in July 2017.

The USCG also introduced policy letters for fuel transfer operations and training of crew on gas fueled ships with Policy Letter 01-15[26] and guidance to water front facilities conducting LNG transfers as marine bunkering operations with Policy Letter 02-15[27] in 2015.



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16715
CG-521 Policy Letter
No. 01-12
April 19, 2012

From: J. P. Nadeau, CAPT
COMDT (CG-521)

To: Distribution

Subj: EQUIVALENCY DETERMINATION – DESIGN CRITERIA FOR NATURAL GAS FUEL SYSTEMS

Ref: (a) International Maritime Organization (IMO) Resolution MSC.285(86) - Interim Guidelines on Safety for Natural Gas-Fuelled Engine Installations in Ships.

1. Purpose. This policy letter establishes design criteria for natural gas fuel systems that provide a level of safety that is at least equivalent to that provided for traditional fuel systems by existing regulations.

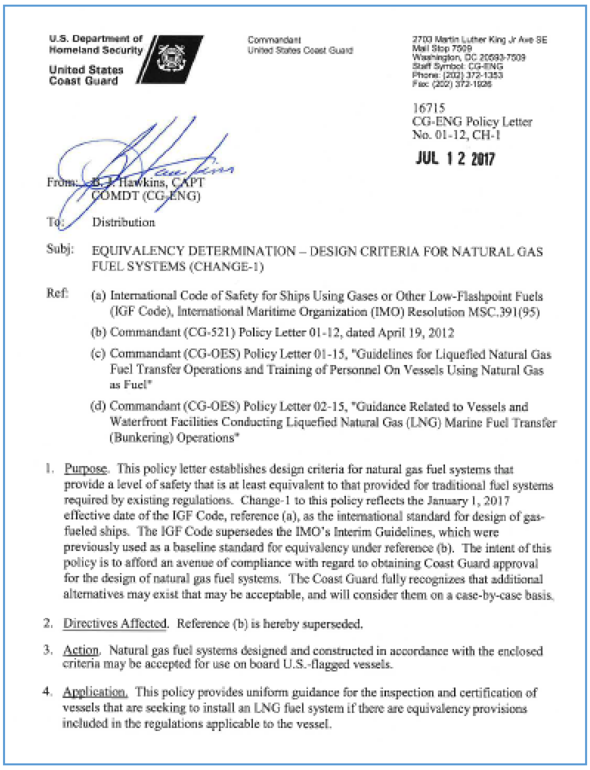
2. Directives Affected. None.

3. Action. Natural gas fuel systems designed and constructed in accordance with the enclosed criteria may be accepted by the Coast Guard Marine Safety Center and Officers in Charge, Marine Inspection (OCMI) for use on board certificated vessels. Other designs will continue to be considered by Commandant (CG-521) on a "case by case" basis.

4. Background.

   a. The use of natural gas as a shipboard propulsion fuel is a leading alternative to oil fuels for meeting domestic and international air emission requirements, including the limits for Emission Control Areas adopted in recent amendments to MARPOL Annex VI. Additionally, current pricing and availability makes natural gas competitive in comparison to more traditional marine fuels. Due to these factors, a number of companies have submitted design proposals for ships utilizing natural gas as fuel. With the exception of boil-off gas used on liquefied natural gas (LNG) carriers, existing U.S. regulations do not address the design and installation of natural gas fuel systems on commercial vessels.

   b. International standards for the design of natural gas-fueled ships are currently being developed by the International Maritime Organization (IMO). In June of 2009, the IMO published interim guidelines in reference (a), which is available on the CG-521 website at http://www.uscg.mil/hq/cg5/cg521/docs/msc_285_86.pdf.



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16715
CG-ENG Policy Letter
No. 01-12, CH-1

JUL 12 2017

From: B. J. Hawkins, CAPT
COMDT (CG-ENG)

To: Distribution

Subj: EQUIVALENCY DETERMINATION – DESIGN CRITERIA FOR NATURAL GAS FUEL SYSTEMS (CHANGE-1)

Ref: (a) International Code of Safety for Ships Using Gases or Other Low-Flashpoint Fuels (IGF Code), International Maritime Organization (IMO) Resolution MSC.391(95)
(b) Commandant (CG-521) Policy Letter 01-12, dated April 19, 2012
(c) Commandant (CG-OES) Policy Letter 01-15, "Guidelines for Liquefied Natural Gas Fuel Transfer Operations and Training of Personnel On Vessels Using Natural Gas as Fuel"
(d) Commandant (CG-OES) Policy Letter 02-15, "Guidance Related to Vessels and Waterfront Facilities Conducting Liquefied Natural Gas (LNG) Marine Fuel Transfer (Bunkering) Operations"

1. Purpose. This policy letter establishes design criteria for natural gas fuel systems that provide a level of safety that is at least equivalent to that provided for traditional fuel systems required by existing regulations. Change-1 to this policy reflects the January 1, 2017 effective date of the IGF Code, reference (a), as the international standard for design of gas-fueled ships. The IGF Code supersedes the IMO's Interim Guidelines, which were previously used as a baseline standard for equivalency under reference (b). The intent of this policy is to afford an avenue of compliance with regard to obtaining Coast Guard approval for the design of natural gas fuel systems. The Coast Guard fully recognizes that additional alternatives may exist that may be acceptable, and will consider them on a case-by-case basis.

2. Directives Affected. Reference (b) is hereby superseded.

3. Action. Natural gas fuel systems designed and constructed in accordance with the enclosed criteria may be accepted for use on board U.S.-flagged vessels.

4. Application. This policy provides uniform guidance for the inspection and certification of vessels that are seeking to install an LNG fuel system if there are equivalency provisions included in the regulations applicable to the vessel.

OTHERS

The Norwegian Maritime Authority (NMA) and the Marine Safety & Security Executive (MSSE) of Transport Canada have also both developed policies to address application of the IGF Code. The NMA published their regulation No. 1883[28] on ships using fuel with a flashpoint of less than 60°C on 27 December 2016. Transport Canada published their 'Marine Safety Management System, Tier I – Policy – Requirements for Vessels using Natural Gas as Fuel' under RDIMS: 11153519[29].

These flag Administration policies provide clarification and guidance for designing and constructing natural gas fueled vessels to the IGF Code and where those vessels are flagged with the respective Administrations.

ABS has points of contact for USCG, NMA, Transport Canada and the majority of the world's flag Administrations to clarify general regulatory issues and policies on low flash point fuels and application of the IGC and IGF Codes. General inquiries can be sent through the ABS website or to the Global Gas Solutions (GGS) team at globalgas@eagle.org.

LOW FLASHPOINT FUELS – CHARACTERISTICS

GENERAL

Traditional marine fuel oils are blends of hydrocarbons derived from petroleum and are categorized as residual or distillate products in accordance with ISO 8217[30]. This ISO standard, 'Fuels (class F) – Specifications of marine fuels', defines a number of key characteristics for these fuels which are commonly known as heavy fuel oil (HFO), marine diesel oil (MDO) and marine gas oil (MGO). However, compliance with the ISO standard is not mandated through IMO, but is typically specified in commercial agreements between purchaser and user. MARPOL Annex VI Regulation 18 details the IMO's requirements for fuel oil availability and quality. The regulation places obligations on fuel oil suppliers, Administrations and operators. In particular, it provides a high-level fuel quality safety requirement requiring that fuel oils shall not contain any added substance or chemical waste that could jeopardize safety of ships, adversely affect machinery, be harmful to personnel or contribute to additional air pollution. The recent fuel quality incidents are an example of unknown substances that can enter the marine residual fuel supply chain. The statement from CIMAC on this issue of 10 November 2018[31] highlights the difficulties in determining the exact cause and source of contaminants. Regulation 18 also provides detailed requirements for the Bunker Delivery Note (BDN) to be provided by the fuel supplier and the retention of fuel oil verification samples by the operator. These fuel sample obligations do not apply to gaseous fuels such as LNG or LPG, although there is an obligation for the sulfur content to be documented by the supplier. More information on conventional marine fuels is available in the ABS *Marine Fuel Oil Advisory*.


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The IGF Code includes a sample BDN for delivery of LNG as a bunker fuel (see Appendix II) and this includes a parameter for recording the sulfur content (even though the typical sulfur content of LNG and other low flashpoint fuels is nearly negligible), to satisfy the MARPOL reporting requirement. The main purpose for the IGF Code detailing the LNG parameters in a standard BDN is to enable the user to verify the LNG composition. This is for obvious commercial reasons, such as documenting energy content, but critical to verify that there are no safety issues for the use of the natural gas onboard that may result from the LNG composition. The calculated methane number (MN) of the LNG, which is an indicator of combustion performance similar to cetane index for fuel oil, needs to be determined to confirm it meets the engine manufacturers requirements. The MN is calculated from the LNG composition (methane, ethane, propane, etc.), which will vary depending on the source, processing and storage of the LNG. Low MN values can cause LP Otto DF engines to encounter problems with combustion knock and which can lead to the engine control system derating the engine. However, this is an area of continual engine development and application specific tuning based on the typical available gas compositions. Normal operation down to a MN of 65-70 is now possible on many engines. It is important to note that MN is only a critical parameter to those engines using the low pressure (LP) Otto combustion process when running on gas and is not applicable to the high pressure (HP) gas injection Diesel engines.

A number of fuel characteristics remain common to all fuel types, such as energy content, density, combustion characteristics, water content and contaminants, but there are specific parameters of particular interest and applicability to each fuel type. For example, pour point or cat fines content may be of interest for conventional fuels but not for the use of LNG as fuel. The high-level fuel contaminant safety obligation given under Annex VI Regulation 18 is also present in the ISO 8217 standard. But in many cases compliance with a fuel standard alone does not mean a fuel is completely fit for purpose. The use of conventional fuel oils is an example of this, where additional filtration, separation and treatment onboard is required to prepare the fuel for combustion and to avoid damage to engines. Furthermore, consideration of compatibility and stability of the fuels when storing and using them onboard is important for conventional fuel oils. Similarly, filtration is also important for LNG, particularly for fuel gas supply systems that may be sensitive to contaminants.

The high-level fuel quality requirements of Annex VI Regulation 18 and ISO 8217 provide some confidence to purchasers. Furthermore, although there is a recognition that marine fuel standards do not address all the factors that operators may need to consider when purchasing fuels, there is still a need for marine fuel standards to be developed to support widespread take-up of the other low flashpoint fuels being considered by industry. Therefore, the work ISO has commenced on the development of a marine fuel standard for LNG, and more recently methyl/ethyl alcohol fuels, are important pieces in the low flashpoint fuel regulatory landscape.

The early adopters of LNG or other low flashpoint fuels and those ships that are burning cargo fuels, such as methanol, ethane and LPG, are spearheading the development of fuel quality criteria, fuel supply system and equipment specifications, together with providing the experience necessary for the development of robust marine fuel standards.

As outlined under the ‘IMO Safety’ section of this advisory, the IGC Code provides detailed prescriptive requirements for natural gas, without requiring additional risk assessment, under Chapter 16 and the IGF Code Part A-1 also includes detailed prescriptive requirements for natural gas, but requires risk assessment to be conducted where required by 4.2.2 of the IGF Code. For other low flashpoint fuels a risk assessment will be part of the approval process for both Codes– see the ‘Risk Assessment’ section of this advisory for more details.

The general safety principles of the IGC and IGF Codes provide the framework for the use of low flashpoint marine fuels. Common safety principles such as fuel tank protective location, double barriers on fuel supply lines, ventilation and gas detection, hazardous area classification, explosion mitigation, etc. are equally applicable to all low flashpoint fuels. However, the specific fuel characteristics may require specific safety features. For example, whether any fuel leaks would be in a heavier than air phase if released, which may be applicable to LPG or ethane, or if additional detectors may be necessary for fuels that may be considered toxic, such as methanol. In the absence of developed prescriptive requirements for those low flashpoint fuels, then the fuel characteristics would be considered during the risk assessment analyses. A tabulated comparison of the fuel characteristics of the main low flashpoint fuels being considered by the marine industry is given in Appendix I of this advisory.

LNG

LNG is a mixture of several gases, principally composed of methane (CH_4), with a concentration that can vary from 70 to 99 percent by mass, depending on the origin of the natural gas. Other hydrocarbon constituents commonly found in LNG are ethane (C_2H_6), propane (C_3H_8), and butane (C_4H_{10}). Small amounts of other gases, such as nitrogen (N_2), may also be present. Natural gas reserves are significant with the International Energy Agency (IEA) estimating reserves at over 250 years. The composition of some typical LNG sources is shown in Tables 2 and 3.

Component Name	Chemical Formula	Composition (Molar)	Average Global Composition
Methane	CH_4	84 to 99%	90.4%
Ethane	C_2H_6	0.1-14%	6.4
Propane	C_3H_8	0-4%	1.8%
Butane	C_4H_{10}	0-2.5%	0.9%
Nitrogen	N_2	0-1.8%	0%

Table 2: Typical LNG Composition

When liquefied at approximately -162°C, the volume required for natural gas is reduced to about 1/600th of that required when in the gaseous state. In this condition LNG is transported in liquefied natural gas carriers (LNGC), and where the heat ingress to the tank leads to constant boil-off gas generation. The BOG is consumed in engines and boilers to maintain LNG cargo temperature and tank pressure. The safety principles and technologies to burn low flashpoint gaseous fuels safely in the marine environment, which are now being applied to other low flashpoint fuels, have been developed in the past 50 years on gas carriers.

The lower heating value of LNG specified by IMO for EEDI purposes is 48 MJ/kg, but as can be seen from Table 3 this is at the lower end of the typical range of values. In all cases the LHV is higher than that of MGO at 42.7 MJ/kg. However, its energy density per unit volume is lower than that of fuel oils and therefore a greater volume of LNG is required when substituting LNG for marine fuel oils for the same energy content; typically this is 1.8 times the volume.

	Alaska	Algeria	Australia	Indonesia	Libya	Malaysia	Nigeria	Norway	Qatar	Trinidad
Methane	99.7%	87.4%	89.0%	91.1%	66.8%	91.2%	90.4%	91.9%	90.1%	96.2%
Ethane	0.09%	8.6%	7.33%	5.51%	19.4%	4.3%	5.2%	5.3%	6.47%	3.26%
Propane	0.03%	2.4%	2.56%	2.48%	9.1%	2.95%	2.8%	1.9%	2.27%	0.42%
Butane	0.01%	0.05%	1.03%	0.88%	3.5%	1.4%	1.5%	0.2%	0.6%	0.07%
C5+	0	0.02%	0	0	1.2	0	0.02%	0	0.03%	0.01%
Nitrogen	0.17%	0.35%	0.06%	0.03%	0	0.12%	0.07%	0.6%	0.25%	0.01%
LHV (MJ/kg)	55.4	49.1	49.4	49.5	53.1	49.4	49.4	49.2	49.3	49.9
MN	94.0	74.8	72.1	74.6	52.9	72.5	71.6	79.0	75.1	86.9

Table 3: Global LNG Composition and Properties

ETHANE

Ethane is a chemical compound with the chemical formula C_2H_6. At standard temperature and pressure, it is a colorless, odorless gas. Ethane can be produced on an industrial scale from either natural gas or as a by-product of petroleum refining. Ethane is typically transported in gaseous form by pipeline, but can be liquefied by cooling to minus 89°C at atmospheric pressure. The primary use of ethane is by the chemical industry as a component in the production of ethylene, which is used to produce polyethylene, PVC, ethylene glycol and styrene.

The typical heating value of ethane is higher than that of distillate diesel fuel oil at approximately 47.8 MJ/kg. However, its energy density per unit volume when liquefied is lower than that of distillates. Therefore, as with the use of LNG, for the same energy content a greater volume of ethane is required when substituting ethane for diesel; typically this is 1.4 times the volume.

The U.S. shale gas revolution has initiated a shift in global LNG trade and stimulated growth in LNG production byproducts such as LPG and ethane. While LPG products can be transported in traditional LPG gas carriers, ethane has historically only been transported on gas carriers designed and certified for the carriage of ethylene. This growth in ethane export has therefore stimulated the construction of a dedicated ethane fleet, the so called Very Large Ethane Carriers (VLECs), consisting of ships using pressurized IMO Type C fuel containment or atmospheric membrane tanks. Such ships are already in service today transporting ethane cargoes for Navigator Gas, Reliance, Ineos and Hartmann.

LPG

LPG is a hydrocarbon fuel composed of a mixture of propane (C_3H_8) and butane (C_4H_{10}). The exact physical characteristics depend on the propane/butane ratio of the fuel – see Appendix I of this advisory for typical properties. LPG can be produced from the refining of crude oil or from natural gas. The top 5 LPG producing countries are the U.S., Saudi Arabia, China, Russia and Qatar. In recent years, propane produced from natural gas has been the fastest-growing component of overall U.S. LPG supply. LPG has substantial reserves because of its dual origins from natural gas processing and crude oil refining.

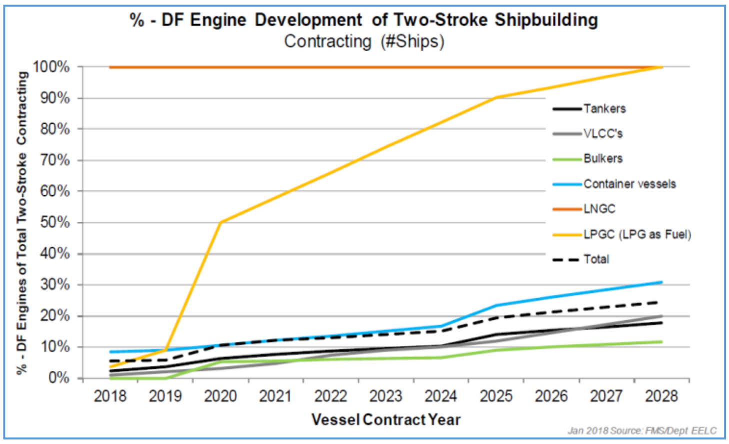

Figure 7: 2-Stroke DF Engine Fleet Projection, MAN Energy Solutions

The typical heating value of LPG ranges from approximately 45.7-46.3 MJ/kg, so is higher than that of MGO at 42.7 MJ/kg. However, its energy density per unit volume is lower than that of fuel oils and therefore, as with the use of LNG and other low flashpoint fuels, a greater volume of LPG is required when substituting LPG for marine fuel oils for the same energy content, typically 1.5 times the volume. In large quantities, LPG is stored or transported in pressure vessels at around 18 bar or semi-pressurized/refrigerated tanks at 5-8 bar and -10 to -20˚C.

As its boiling point is below room temperature, LPG will evaporate quickly at normal temperatures and pressure. However, since it is heavier than air, in the event of a leak it will settle in low spots. This therefore needs to be considered, for both LPG and ethane, when configuring the ventilation and gas arrangements for ship spaces containing LPG fuel supply or combustion equipment and machinery.

A number of LPG operators (Exmar, BW, Dorian) have recently announced that they will be burning LPG on their LPG carriers using the MAN ME-LGIP engine. Indeed, MAN ambitiously predict that 100% of 2-stroke LPG carriers will be burning their cargoes by 2028 – see Figure 7. As with the early development of LNG as a fuel on LNGC, the LPG carriers will drive the technology development. There is already a strong global trade in LPG and it has long been a fuel for commercial and domestic heating and cooking applications, together with being used as an automotive fuel. Although historically linked closely to oil prices, an increase in LPG sourced from natural gas may see a delinking in the future and further opportunities for the use of LPG as fuel.

METHANOL

Also known as methyl alcohol, methanol is a clear, odorless chemical compound that has just an additional oxygen atom compared to methane and therefore has the chemical composition CH_3OH. It is water soluble and biodegradable. Methanol is used to produce many other chemical derivatives, which are in turn used to manufacture many everyday products. Today methanol is predominantly produced from natural gas and coal, but is seen as an ideal future fuel since it can be derived from many renewable energy sources. These include bio wood sources but also by combining hydrogen produced from water electrolysis with carbon captured from the atmosphere.

Methanol is a liquid at atmospheric pressure, with a boiling point of 65˚C. Its energy density, at 19.9 MJ/kg, is significantly lower than that of conventional fuel oils and therefore requires 2.4 times more storage volume for the same energy content.

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Methanol has historically not been classified as toxic by the IBC Code when carried as a cargo, but is categorized as toxic by typical Safety Data Sheets (SDS). Methanol also burns with an invisible flame, so requires special fire detectors, fire extinguishing systems and operational procedures. The use of methanol as a marine fuel does therefore bring its own challenges, but falling within the scope of the IGF Code, the fuel specific safety requirements are already under development and apply the same basic safety principles as adopted for natural gas.

Methanol has clean burning properties enabling reduced exhaust emissions, in particular SOx and PM, with lower NOx emissions than conventional fuel oils. Methanol burning engines are however expected to require exhaust emissions aftertreatment equipment to reach IMO Tier III levels, or alternatively by mixing water with the methanol fuel to lower peak combustion temperatures to achieve Tier III.

HYDROGEN

Hydrogen is also under consideration as a marine fuel and, when produced from renewable energy, is the cleanest fuel of all those identified as potential long-term energy carriers and fuels. However, it is not without its own challenges, including safely containing the hydrogen molecules themselves.

The heating value of hydrogen is the highest of all potential fuels at approximately 120.2 MJ/kg. However, its energy density per unit volume, even when liquefied, is significantly lower than that of distillates. Therefore, as with the use of LNG and the other low flashpoint fuels, for the same energy content a greater volume of hydrogen is required when substituting liquefied hydrogen for diesel, typically 4.1 times the volume. This means that compressed or liquefied storage of pure hydrogen may only be practical for small ships. The deep-sea fleet will likely need a different fuel as a hydrogen carrier, such as ammonia, to limit significant loss of cargo space.

The use of hydrogen as a marine fuel is covered within the scope of the IGF Code, but at present there are no specific initiatives at IMO to develop hydrogen-focused requirements. This could however be a positive rather than a restrictive position, since it allows the risk based approach of the alternative design process to be applied and greater freedom in design solutions. The only IMO reference instrument in place is that developed to support the carriage of liquified hydrogen, MSC.420 (97)[32], and applicable to ships subject to the IGC Code. There are pilot projects investigating the use of hydrogen as a fuel, the deep-sea transport of liquefied hydrogen and also liquefied hydrogen bunker ship concepts.

Developing the hydrogen economy has been seen in energy and transport sectors as the potential long term objective to provide a sustainable and clean future. This requires the production of hydrogen from clean renewable sources and also the commercialization of fuel cells. Fuel cells supplied directly from hydrogen fuel sources (rather than through the reforming of other hydrogen carriers) is the preferred option. IMO has been developing requirements for fuel cells for some time and currently plans to release these as 'interim guidelines' in due course. The long term take-up of hydrogen as a marine fuel for the deep sea fleet requires both substantive developments in hydrogen fuel supply and fuel cells. This may be achievable in the 2050 timeline, but there are also some projects looking at using hydrogen, as a supplementary/mixed fuel, in conventional diesel and DF engines as a means of reducing the CO_2 footprint. This may prove to be a valid route to stimulating the longer term use of hydrogen as a marine fuel and allowing the combustion of hydrogen in near conventional reciprocating internal combustion engines.

AMMONIA

There is also increased interest in ammonia as a long-term marine fuel. With the chemical composition of NH_3 it is a direct solution for zero carbon combustion at the prime mover. If produced using hydrogen from renewal energy sources, it has the potential to become the clean and sustainable fuel choice. Although there are obvious safety issues to consider, there is a long history of safe transport and storage of ammonia. It is also a widely traded global commodity used as a feedstock for many products such as fertilizers.

The typical heating value for ammonia of approximately 22.5 MJ/kg is similar to methanol. As with all the alternative fuels being considered, the energy density per unit volume of ammonia is lower than that of fuel oils and therefore for the same energy content would require approximately 2.4 times the volume. In large quantities, ammonia can be transported in LPG carriers and has a boiling point of -33˚C.

Ammonia has been used as a fuel before in road transport when conventional fuels were in short supply. The engine technology developed by MAN Energy Solutions for the combustion of liquid low flashpoint fuels such as LPG, methanol and DiMethyl Ether (DME) - the slow speed ME-LGI engine - is readily suitable for combustion of ammonia in a similar manner.

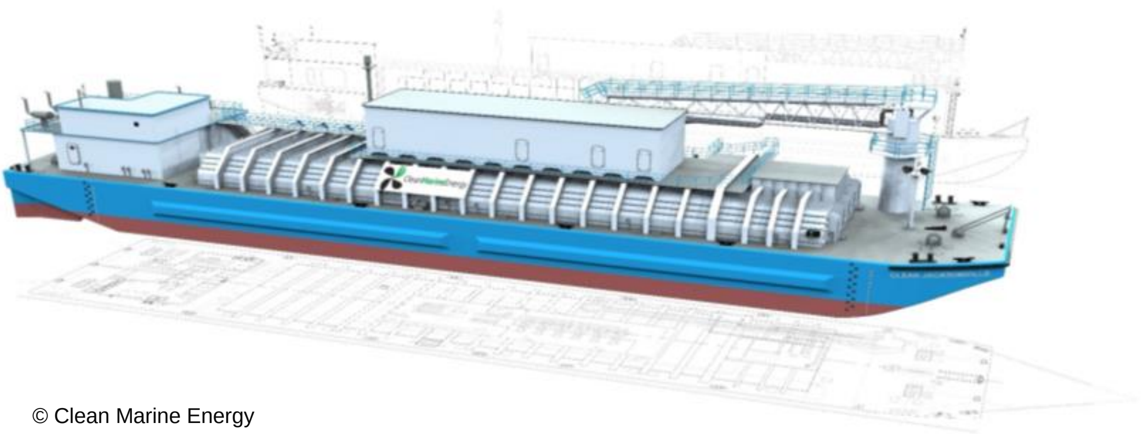
As indicated in the 'IMO Safety' section of this advisory, the 2016 IGC Code permits the burning of cargoes other than natural gas when not identified as toxic products. Therefore this would exclude the burning of ammonia cargoes on IGC Code ships, unless appropriate regulations were agreed or as an exemption with the vessel flag Administration.

See Appendix I of this advisory for typical properties of low flashpoint fuels.

USE OF LOW FLASHPOINT FUELS - OVERVIEW

FUEL AVAILABILITY

Fuel availability for any of the low flashpoint fuels is one of the challenges to widespread take up, and is frequently discussed in the context of the ‘chicken and egg’ conundrum. However, there are initiatives underway to develop new marine fuel supply chains. In all cases the three basic routes to supply are truck-to-ship, ship-to-ship and tank-to-ship. Truck-to-ship is usually the first bunkering method applied but is only suitable for delivering small quantities. Land based tank infrastructure can require significant investment and take many years to develop and obtain the necessary approvals. Hence the use of dedicated bunker vessels is anticipated as a preferred option for many operators.



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The U.S. shale gas developments have stimulated a shift in global LNG supply chains for primary energy purposes and the transition of U.S. LNG import terminals to export terminals. This has also stimulated an increase in exports of U.S. natural gas production byproducts such as LPG and ethane. This growth in LNG availability has in turn motivated a number of operators to develop their own LNG supply chains, and also oil majors and independent operators to invest in a number of dedicated LNG bunker vessels to support the anticipated growth in LNG as a marine fuel. The LNG bunker supply infrastructure is therefore starting to develop, with LNG now available in most of the main marine bunkering hubs.

The LNG carrier fleet is generally built for the purposes of delivering large amounts of LNG across the globe; this has necessitated the construction of dedicated small LNG bunker vessels in the range of 200-10,000m^3. These bunker vessels can be expensive to construct and frequently are built for specific contract supplies, e.g. the largest LNG fueled container vessels currently on order also have a dedicated 18,600m^3 LNG bunker vessel under construction in China.

Similar developments can be anticipated for the other low flashpoint fuels under consideration. For example, LPG carriers are traditionally much smaller than LNG carriers and therefore there already exists a reasonably large small LPG carrier fleet that could be utilized as LPG bunker vessels relatively easily. Similarly, liquid fuels such as methanol are simpler to handle and would be closer to conventional bunker vessels. In addition to methanol being traded and transported in chemical carriers for many years, there is also the experience of the OSV and PSV fleets handling methanol for the offshore industry, which can therefore also be reference points for the wider take-up of methanol as a bunker fuel.

We can see therefore that the alternative fuel bunker fleet is developing, and will continue to do so, but the specifications of the bunker vessels will be very different depending on the fuel, or fuels, they wish to carry. Since the DF engines require conventional HFO or MGO fuels for the pilot fuel there is also a continuing need to bunker conventional fuels when bunkering LNG, albeit in smaller quantities than if it were the main fuel. This has driven the development of so-called multi-fuel, or multi-purpose, bunker vessels such as the “Bunker Breeze” located in Algeciras in Spain that is configured to supply 4,000m^3 of fuel oil, 1,000m^3 of MGO and 1,200m^3 of LNG.

See Appendix IV for a listing of some of the LNG bunker vessels already in operation.

In Europe the EU has supported LNG as fuel through funding for specific ship projects and also through the development of the LNG ports TEN-T network. Dedicated LNG bunker vessels are in service in Algeciras, Huelva, Rotterdam, Stockholm, Zeebrugge and the Baltic/North Sea region.

For other low flashpoint fuels the infrastructure is less advanced, but the existence of established commercial trading products can support such developments. For example, LPG and methanol are widely traded commodities with an existing global distribution network that could be leveraged to support marine fuel bunkering.

In all cases to date the early adopters and pilot projects have negotiated fuel supply and infrastructure development in parallel with the construction or conversion of the low flashpoint fueled ships.

EMISSIONS PROFILES AND ENVIRONMENTAL COMPLIANCE

The determination of the emissions characteristics of reciprocating internal combustion engines is a complex science that is tightly regulated through international, regional, national and local regulations and verified through application of defined standards, e.g. the IMO NOx Technical Code is based on parts of the ISO 8178[33-38] series of standards. These limits and standards focus on limiting and certifying the gaseous (NOx, HC, CO) and particulate matter (PM) emissions from the engine. However, of these IMO only sets limits on NOx. SOx emissions are regulated through control of the sulfur content of the fuel. For certain engine types there are specific allowances, such as Otto process natural gas engines (which are known to emit high amounts of methane in the exhaust, with methane having a large GWP) only historically having HC regulated as NMHC (non-methane HC) rather than THC (total HC) in land based emission regulations. There may also be additional limits to consider depending on the engine, fuel or aftertreatment technology used to achieve emissions compliance. For example, formaldehyde emissions from Otto process natural gas engines, or ammonia slip from engines using Selective Catalytic Reduction (SCR) to control NOx, or vanadium emissions from vanadium-based SCR catalysts.

For U.S. flagged ships, the applicable emissions regulations are regulated through the Code of Federal Regulations (CFR) which can apply additional, or different, limits to those regulated by IMO. For larger engines typically used in deep sea ships there is closer alignment to the IMO regulations, but these are different emissions control regimes with their own limits, test and certification requirements. For marine applications the most relevant CFR instruments are 40 CFR 1042[39], 40 CFR 1043[40], 40 CFR 94[41] and 40 CFR 1065[42]. The U.S. Environmental Protection Agency (EPA) developed these CFR standards with emissions limits characterized according to engine cylinder displacement. The applicable emission limits change with time, power and engine cylinder displacement. Category 1 engines have cylinder displacements below 5 liters for Tier 1 and 2 emission limits and below 7 liters for Tier 3 and 4 limits. Category 2 engines have cylinder displacements of between 5-30 liters for Tier 1 and 2 emissions limits and between 7-30 liters for Tier 3 and 4 limits. Category 3 engines are defined as having cylinder displacements above 30 liters. A full study on emissions profiles and regulations is beyond the scope of this publication, however Table 4 shows a simple comparison of gaseous and particulate emission limits for large internal combustion engines from U.S., EU and IMO regulations, together with EU and IMO fuel sulfur limits.

	NOx (g/kWh)	HC (g/kWh)	CO (g/kWh)	PM (g/kWh)	PN (1/kWh)
U.S. EPA Tier 4 - Category 1/2 engines, > 3700kW	1.8	0.19	5.0	0.12	-
U.S. EPA Tier 3 - Category 3 engines	3.4-1.96*	2.0	5.0	-	-
EU Euro 6 Heavy Duty diesel engines (2013)	0.4	0.13	1.5	0.01	$8.0x10^{11}$
IMO Tier III (2016)	3.4-1.96*	-	-	-	-
	* Engine speed based limit, 130-2000rpm				

	1996	2000	2005	2009
EU Road Diesel Fuel Sulfur Limit (ppm)	500	350	50	10

	1997	1997	2010	2012	2015	2020
IMO Fuel Sulfur Limits (ppm)	45,000	15,000	10,000	35,000	1,000	5,000
	Global	ECA	ECA	Global	ECA	Global

Table 4: Emissions and Fuel Sulfur Limits

Emissions profiles can vary widely depending on the engine technologies, and fuels used by those engines, and thus the limits set vary by engine size, power, type and fuel. The determination and certification of the emissions profile from a specific engine type is dependent on accurate measurements of many emissions, ambient, fuel and engine parameters. These are subject to third party verification and certification following the applicable tests, e.g. ISO 8178-1 for test bed measurement systems of gaseous and particulate measurements, ISO 8178-5 for test fuels, and ISO 8178-6 for reporting, etc.

The use of natural gas and other low flashpoint fuels, which are inherently low in sulfur, are a means of complying with the SOx emissions limits of MARPOL Annex VI, but also offer significant further reductions in the SOx and the sulphate portion of PM, since the sulfur content of these fuels is typically less than 30ppm. NOx formation is linked to peak combustion temperatures and these are much higher for diesel engines in general compared to gas engines. Similarly, this means that DF engines using the lean burn Otto process to burn natural gas have much lower NOx emissions than those using the Diesel diffusion combustion process. A comparison of the general emission profiles for current marine DF low and high pressure engine technologies, when operating on natural gas, compared to the same engine using diesel or residual fuels, is shown in Figure 8. The LP DF engines can meet the current IMO NOx limits without emissions abatement equipment.

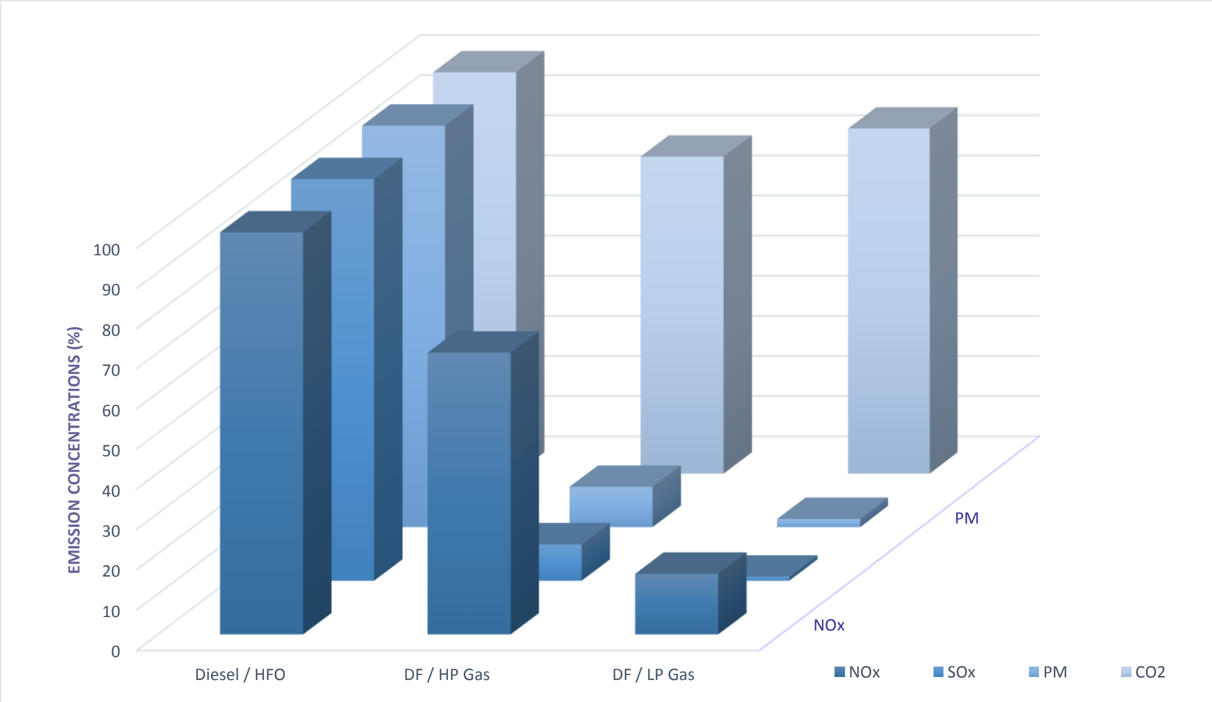


Figure 8: Dual Fuel Engine Emissions

Energy efficiency, Global Warming Potential (GWP), CO_2 emissions and GHG emissions are generally regulated through other instruments. However, the GHG and gaseous emission requirements must be considered at the same time. The trend from land based and automotive sectors is to reduce all of these emissions to air at the same time, so as to concurrently reduce the harmful impact to human health and to the natural environment. The adoption of the initial GHG strategy by the IMO MEPC in April 2018 now signals the further measures on energy efficiency and GHG reduction that IMO intends taking. With ambitions to further reduce emissions of CO_2 and GHG from shipping by at least 50% by 2050, compared to 2008, while at the same time pursuing efforts towards phasing them out entirely, signals a strong commitment to the development and deployment of clean and sustainable fuels and technologies in the marine environment. To determine the complete emissions profile of an engine using a specific fuel requires careful consideration of the gaseous and particulate emissions at the tailpipe, but also needs to consider the whole fuel production, transport and operational emissions, on a well-to-funnel, or well-to-wake, basis to accurately compare the environmental impacts of each of the routes to compliance. Accurate marine emissions factors, for each of the fuels being considered, are therefore required to provide robust comparative studies. The University Maritime Advisory Services (UMAS) study commissioned by Transport & Environment of 'LNG as a marine fuel in the EU'(43) from June 2018 and the thinkstep 'Life Cycle GHG Emission Study on the use of LNG as Marine Fuel'(44) on behalf of SEA\LNG and SGMF from April 2019 are examples of such studies. The use of carbon capture technologies, and/or carbon taxes, may be necessary to stimulate the uptake of some fuels and technologies and to create a level playing field that can move the marine industry towards the use of carbon free and carbon neutral fuels and thereby meet the IMO GHG ambitions.

Environmental Compliance

Compliance with MARPOL Annex VI Regulation 13 for NOx emissions is demonstrated in the usual manner by test bed emissions testing in accordance with the NOx Technical Code and issuance of an EIAPP (Engine International Air Pollution Prevention) certificate. A number of updates have been made to Annex VI and the NTC by MEPC.251(66)(45) and MEPC.272(69)(46) to accommodate emissions testing of gas and dual fuel engines using alternative fuels. Engines are to be tested on all fuels intended to be used in operation. Fuel samples, gaseous and liquid as applicable, taken at the parent engine emissions testing are analyzed independently for composition and the results used in the calculation of the respective cycle weighted NOx emission value.

Further guidance on the application of Annex VI and the NTC Tier III requirements for gas and dual fuel engines has been issued by IMO under MEPC.1/Circ.854(47). In particular this clarifies industry questions regarding recording the engine NOx Tier status at entry and exit to ECAs, process to be followed in the event of a failure or gas non-availability, and the obligations for any Auxiliary Control Device (ACD) or features that limit operation on gas (for example low load operation), to be clearly detailed in the approved technical file.

Compliance with MARPOL Annex VI Regulation 14 for SOx would be by the use of sulfur compliant pilot fuels regulated and documented in the usual manner by the BDN and MARPOL fuel samples, together with documentation to support the sulfur content of the alternative fuel in accordance with Annex VI Regulation 18.4.

Compliance with IMO's EEDI requirements for energy efficiency is again undertaken through the usual certification channels and finalized with issuance of the IEEC based on the applicable reference line and EEDI phase. For dual fuel applications, there are however some additional complications with regard to which fuel is considered the primary fuel and the respective conventional and alternative fuel tank capacities. This is detailed in the latest IMO EEDI calculation guidelines MEPC.281(70)[48] for the calculation of the attained EEDI value, and can lead to a lower EEDI value where the primary (low flashpoint) fuel has a lower CO_2 footprint than conventional fuels. As noted in the 'Energy Efficiency and GHG' section of this advisory, further work on methane emission regulation and robust lifecycle GHG/carbon intensity guidelines for all fuel types is part of the ongoing IMO work on GHG reduction.

ABS RULES

ABS has the two IMO safety codes related to the carriage and use of natural gas and other low flashpoint fuels embedded directly in the Rules. The IGC Code is incorporated under Part 5C-8 of the ABS *Rules for Building and Classing Marine Vessels* (MVR) for specific vessel types, *Vessels Intended to Carry Liquefied Gases in Bulk*, and the IGF Code under part 5C-13 for *Vessels Using Gases or other Low-flashpoint Fuels*.

Both 5C-8 and 5C-13 of the Rules also incorporate additional ABS requirements and interpretations, together with applicable IACS URs and UIs. The text of the statutory codes is shown in *italics* to differentiate between the statutory Code text and additional ABS or IACS text.

Since both IGC and IGF Codes have been developed on a prescriptive basis for the burning of natural gas, there are additional steps to be undertaken when burning other low flashpoint fuels. This involves a risk assessment process (see below) but is captured within both sections of the Rules to enable the assignment of the applicable notation to any ship type. These additional notations recognize application of the alternative or equivalent design approaches outlined in the IMO Codes for the burning of low flashpoint fuels other than natural gas. For example, the '**LFFS(DFD-Methanol)**' notation would be assigned to an IGF Code Low Flashpoint Fueled Ship using methanol as a fuel, and the '**DFD-LPG**' notation would be assigned to an IGC Code gas carrier using LPG as a fuel.

ABS publications that supplement the Class and statutory requirements and can facilitate design of IGC and IGF vessels and application of natural gas or other low flashpoint fuels are tabulated in Appendix V. All ABS Rules, Guides and Guidance Notes can be downloaded free of charge at www.eagle.org

Appendix VI provides a list of frequently asked questions for LNG and other low flashpoint fuels, which includes examples of typical rule and regulatory enquiries.

RISK ASSESSMENT

Risk assessments and engineering analyses are required to differing extents for the use of LNG and other low flashpoint fuels on marine vessels. Both the IGC and IGF Codes include such requirements, but the extent and process to be followed should be agreed with the flag Administration in each case. Where required, risks should be analyzed using acceptable and recognized risk analysis techniques, eliminate the risks where possible, mitigate those risks that cannot be eliminated, and document the process. The risk assessment may utilize HAZID, HAZOP, FMEA, or other recognized risk analysis techniques, and provide valuable design recommendations. The main objective is to demonstrate that the design meets the overall safety objectives and provides an equivalent level of safety. ABS can facilitate such risk assessment studies at any stage of a concept or design maturity.

The IGC Code does require risk analysis for certain ship arrangements, such as an integrated cargo control system, but is not required for the use of natural gas as a fuel when the requirements of Chapter 16, 'Use of Cargo as Fuel' are applied. In accordance with 16.9 of the IGC Code, other cargo gases that are not toxic may also be used as fuel provided the use is agreed by the Administration, the installation complies with the requirements of 16.9, and provides the same level of safety as natural gas. The only prescriptive requirement under 16.9 that deviates from the standard natural gas requirements is 16.9.5, which requires that both the ventilation inlet and outlet of the fuel gas piping double barrier should be taken from a non-hazardous area external to the machinery space.

For statutory IGC applications, demonstrating the same level of safety as natural gas typically requires application of a risk assessment process. The extent of that risk assessment will be dependent on the fuel being considered and the extent to which the design deviates from the IGC prescriptive requirements for natural gas. Although many proposed designs for using gases other than natural gas as fuel on gas carriers, such as ethane or LPG, can be adequately designed in accordance with the requirements and intent of the IGC Code for natural gas, application of the 'Equivalents' process of 1.3 of the IGC Code would typically be required by the flag Administration. Upon successful conclusion, this process requires the flag Administration to make a notification to IMO through the IMO GISIS database that an equivalent has been applied to that specific vessel; ABS can facilitate that process with support to the flag Administration in our capacity as RO for the majority of the worlds flags. The 'Equivalents' GISIS notification enables the information to be available to other contracting governments to the SOLAS convention.

For ships using natural gas as fuel (part A-1 of the IGF Code) and complying with the detailed prescriptive requirements contained in that part, a risk assessment need only be conducted where explicitly required. Section 4.2.2 of the IGF Code details the parts of the IGF Code that are to be considered for risk assessment when burning natural gas as fuel. For example, this includes reference to fuel containment systems under 6.4.1.1 of the IGF Code. ABS' understanding of the intention of that specific risk assessment requirement is to capture novel fuel containment systems within a risk assessment, but also evaluate any fuel containment features that deviate from the Code requirements and to assess the proposed arrangement of LNG tanks in all cases. Another example is the reference to closed and semi-enclosed bunker stations under 8.3.1.1 of the IGF Code, for which IACS UI GF9[49] provides guidance that the risk assessment "special consideration" is to include, but not be restricted to, the following design features:

- Segregation towards other areas on the ship;
- Hazardous area plans for the ship;
- Requirements for forced ventilation;
- Requirements for leakage detection (e.g., gas detection and low temperature detection);
- Safety actions related to leakage detection (e.g., gas detection and low temperature detection);
- Access to bunkering station from non-hazardous areas through airlocks; and
- Monitoring of bunkering station by direct line of sight or by CCTV.

A further example is the requirement for determining the capacity of LNG drip trays, as required by 5.10.5 of the IGF Code, which effectively requires an engineering calculation, or analysis of the maximum credible release for the proposed piping and shutdown arrangements, as may be determined by the risk assessment.

For application of other low flashpoint fuels to IGF Code ships, a risk assessment is to be undertaken to confirm that the risks from the use of the low flashpoint fuel affecting persons on board, the environment, and the structural strength or the integrity of the ship are addressed. The IGF Code requires that consideration is given to the hazards associated with physical layout, operation and maintenance following any reasonably foreseeable failure. The risk assessment should consider, as a minimum, loss of function, component damage, fire, explosion and electric shock.

Similar to the process for IGC ships detailed above, the IGF Code also includes a requirement for demonstrating equivalence. Section 2.3 of the IGF Code details the process for 'Alternative design' and indicates that fuels not specifically addressed by the IGF Code may be used, provided they provide an equivalent level of safety of the relevant chapters of the IGF Code. The equivalence is to be demonstrated as specified in SOLAS Regulation II-1/55, which refers to MSC.1/Circ.1212[9].

The process to demonstrate an equivalent level of safety through the risk assessment process will vary depending on the complexity of the design and the extent it deviates from the prescriptive arrangements. The flag Administration may also have requirements and expectations on the process. Therefore, dialogue with ABS and the flag Administration at an early stage of the development process is important for the execution of a successful project, and may require reevaluation as the design matures and the complexity of the risk assessment increases.

The main activities in the risk assessment process are:

- Develop the risk assessment plan;
- Prepare and conduct the initial risk assessment; and
- Conduct an update of the initial risk assessment and/or perform additional detailed risk assessment, as applicable.

Risk assessment plan – The risk assessment plan, sometimes referred to as the Terms of Reference (ToR), defines the assessment scope, proposed risk methodology, workshop schedule, and team details. Dialogue with the flag Administration will be required to confirm that any flag specific requirements are addressed. For example, USCG Policy letter No. 01-12 CH-1[25] requires additional items from those identified by 4.2.2. of the IGF Code to be considered in the risk assessment. These include gas fuel storage tanks located below or directly adjacent to accommodation spaces, service spaces or control stations and requests for higher loading limit (LL) than that determined by application of 6.8.1 of the IGF Code. For the latter request, the USCG has clarified that a LL up to 95% would only be permitted where the risk assessment identifies that the probability of the tank contents being heated up due to fire is very small based on the tank location and insulation. A well-defined risk assessment plan is therefore necessary to efficiently execute the risk assessment.

Initial risk assessment – Prior to undertaking the initial risk assessment workshop, it is good practice for the facilitator to distribute relevant plans and details so the risk assessment team is familiar with the risk assessment plan and the concept design prior to the workshop. A Hazard Identification (HAZID) risk assessment technique is typically applied at the initial risk assessment. Utilizing a variety of tools to identify and capture the identified hazards, the HAZID may, for example identify further engineering analyses, such as gas dispersion studies, to be conducted to evaluate that the hazard and safety mitigation has reduced the hazard to an as low as reasonably practical (ALARP) level. The HAZID may also produce recommendations that certain systems are further evaluated by a Hazard and Operability (HAZOP) assessment.

Initial risk assessment update or additional risk assessment – As the project matures, a more detailed or refined risk assessment may be required if the initial risk assessment did not provide sufficient information to confirm that the hazards have been suitably mitigated to acceptable risk levels, or if the initial risk assessment recommended the aforementioned further analyses such as HAZOP or gas dispersion studies be undertaken to verify the hazards have been reduced to ALARP and provide an equivalent level of safety. An update to the initial risk assessment may also be required if the initial risk assessment was undertaken at an early stage in the design process and the design has deviated, or matured, to an extent that the initial risk assessment needs to be repeated.

From the above we can conclude that risk assessment forms a part of the process for application of natural gas as fuel to IGF Code ships, and for other low flashpoint fuels to all ship types. The extent of the engineering analyses is to be to the extent acceptable to the flag Administration, but the objective is to demonstrate that the same level of safety as natural gas has been achieved. It is ABS' experience that through the many risk assessments that have already been applied, for natural gas and other low flashpoint fuel concepts (that apply the principles and prescriptive requirements for natural gas, as far as applicable, together with considering the specific fuel properties), then standardized designs and approaches have already emerged. This design and concept approval experience, together with the growing knowledge gained by the early technology adopters already burning ethane and methanol on ships in service, means that the number of viable marine fuel options is growing.

For more information on risk analysis techniques, see the ABS *Guide for Risk Evaluations for the Classification of Marine-Related Facilities* and the ABS *Guidance Notes on Risk Assessment Applications for the Marine and Offshore Oil and Gas Industries*. ABS offices and specialist risk and subject matter expert groups, such as GGS and Advanced Solutions, can assist at all stages of the risk assessment process. See also IACS Recommendation No.146[22] for a detailed risk assessment process tailored to meet the requirements for risk assessment as required by the IGF Code.

BUNKERING

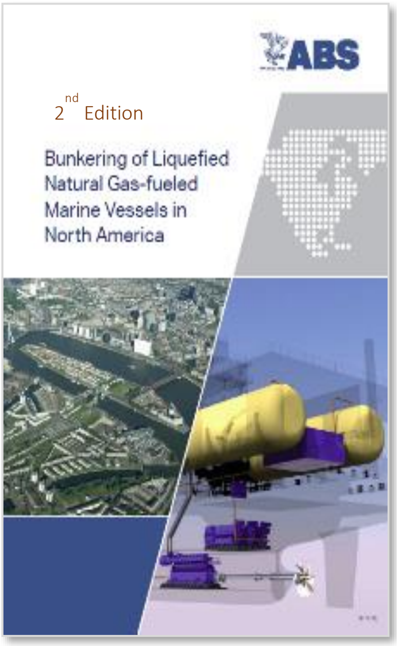
Together with fuel supply and infrastructure, the bunkering of LNG and other low flashpoint fuels remains one of the challenges to widespread adoption of these fuels. However, as we have seen from the 'Fuel Availability' section of this advisory there are a number of LNG bunkering projects already in place. Furthermore, in the past 10 years there have been many industry initiatives that have helped develop technical specifications, standards and best practices to support the development of the LNG bunkering infrastructure and provide regulatory frameworks for port authorities, bunker suppliers and other stakeholders. Specifically, and as detailed above, the ISO 20519:2017[13] standard covering the LNG bunkering transfer systems, the ISO/TS 18683:2015[14] LNG supply guidelines, the IACS LNG bunkering guidelines[21] and the USCG policy letters[26, 27] have all supported this process.

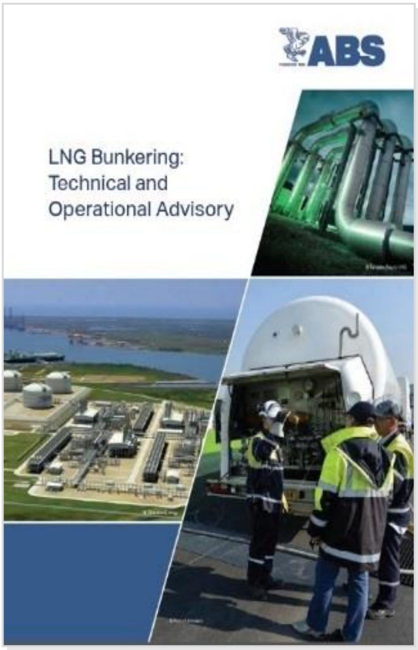
Also, during that period, the Society for Gas as a Marine Fuel (SGMF) has been created to support the uptake of gas as fuel and has published a number of documents providing guidance for gas as fuel and LNG bunkering. These include the "Safety Guidelines – Bunkering"[50], "Bunkering of Ships with LNG"[51], "Simultaneous Operations during LNG Bunkering"[52] and "Recommendation of controlled zones during LNG bunkering"[53] publications, which are all available through the SGMF website.

EMSA also published a comprehensive study in 2018, the "Guidance on LNG Bunkering to Port Authorities and Administrations"[54] to support the EU adoption of LNG as a marine fuel.

ABS has also been active in this process and published the *North American LNG Bunkering Study*[55] to provide comprehensive information on LNG, bunkering, training, risk assessment, etc. for gas fueled ship operators, bunker suppliers and state and port authorities. While targeting U.S. industry developments this document also provides detailed generic information applicable to all considering LNG as a marine fuel. ABS has also published the *LNG Bunkering Advisory*[56] to provide information on tank capacity, compatibility, operational issues, monitoring, bunkering and custody transfer.

Furthermore, in January 2017 ABS published the ABS *Guide for LNG Bunkering* to outline the LNG bunkering requirements for the design, construction and survey of liquefied gas carriers and barges fitted with dedicated LNG transfer arrangements and intended to operate in regular LNG bunkering service. Among other safety topics, the guide addresses bunkering station safety, lifting and hose handling equipment, control, monitoring and ESD safety systems, and emergency release systems. Compliance with the Guide can be recognized with the general optional '**LNG Bunkering'** notation. Where a vapor return system is fitted to deal with vapor return from the receiving vessel, an optional '**VRS'** notation may also be assigned.





There are also similar efforts underway for the development of a methanol bunkering infrastructure. As a liquid fuel at ambient conditions, bunkering equipment and practices for methanol are much closer to that for conventional fuel oil bunkering. Historical expertise and best practice has been developed through the chemical tanker sector and ships subject to the IBC Code[57], but also through the offshore sector with the experience gained through handling methanol for drilling operations. For example, the USCG CG-ENG policy letter 03-12[58] provides USCG policy for implementation of IMO Resolution A.673(16) for handling of hazardous and noxious liquid substances in bulk on OSVs, with specific requirements for handling methanol.

The Methanex Corporation is the world's largest producer and supplier of methanol and is a good source of information for methanol prices, supply infrastructure, safe handling practices and information on methanol as a marine fuel. The Methanol Institute is also a key player in this sector promoting the use of methanol as a fuel. For further information on methanol as a marine fuel see the FCBI Energy "Methanol as a Marine Fuel Report"[59] and the Methanol Institute "Methanol Safe Handling Manual"[60].

TRAINING

Training of personnel onboard ships burning natural gas or other low flashpoint fuels is essential to verify crews are competent in dealing with the additional risks and hazards associated with each fuel. Part C-1 of the IGF Code details requirements for drills, emergency exercises and operation of gas fueled ships. These include regulations for maintenance, bunkering operations, enclosed space entry, inerting and purging of fuel systems and hot work on or near fuel systems. Furthermore, both IGC and IGF Codes refer to the STCW Convention[61] for the training requirements for operational and safety aspects for liquified gas carriers and ships using gases or other low flashpoint fuels respectively. The STCW Convention and Code were amended in 2015 by MSC.396(95)[62] and MSC.397(95)[63] to add specific training requirements and certification for IGF Code seafarers, and which entered into force on 1 January 2017.

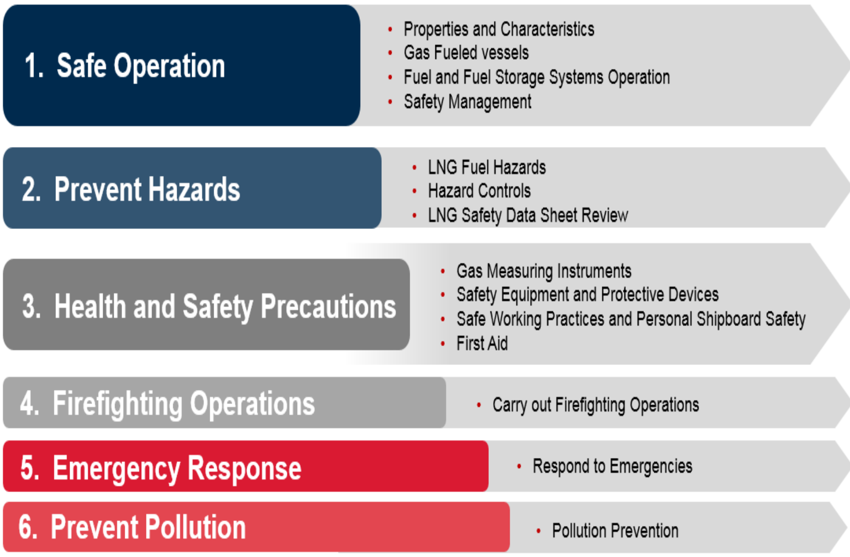
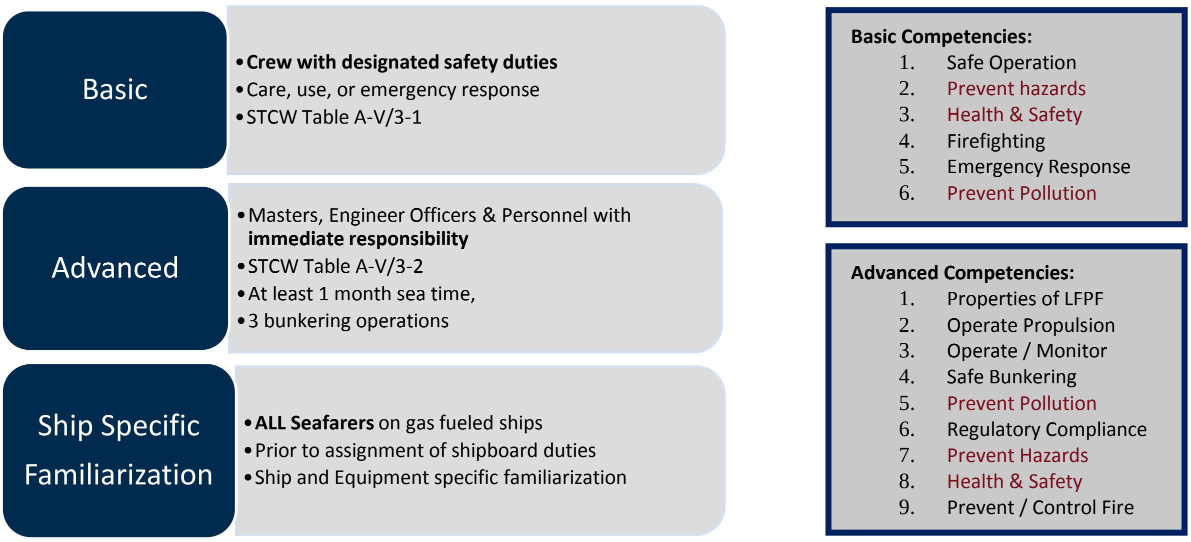


Figure 9: Learning Objectives

The new IGF Code regulations identified under STCW Table A-V/3-1 and A-V/3-2 describe the required competence, knowledge, understanding and proficiencies for basic and advanced training. The learning objectives are shown in Figure 9. Vessels under the jurisdiction of flag Administrations signatory to SOLAS should ensure that seafarers assigned to gas fueled ships have the specified certificates of proficiency in accordance with the regulations; the Administration shall approve courses and issue endorsements indicating completion of the qualification. The training structure comprises 'Basic training' for seafarers with "… designated safety duties associated with the care, use or in emergency response to the fuel …" and 'Advanced training' for "… Masters, engineer officers and all personnel with immediate responsibility for the care and use of fuels and fuel systems on ships subject to the IGF Code …". The Basic training is a pre-requisite for the Advanced training. The Basic training must include practical firefighting exercises and instruction conducted under approved and realistic conditions. For Advanced training, there is also a requirement for 30 days of seagoing service onboard an LNG fueled vessel and three bunker transfer operations, two of which may be simulated. The training competencies are shown in Figure 10.

Figure 10: Training Competencies



There is an equivalency provision for seafarers who have been certified and hold a valid endorsement for service on liquefied gas carriers. However, this means certain minimum seagoing service and cargo transfer participation requirements must be met, e.g. 3 months / 3 LNG transfers within the last 5 years for Advanced training equivalence. This provision is sometimes mistakenly interpreted as meaning that attending the liquefied gas carrier training course alone is sufficient for IGF Code gas fueled ships compliance.

While Administrations are yet to develop their own detailed routes to proficiency certification, ABS has worked extensively in North America with the USCG and Transport Canada, and in partnership with United States Maritime Resource Center (USMRC), to develop training courses for gas fueled ships that meet the requirements of the STCW Convention. Training courses can be tailored to the shipowners requirements but as a minimum include a combination of classroom training, fuel containment and fuel supply system simulation, bunkering simulation and practical fire-fighting exercises. The typical Basic training schedule comprises two days of classroom instruction followed by one day of LNG firefighting, including live fire field exercises held at specialist facilities such as the Massachusetts Firefighting Academy or TEEX Brayton fire training field (Texas A&M). For Advanced training competency there are two additional days of classroom training for masters, engineer officers and others designated as having immediate responsibility.

VESSEL REFERENCES

The first application of natural gas as fuel outside dedicated gas carriers started in Northern Europe in the year 2000 with the conversion of the short sea ferry *Glutra*. Since then the use of natural gas as fuel has expanded into all ship types and with ever-increasing ship size, such that it is now considered a viable alternative to conventional fuel oil powered ships. However, the number of LNG and alternative fueled ships currently in operation is still a relatively small part of the 90,000 vessel global merchant fleet. Excluding gas carriers and inland waterway vessels, as of June 2019, around 130 gas fueled ships have been delivered since the year 2000, with approximately another 100 on order. Significantly, some of the largest ships on order in recent years, containerships and cruise ships, have been ordered with LNG fueled propulsion systems. Appendix III to this publication contains a list of the delivered LNG, ethane and methanol fueled ships.

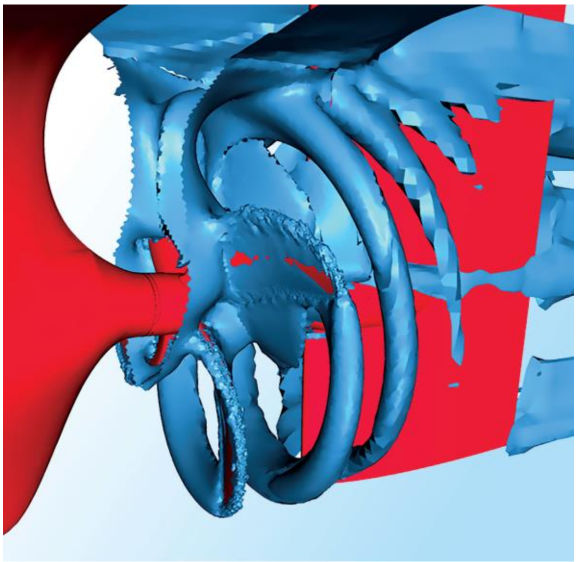
Appendix III does not include details of the LNG fueled gas carriers since the LNG as fuel fleet is more mature than the other low flashpoint fuel fleet. As with the historic development of technologies for the burning of natural gas as fuel on the LNGC fleet, which is a convenient means for controlling LNG tank temperatures and pressures, there is an increase in dedicated gas and chemical carriers also consuming their cargoes as fuel. In many cases this is for convenience, cargo management and as a means of complying with the fuel sulfur limits of MARPOL Annex VI Regulation 14; we see and expect the trend of burning LNG on LNG carriers, LPG on LPG carriers, ethane on ethane carriers and methanol on methanol carriers to continue. No doubt other fuels under consideration, such as ammonia, may also see initial application on dedicated gas or chemical carriers. There are also several pilot projects trialing hydrogen and biofuels.

As can be seen from Appendix III, there are IGC Code ships designed specifically for the emerging global ethane trade that have being delivered with ethane burning engines. Wärtsilä delivered the world’s first ethane fueled gas carriers in 2015 for the Ineos Dragon class ships fitted with 6L50DF and 6L20DF engines capable of burning LPG or ethane. In the case of the ABS Classed *Navigator Aurora* this was originally delivered as an LNG powered ethylene/ethane/LPG carrier, but became the world’s first ship to be converted to burn ethane in July 2018 when the MAN 6S50ME-C 8.2 GI main engine was converted to the ethane burning “GIE” designation.

Similarly the *Stena Germanica* Ro-Pax ferry was converted for burning methanol as a fuel in 2015. There are also the seven methanol powered methanol carriers in operation for Waterfront shipping, with another four on order for delivery in 2019.

TECHNO ECONOMIC ANALYSIS

ABS has developed a number of services, tools, models and practices to help shipowners, operators and designers assess the right technology, or fuel strategy, appropriate for meeting the applicable Class and statutory requirements, together with the needs and operating profile of their fleet. These services can be delivered by ABS' Advisory Services or Advanced Solutions groups and aim to help clients tackle the rapidly changing marketplace, operational, environmental, safety and regulatory dynamics.



When considering LNG or other low flashpoint fuels, whether for new construction or retrofit projects, of particular relevance amongst this suite of services is the techno-economic analysis. Modelling a number of alternative scenarios against a conventional vessel base case, and including relevant client specific requests and assumptions, these techno-economic studies bridge the gap between technical design and economic assessment and apply recognized Life Cycle Cost Analysis (LCCA) and GHG analysis methodologies outlined in the NIST Handbook 135 LCCA[64] and ISO 14040/44[65, 66] life cycle assessment standards.

The modelling can evaluate technology investment options to assess the competitiveness against a number of relevant metrics such as regulatory compliance, payback period, net present value (NPV), return on investment (ROI), and other key metrics. This can support the decision making process for critical investments. Comparisons against the base case of alternative fuels, installation of an Exhaust Gas Cleaning System (EGCS), such as a SOx scrubber, or the impact of fitting of an energy saving device, may be typical scenarios evaluated by such studies.

SYSTEM AND EQUIPMENT ARRANGEMENTS

CONCEPTS

The regulatory and Classification foundations are in place for the use of all low flashpoint fuels in marine applications. The specific vessel arrangements will vary depending on the actual fuel(s) being applied and the particular fuel containment, fuel gas supply system and prime mover technologies selected for those fuels. There will be design compromises and additional complexity in all cases compared to conventional ship designs developed over the last 100 years or so for fuel oil ships.

Furthermore the link between fuel storage, fuel preparation and fuel consumer is much more interdependent than with conventional fuels. Critical equipment and system design decisions cannot be made in isolation.

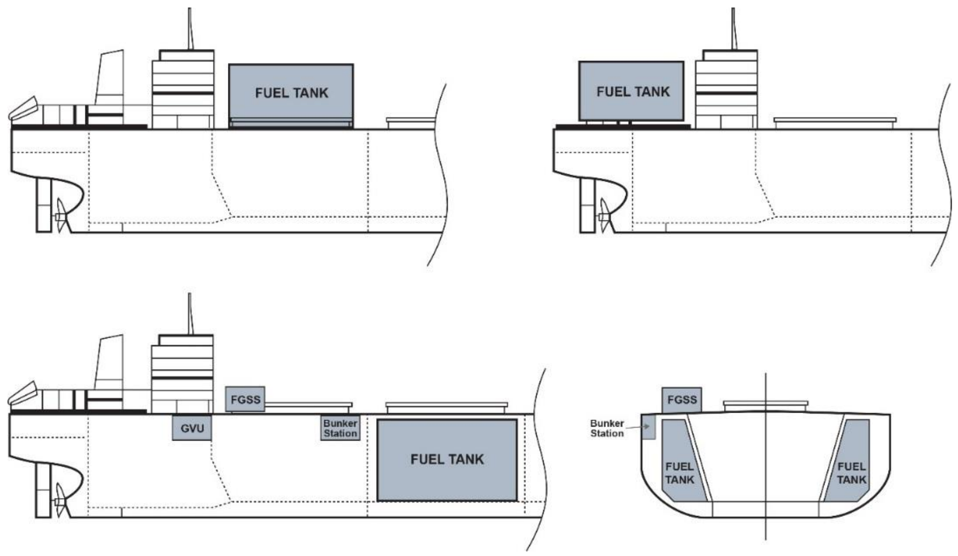
The additional energy and emissions reductions potential that battery, hybrid and fuel cell technologies may play as part of the power and propulsion concept adds yet more variables to the decision making process.

The following sections focus on the typical design solutions that have evolved for fuel storage, fuel supply and fuel consumption, using LNG as a fuel, and which themselves have evolved from the technologies developed by the LNGC fleet. Many of the technologies and safety principles are transferable to the other low flashpoint fuels being considered, but for some fuels, such as methanol, which does not have the cryogenic complexity and is a liquid at ambient conditions, simpler solutions may be applicable.

VESSEL ARRANGEMENTS

For LNG fueled ships, the main systems to be accommodated in a design concept that are different, or additional, to conventional ship designs are the LNG fuel containment system, associated LNG bunker station and transfer piping, a fuel gas supply system (which may be located in a fuel preparation room or tank connection space), the double wall fuel gas distribution piping, gas valve unit (which may be located in a GVU room), gas consumers, nitrogen generating plant, vent piping systems and mast(s), and for some LNG tank types, additional equipment for managing tank temperatures and pressure.

The protective LNG tank location criteria of the IGF Code allows both a deterministic route, based on the 2016 IGC criteria dependent on tank volume, and also a probabilistic method. The probabilistic method requires the input of a number of ship and tank parameters to calculate the required ‘f_{CN}’ value, which must be below 0.04 for cargo ships and 0.02 for passenger ships. Most projects apply the probabilistic method since it can give a less conservative result than the deterministic, however the f_{CN} value accounts only for the probability of collision damage that may occur within a zone limited by the longitudinal projected boundaries of the fuel tank and cannot be considered or used as the probability of the fuel tank to become damaged as a result of a collision. The real probability will be higher when accounting for longer damages that include zones forward or aft of the fuel tank, and which should be considered by the vessel risk assessment. A practical LNG tank location that does not compromise safety or cargo capacity and operations is a major challenge. Figure 11 shows some typical options for the location of the LNG tanks and main equipment.



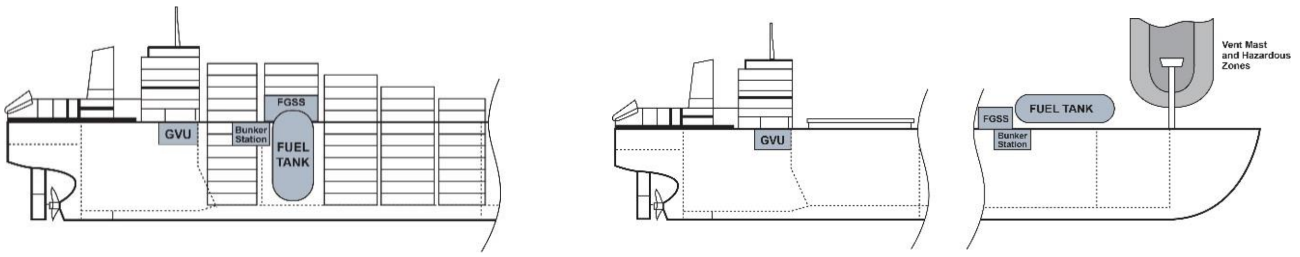


Figure 11: LNG Vessel Arrangements

One of the areas where the IGF Code differs from the IGC Code is in allowing single barrier fuel piping and consumers within machinery spaces. This is called the 'ESD machinery space' concept and introduces additional measures to provide an equivalent level of safety to the conventional non-hazardous machinery space. Application of the ESD machinery space has been limited so far because of the growing availability of engines that can be supplied meeting the double barrier criteria, and also perhaps because of the additional vessel complexity and cost that meeting the ESD machinery space concept brings. However, this may be a viable concept for small engines or fuel cell installations, where it may be applied as self-contained power modules within a larger machinery space. The non-hazardous machinery space concept is based on the use of double barriers for all gas-containing components such that a failure in a single barrier cannot lead to a fuel gas release into the space. The main differences between the two machinery space concepts are shown in Figures 12 and 13. The non-hazardous machinery space also shows the GVU room. This may be a separate space outside of the machinery space, or may be a GVU unit, sometimes also known as gas valve train (GVT), which is a self-contained unit that is essentially an extension of the double barrier piping system and may be located within the non-hazardous machinery space.

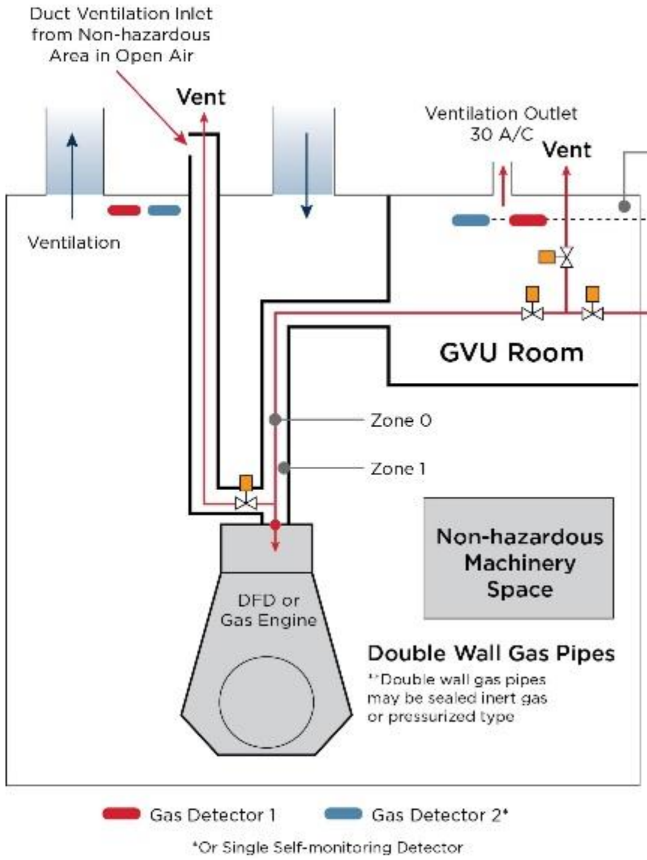


Figure 12: IGF Non-Hazardous Machinery Space Concept

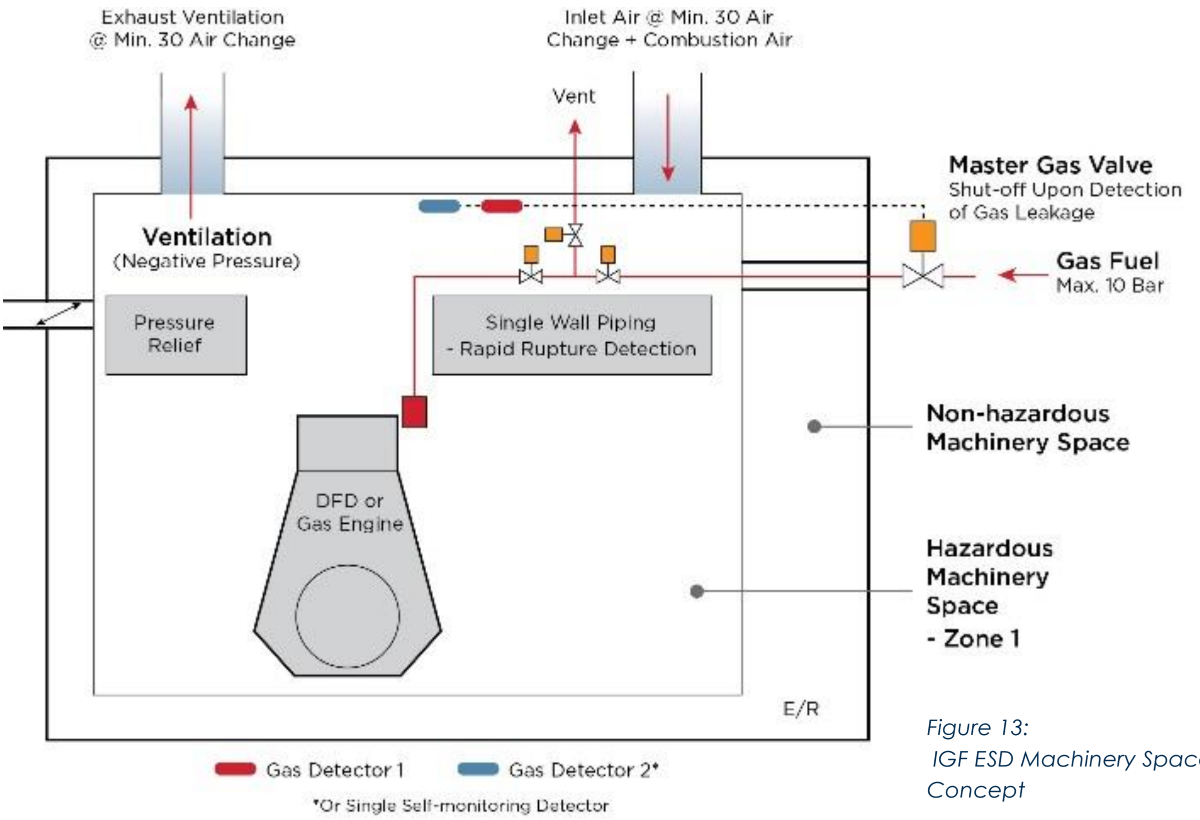
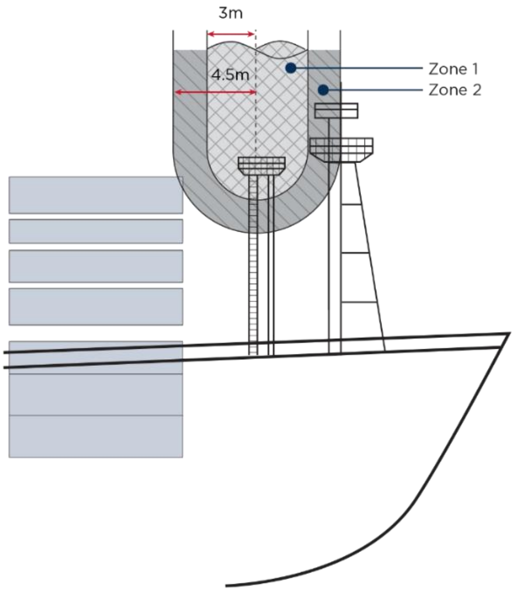


Figure 13: IGF ESD Machinery Space Concept

In addition to the LNG tank location and machinery space concept decisions detailed above, low flashpoint fuels vessels also have to find practical locations that meet all statutory and Class requirements for the fuel preparation room, vent mast and the nitrogen generating equipment. See the ‘Fuel Gas Supply Systems’ section of this advisory for more information on fuel preparation rooms. The vent mast location can be a particular challenge because of the requirements on hazardous area zones around the vent mast exit and the physical location criteria for the LNG tank pressure relief valve vents. These need to be at least 10m from any air intake, air outlet or opening to accommodation, service and control spaces or other non-hazardous area and any exhaust system outlet. They also have to be at least 6m above the weather deck and 6m above working decks and walkways. For example, this can cause challenges with location of reefer containers on container vessels – see Figure 14 - and physical location problems on small vessels; however the IGF Code does provide the option for special consideration by the Administration on vent mast height.

Figure 14: Hazardous Areas Around Vent Mast



FUEL STORAGE

LNG

The design and operational requirements for different LNG fuel containment systems are given in the IGC and IGF Codes, namely independent tank types A, B and C and dependent membrane tanks – see Figure 15. Types A, B and membrane are low pressure, nominally ‘atmospheric’ tanks and Type C are designed using pressure vessel codes. The predominant technology used for LNGC fuel containment in the past 20 years are the membrane and Type B Moss systems.

Type A, B and membrane tanks require a secondary barrier to protect in case of leak from the primary barrier. Type A and membrane systems require a full secondary barrier. Type B require a partial secondary barrier since they are designed using advanced fatigue analysis tools and a ‘leak before failure’ concept, for which small leaks can be managed with partial cryogenic barrier protection and inert gas management of the interbarrier space. Type C tanks are designed using pressure vessel code criteria and conservative stress limits therefore do not require a secondary barrier.

The easiest way to keep the LNG cooled at ambient pressure is to let part of the cargo boil off. LNG is therefore stored and transported as a boiling liquid and requires an effective boil-off gas management strategy. Historically cargo containment systems were designed with maximum boil-off rates (BOR) of 0.15% volume per day, which matched well with the fuel requirements of the relatively low efficiency steam turbine plants. The transition to diesel electric and slow speed DF engines that started in 2005 has driven designs with improved LNG tank insulation and reduced BOR as low as 0.08% to better match the available BOG to the higher efficiency of the internal combustion engines.

For gas fueled ships, the amount of BOG available will not be sufficient to sustain the ships power demands, so the fuel gas supply systems need to force vaporize the LNG into conditions suitable for the engines. But the ship will still need to manage the BOG and LNG tank pressures at all times, which can lead to many potential combinations for fuel supply and BOG management equipment.

A comparison of the fuel containment main characteristics and attributes are shown in Tables 5 and 6. All gas-fueled ships in operation at present have IMO Type C pressurized fuel tanks. This is because they are relatively cheap to manufacture and simple compared to the other fuel containment types, particularly in the smaller sizes required by the current gas fueled fleet. Type C tanks can also simplify the required BOG management equipment because of their pressure accumulation capability. They are not however the most space efficient option.

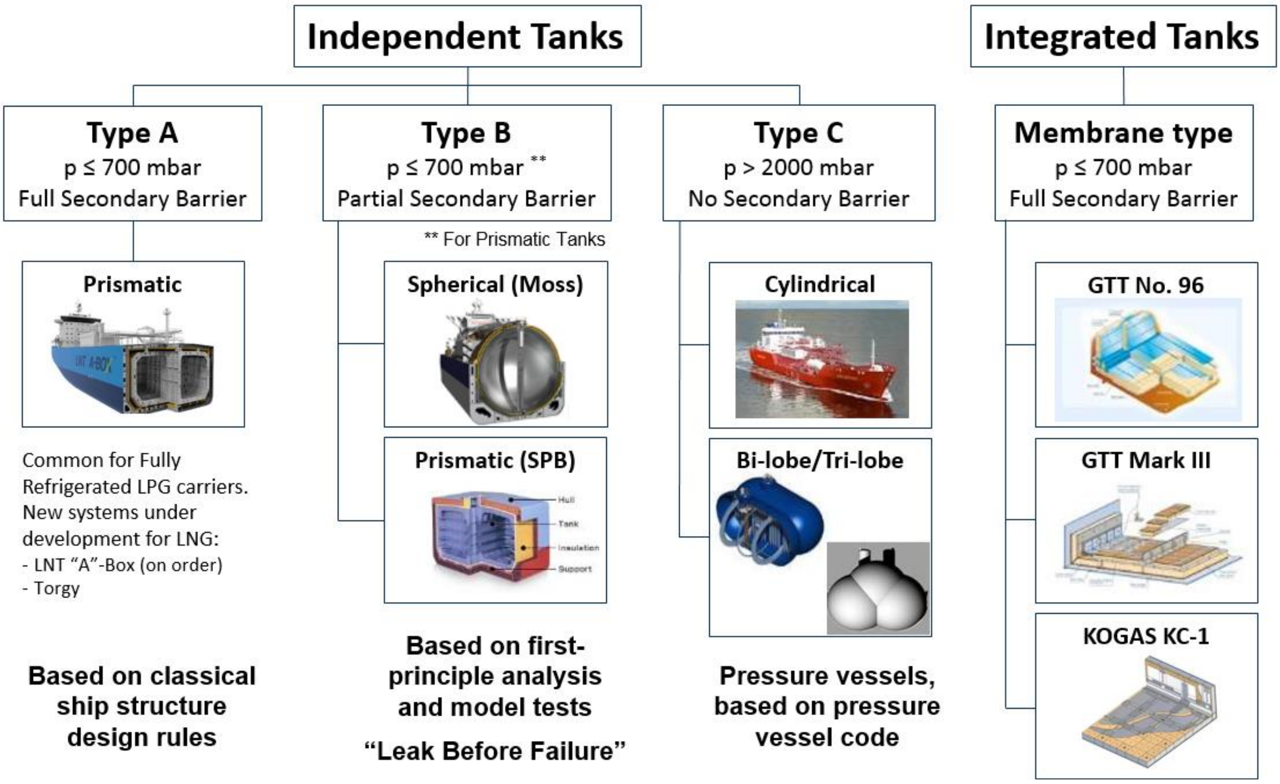


Figure 15: IMO LNG Fuel Containment Systems

TYPE OF TANKS		MAIN CHARACTERISTICS
PRISMATIC INDEPENDENT TANK	TYPE A	Prismatic tank not connected to the hull structures, but simply supported by a number of supports and kept in position by chocks and anti-lifting devices. Structures calculated with common ship structural analysis criteria
	TYPE B	As type A, but with structures calculated using sophisticated fatigue analysis
CYLINDRICAL INDEPENDENT TANK	TYPE C	Cylindrical pressure vessels supported by saddles, generally 2, blocked to one saddle and free to move on the other. Calculated using pressure vessel criteria
	TYPE C - BILOBE	As Type C, composed of two joined cylinders
MEMBRANE TANKS	NON SELF SUPPORTING	Non self supporting tank consisting of thin layer (membrane supported through insulation by the adjacent hull structure)
	SELF SUPPORTING (EXOSKELETON)	As above, but supported by an independent structural box. Designed for on deck applications

Table 5: IMO LNG Fuel Containment System Characteristics

ITEM	TYPE B (PRISMATIC)	MEMBRANE (GTT)	TYPE C
Secondary Barrier	Partial secondary barrier required	Complete secondary barrier required	No secondary barrier required
Volume Efficiency	Medium as it can follow the compartment shape, however space for inspection to be provided around the tank	Maximum effectiveness as the whole hold is utilized	Least space efficient. Independent tanks, simple cylindrical shape, frequently located on deck. Bi-lobe and tri-lobe give improved space efficiency
Fabrication	Similar to ship normal structures (skilled welders)	Requires high skills and accuracy (special licenses provided by the designer)	Pressure vessel construction (skilled welders)
Inerting requirements	Hold can be filled with dry air, but sufficient inert system should be available onboard	Additional systems for pressurizing and inerting the interbarrier spaces are necessary	Hold can be filled with dry air if condensation and icing is an issue (non vacuum tanks)
Sloshing	In general, it is not an issue due to tank internal structure	May be a serious issue, in particular for large tanks, but specially designed reinforcements are used	In general, it is not an issue
Capability to retain boil-off inside the tank	Design pressure not higher than 0.7 bar according to the Codes, therefore they cannot withstand the pressure developed by the boil-off for a long time	Design pressure not higher than 0.7 bar according to the Codes, therefore they cannot withstand the pressure developed by the boil-off for a long time	High pressue accumulation capability, e.g. LNG tanks 10bar and LPG 18bar
Inspections	Inspection relatively easy as the tanks are fully accessible on both sides	Inspections may be difficult as certain parts are not accessible and require special testing or inspection procedures	Inspection is relatively easy as the tanks are fully accessible on both sides, smaller tanks through man or remote access holes
Maintenance and repairs	Similar to normal ship structures, though insulation can restrict access	Specialized workers required and usually time consuming	Similar to normal ship structures, though insulation can restrict access

Table 6: IMO LNG Fuel Containment System Comparison

Large deep sea vessels will likely specify membrane fuel containment systems to limit the loss of cargo space compared to conventional fueled ships, and this is validated by the specification of the largest LNG fueled container ships currently on order. However, sloshing can be an issue that requires special consideration for membrane tanks. On LNGCs the membrane tanks are designed to operate near full on cargo transits and with a minimum of heel (to keep the tanks from warming up) during the ballast trip. Gas carrier membrane tank filling levels are typically limited to ≤10% for heel and ≥70% with cargo due to this potential for damage to the thin membranes from LNG sloshing. Although smaller, LNG membrane tanks for gas fueled ships need to be designed to accommodate all LNG filling levels in service. Therefore the tanks will be designed with higher density insulation materials and membrane reinforcement in critical areas. Figure 16 shows the Arista Shipping *Project Forward* concept using such a membrane tank application for a deep sea LNG fueled bulk carrier.

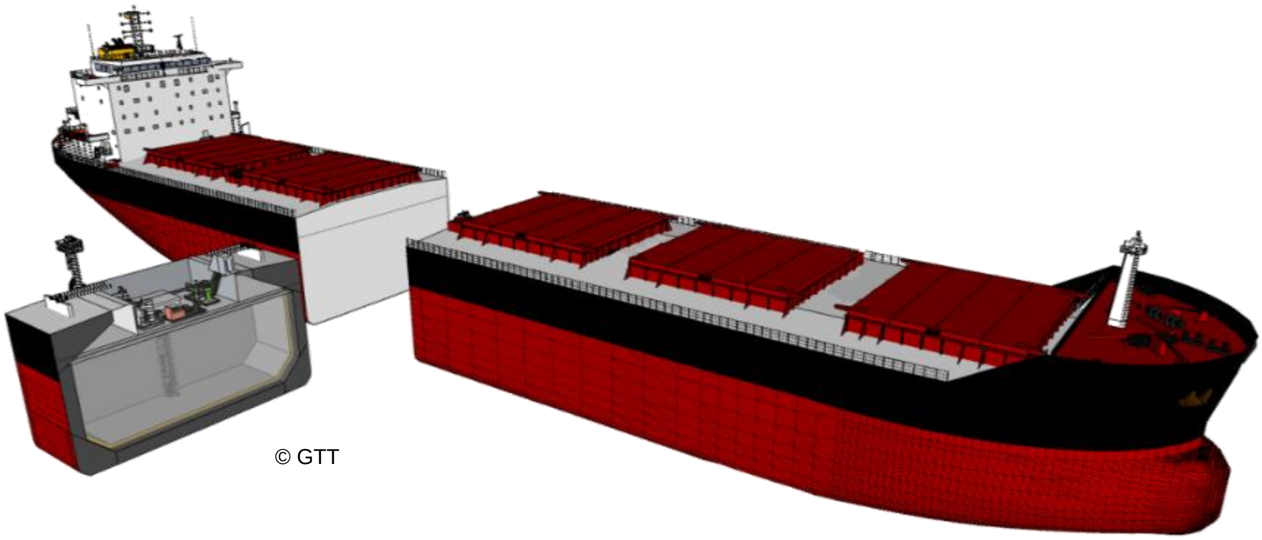
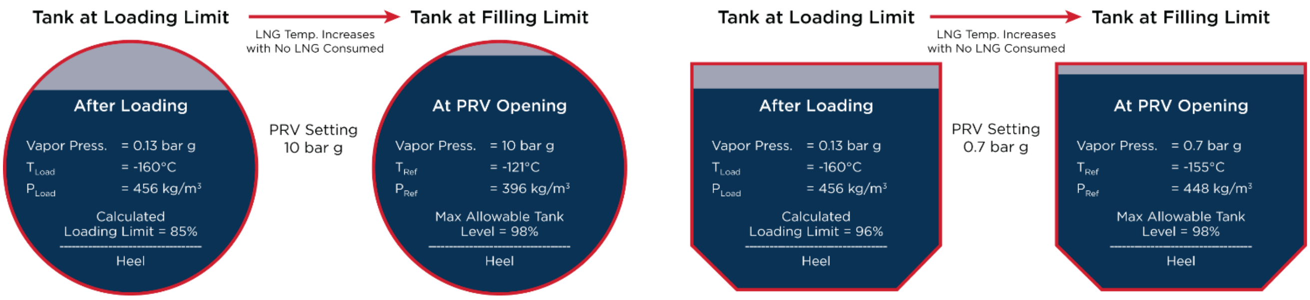


Figure 16: 'Project Forward' LNG Fueled Bulk Carrier

The LNG fuel containment system selected will influence the installed equipment for BOG management and also have an operational impact on tank filling levels and how bunkering (tank pressure and vapor return) is managed in service. The complexity of LNG bunker vessels is greater than conventional fuel oil bunker vessels and introduces specific compatibility challenges. More information on BOG management, tank loading and filling limits and LNG bunkering can be found in the aforementioned ABS *LNG Bunkering Advisory*[56] but Figure 17 shows some of the main differences between the LNG properties when using Type C pressurized tanks and atmospheric tanks.

Figure 17: Pressurized and Atmospheric LNG Tank Scenarios



The IGC and IGF Codes permit a number of ways to manage the BOG, including consumption, reliquefication, cooling and pressure accumulation. The IGF Code sets criteria for controlling tank pressure and temperature at all times and for maintaining tank pressure below the relief valve setting for 15 days when the vessel is idle with domestic load only. The 15 day criteria may be difficult for atmospheric tanks to achieve on hotel load only and may therefore necessitate the fitting of additional BOG management equipment, such as reliquefication systems. IACS UI GF8[67] has clarified that the activation of the gas fueled safety systems is not considered an emergency situation for the vessel, and therefore this 15 day criteria is to be met when the gas as fuel safety systems have been activated; which therefore requires sufficient pressure accumulation capability or redundant BOG management equipment.

IGF Code 6.9.1 ***Control of tank pressure and temperature***

6.9.1.1 With the exception of liquified gas fuel tanks designed to withstand the full gauge vapour pressure of the fuel under conditions of the upper ambient design temperature, liquified gas fuel tanks' pressure and temperature shall be maintained at all times within their design range by means acceptable to the Administration, e.g. by one of the following methods:

.1 reliquefaction of vapours;

.2 thermal oxidation of vapours;

.3 pressure accumulation; or

.4 liquefied gas fuel cooling.

The method chosen shall be capable of maintaining tank pressure below the set pressure of the tank pressure relief valves for a period of 15 days assuming full tank at normal service pressure and the ship in idle condition, i.e. only power for domestic load is generated.

OTHER LOW FLASHPOINT FUELS

The above section outlines some of the principles around the storage of LNG which need to be considered for application of LNG as a fuel and for compliance with the Class and statutory requirements. Some of these are equally applicable for the carriage of other low flashpoint fuels, depending on what fuel is to be carried and in what state (gas or liquid) that the fuel is to be stored onboard. For example, LPG is typically transported in Type C pressurized tanks at 18 bar; ammonia and ethane can also be transported in similar pressurized/semi-pressurized/refrigerated tanks. Hydrogen can be stored in high pressure tanks or in liquefied fuel containment systems.

The low flashpoint fuels that are liquid at ambient conditions, such as methanol or ethanol, can be stored in conventional fuel tanks and thus can be simpler to apply. Methanol, specifically because of its solubility in water, is often proposed for locations below the waterline next to the shell. This can promote the use of a number of ballast tanks as potential fuel tanks. However, these tanks need special coatings, and due to the low flashpoint will require a nitrogen blanket to the tank vapor space. Regardless of the fuel or technology selected, the decision process is very vessel specific. Table 7 highlights some of the fuel characteristics and fuel storage tank requirements for low flashpoint fuels.

	MGO	Methane	Ethane	Propane	Butane	Hydrogen	Ammonia	Methanol	Ethanol
Flash point, deg.C	>60	-188	-135	-104	-60	-	132	11	16
Boiling Point, deg.C 1bar	180-360	-162	-86	-42	-1	-253	-33	65	78
Density, kg/m^3 liquid	900	450	570	500	600	76.9	696	790	790
Conventional or cryogenic/pressurized tanks	CONV	CRYO	CRYO	CRYO	CRYO	CRYO	CRYO	CONV	CONV
Secondary tank barrier required	NO	YES*	YES*	YES*	YES*	YES*	YES*	NO	NO
Additional cofferdam or hold space requirements	NO	YES	YES	YES	YES	YES	YES	YES	YES
Volume comparison MGO, energy density	1	1.78	1.41	1.66	1.40	4.16	2.45	2.44	1.82

* Except Type C tanks

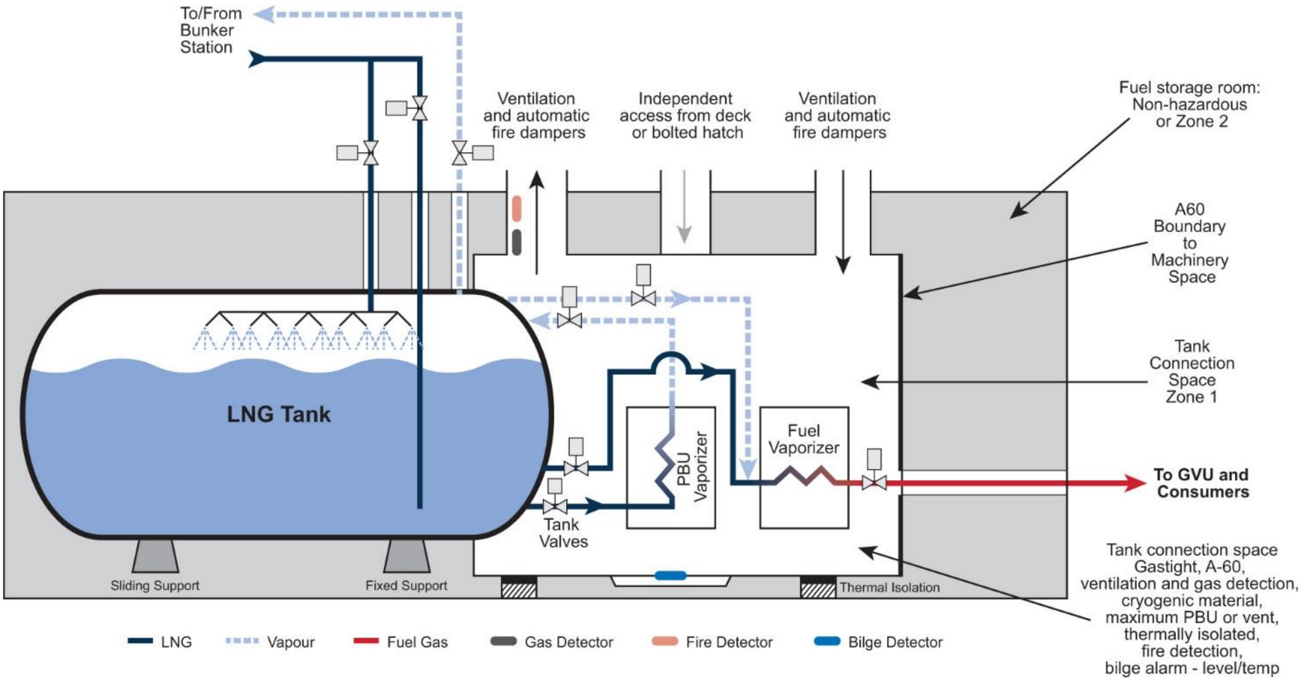
Table 7: Low Flashpoint Fuels

FUEL GAS SUPPLY SYSTEMS

The purpose of the fuel gas supply system (FGSS) is to deliver fuel at the correct temperature and pressure to the engine or consumer. The use of low flashpoint fuels and gases introduces complexity to the fuel supply and consumer systems and there is a greater interdependence between the key systems than with conventional fuel systems. For gaseous fuels using cryogenic/pressurized liquefied storage, the fuel may be pumped or pressure fed, directly in liquid form, such as LNG, from the tank and vaporized to a gaseous state for the consumer, or supplied in combination with the use of compressed gas from the natural tank boil-off gas.

The early gas as fuel vessels operating in northern Europe utilize Type C LNG tanks with low-pressure fuel supply systems. The fuel supply pressure is approximately 5 bar for the LP Otto process 4-stroke engines, with the fuel pressure being created through the natural BOG and pressure accumulation, in combination with pressure build up (PBU) units. The PBUs and other fuel vaporizing equipment may be contained in the 'tank connection space' (TCS). The TCS is a unique concept to the IGF Code that can feature low-level LNG tank connections, something not seen on LNGC. The IGF Code applies special requirements for the TCS that are intended to mitigate the consequences of potential LNG or gas leaks from the LNG tank connections and equipment within that space. See Figure 18 for a schematic of a Type C LNG tank with integrated TCS and some of the safety features required by the IGF Code.

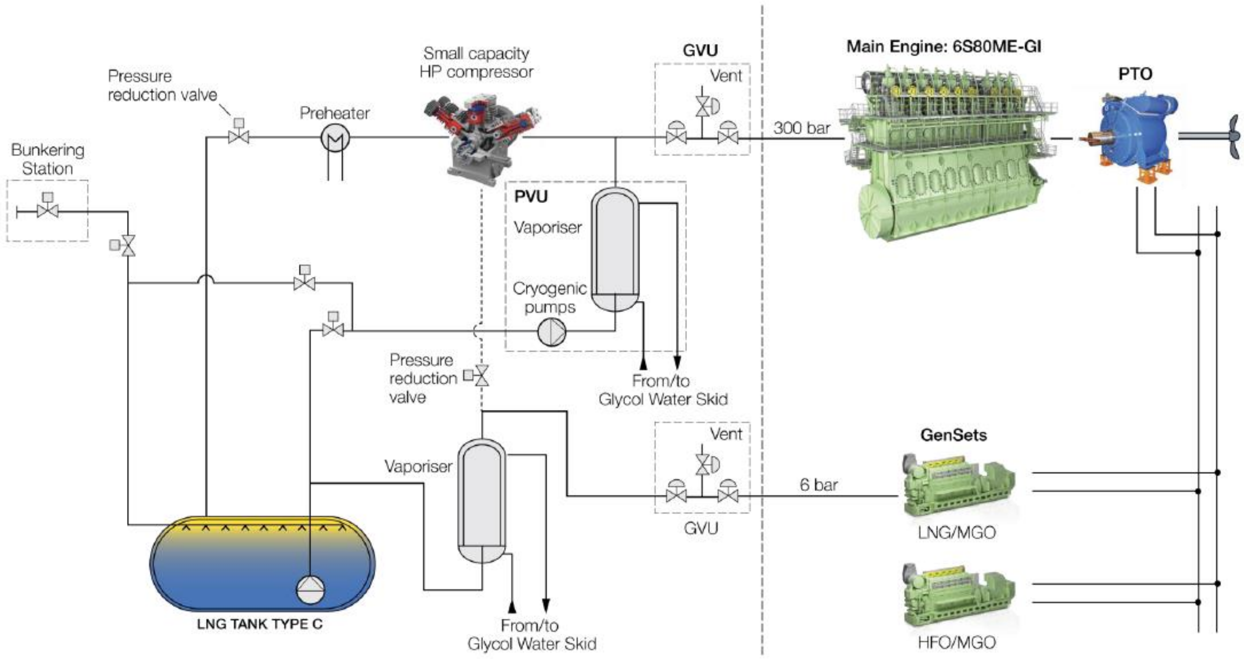
Figure 18: IMO IGF Code 'Tank Connection Space'



Other vessel arrangements locate the fuel preparation equipment in a dedicated space, similar to the cargo machinery space on deck of a gas carrier, which is defined as the 'fuel preparation room' by the IGF Code. There are also specific requirements for the fuel preparation room in the IGF Code, including treating it as a category A machinery space for fire detection and protection, gas detection and ventilation systems, leak protection systems, etc. Fuel preparation rooms may be located close to the machinery space (to reduce fuel gas supply piping distances) or close to the LNG tanks (to reduce the LNG piping distances). Where a fuel preparation room is located below deck then it is to meet the IGF Code requirements for a TCS.

The introduction of the high pressure systems, typically around 300bar, used by the MAN ME-GI engine and the 15 bar systems for the Winterthur Gas & Diesel (WinGD) X-DF engines mean there are many options available for FGSS equipment. For DF installations, there is no requirement for FGSS redundancy since the basic safety concept is that the primary fuel remains fuel oil and seamless transition back to oil mode is required in the event of a safety system trip of the low flashpoint fuel system. In those cases where gas is the means of Tier III NOx compliance then MARPOL Annex VI/NTC permits transit to the next port in Tier II mode. However, for practical reasons redundancy of rotating and reciprocating FGSS equipment, such as submerged LNG pumps or HP cryogenic pumps, is often specified by ship owners and operators for redundancy, reliability and maintenance purposes. Figure 19 shows an example of the FGSS equipment that may include a mix of high and low pressure supply systems utilizing compressors or LNG pumps with vaporizers.

Figure 19: Example Fuel Gas Supply System



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The FGSS can be one of the more complex and expensive systems required for gas fueled applications. The FGSS needs to ramp fuel supply quantities and pressures up and down depending on the engine fuel demand. This transient fuel demand can be a challenge, particularly to maintain fuel supply readiness in high demand or zero demand scenarios, without causing a shut down of the FGSS. It may also not be part of the engine OEM supply, but solely designed to comply with the engine OEMs specifications. This can cause some commercial issues and both of the main slow speed marine engine suppliers have developed their own systems. These to provide more cost effective solutions, but also to more closely link the FGSS and the consumer to improve reliability and control system interaction. Figures 20 and 21 show the MAN Energy Solutions 'pressure valve unit' (PVU) system and the WinGD 'iGPR', (integrated Gas Pressure Regulating), GVU system. The MAN system utilizes engine OEM hydraulic control system know-how to control cryogenic LNG pump units. The WinGD system brings the gas supply regulating units, typically contained within the GVU, under the engine OEM supply and engine control systems.

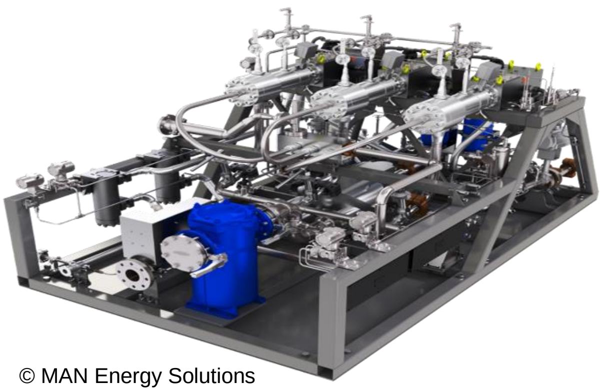

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Figure 20: Pressure Valve Unit (MAN Energy Solutions)

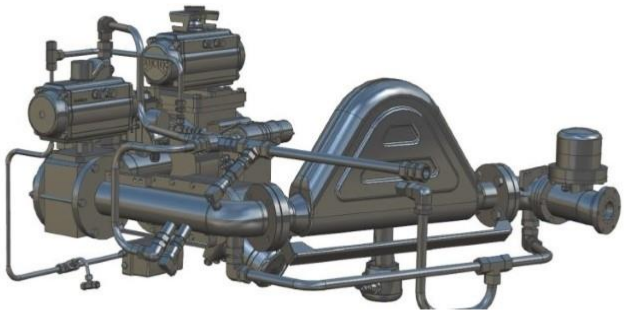

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Figure 21: iGPR (WinGD)

Liquid fuel systems can be simpler than the gaseous systems detailed above. However, this depends on the properties of the fuel being used but also the prime mover technology. The MAN ME-LGI engine uses a FGSS similar to conventional fuel oil supply systems with the fuel being supplied by a low pressure system (8-40bar) to the dedicated engine fuel injector. Other systems can be more complex, such as the trial system developed by Wärtsilä for the *Stena Germanica* conversion which included a 600bar methanol supply pump – see Figure 22.

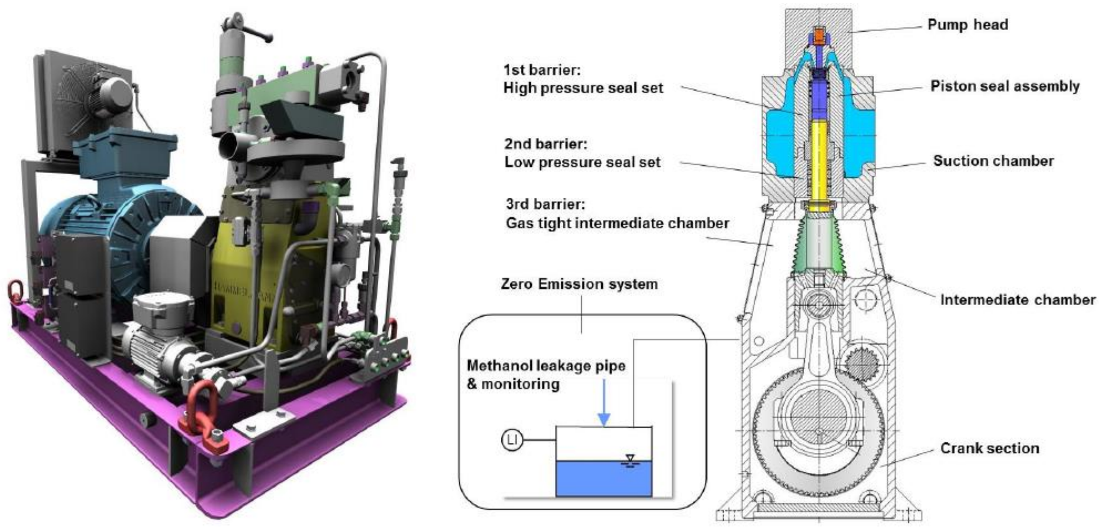

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Figure 22: High Pressure Methanol Fuel Supply Pump

PRIME MOVERS

In recent years the marine industry has seen growing application of natural gas burning dual fuel and single gas fuel engine technologies introduced to the market. Much of the engine OEM experience with gas engines has been developed from the land based power generation sector where gas supply infrastructure is extensive. For marine applications, gas-only engines have so far been limited to small local ferries with access to regular LNG supply, typically by truck in small quantities. The deep sea fleet has opted for DF engines for fuel flexibility and viability while the LNG supply infrastructure develops. However, flexibility adds complexity and cost, and for those engines using different combustion processes for oil and gas modes, i.e. Otto process engines (see below), then the engine design is the best compromise that the OEM can achieve; it is neither the best Diesel engine it can be nor the best gas engine it can be. Should natural gas replace oil as the main marine fuel in the future, it is likely that single fuel gas engines would become dominant because of the higher efficiencies that are achievable.

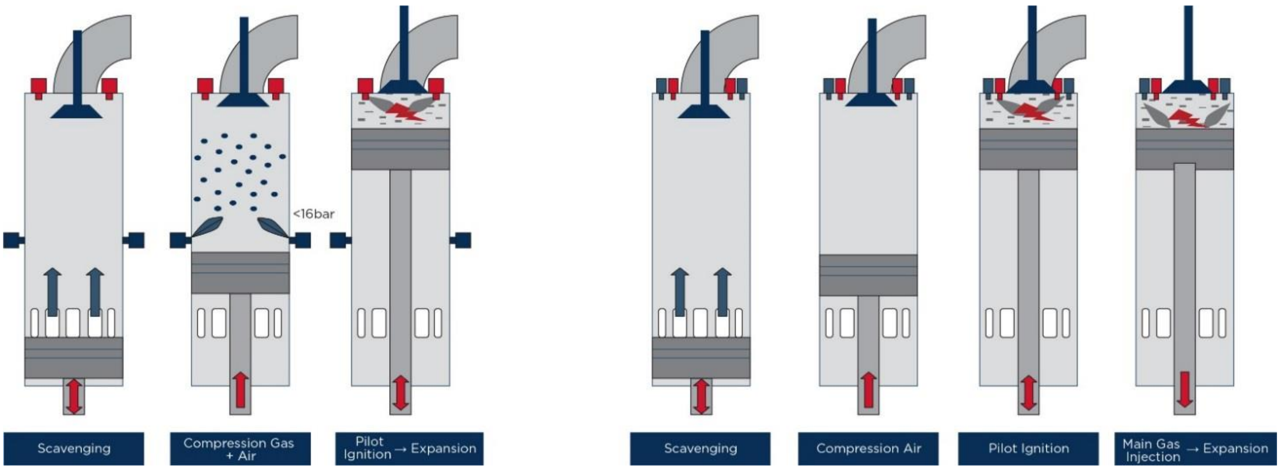
In terms of installed power and engine numbers, the 4-stroke dual fuel engine technology selected by diesel-electric gas carriers is dominant, although the non-gas carrier fleet is slowly growing, and growing across all ship types. We are now also seeing the real world application of slow speed DF engines to gas carriers and other ship types, with the LNG fueled container ship, the U.S. flagged and ABS classed *Isla Bella*, entering service early in 2016 with the world's first MAN ME-GI engine order.

DIESEL vs OTTO COMBUSTION PROCESSES

Both of the main marine slow speed 2-stroke diesel engine manufacturers, MAN Energy Solutions – formerly MAN Diesel and Turbo - and Winterthur Gas & Diesel, offer dual fuel internal combustion engines. However each manufacturer has selected a completely different combustion process for when the engine operates in gas mode. This has led to lively debate as to which is the best technical, environmental and cost effective solution. This has also made the propulsion system selection challenge more difficult, particularly when also considering any proposed solution to meet the IMO MARPOL Annex VI Regulation 14 fuel sulphur limits and the Regulation 13 Tier III ECA NOx limits.

The two different gas mode combustion concepts are low pressure gas engines using the Otto cycle and high pressure (HP) gas engines using the Diesel cycle. The LP DF engines utilize the Otto process in gas mode and the conventional Diesel process when in oil mode. The HP DF engines use the Diesel combustion process in both oil and gas modes. For both concepts the gas is ignited by a pilot injection of liquid fuel from the conventional fuel injection system or a dedicated pilot system. MAN have selected the HP Diesel process for the ME-GI engines and WinGD have selected the LP Otto process for the X-DF engines. The Otto and Diesel combustion processes in slow speed 2-stroke engines are shown in Figure 23.

Figure 23: Otto vs Diesel Combustion Process



The point during the combustion cycle where the gas is injected dictates the required gas supply pressure. The dual fuel and single fuel 4-stroke engines in operation use the Otto cycle with gas supply pressures of approximately 5 bar. However, from the IGF Code regulatory perspective, the WinGD X-DF is considered a high pressure engine because it is designed for a gas supply pressure of up to 13 bar and the IGF Code defines HP as 10 bar or over. The high pressure DF ME-GI engine uses gas delivered by a direct injection system at approximately 300-350 bar. Regardless of where the statutory regulations have placed the demarcation line between low and high pressure (which is mainly for the purposes of piping and pressure vessel design and certification), the two distinct engine combustion concepts fall into the low pressure Otto combustion category at up to approximately 20 bar and high pressure Diesel combustion process at 300+bar. The two different combustion concepts lead to different peak combustion temperatures in gas mode and hence have different emissions profiles.

Figure 24 shows typical Otto cycle gas engine design and operation windows with respect to Brake Mean Effective Pressure (BMEP) and air fuel ratio (AFR). Higher efficiencies are achieved with higher BMEPs, but we can see how the lean burn combustion control systems in these engines have to operate in the ever-narrowing window between misfire and knock as BMEP increases. For advanced lean burn engines with higher BMEPs, the operating window is practically limited to around 18 bar BMEP. Although marine 4-stroke medium speed engines using the HP Diesel combustion process in gas mode have been utilized in offshore applications in the past, all medium and high speed marine gas or DF engines currently offered for marine applications apply the LP Otto process in gas mode.

Of the slow speed engine manufacturers, MAN Energy Solutions were first to market with their high pressure ME-GI engine that was revealed to the world in 2011. This engine is a development of the 'ME' series electronic engine and the 'MC-GI' mechanical DF engine of the 1990s that found application for land based power generation. WinGD came to the market later but have achieved significant market share and build on the extensive Wärtsilä experience with low pressure fuel gas supply systems for their 4-stroke medium speed DF engines.

Figure 24: Otto Combustion Process Operating Points

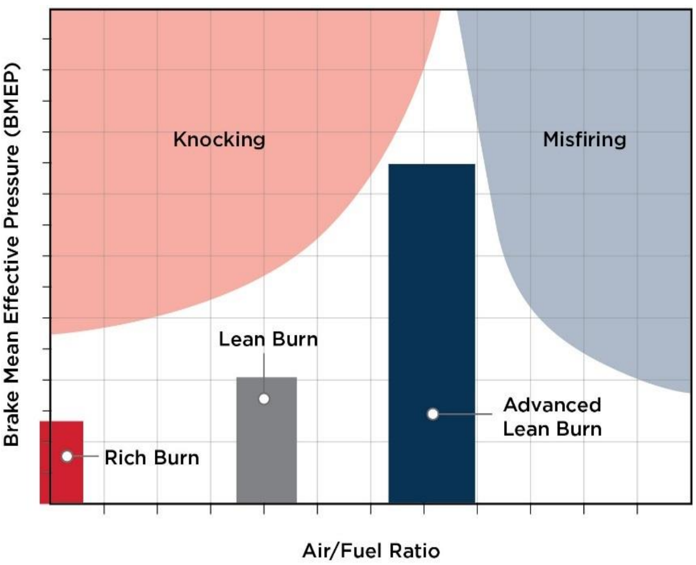


Table 8 highlights some of the key parameter differences between the two slow speed DF concepts. The high pressure engine effectively operates in the same manner when running on gas as when running on diesel and is therefore not subject to some of the transient response problems, gas quality or issues associated with compressing gas/air mixtures that the Otto cycle engines are. However, the Otto cycle engines can achieve IMO Tier III NOx compliance without exhaust aftertreatment and utilize simpler fuel supply systems. The determination of the suitability of a specific concept, or engine type, to a ship is very much a case specific decision and matter of personal preference. For some it is simply that they are not comfortable with high pressure gas or the increased complexity and cost that HP fuel gas supply systems may bring. For others it is concerns with Otto cycle engine knock caused by poor gas quality and low Methane Number (MN) or the GHG impact of methane slip.

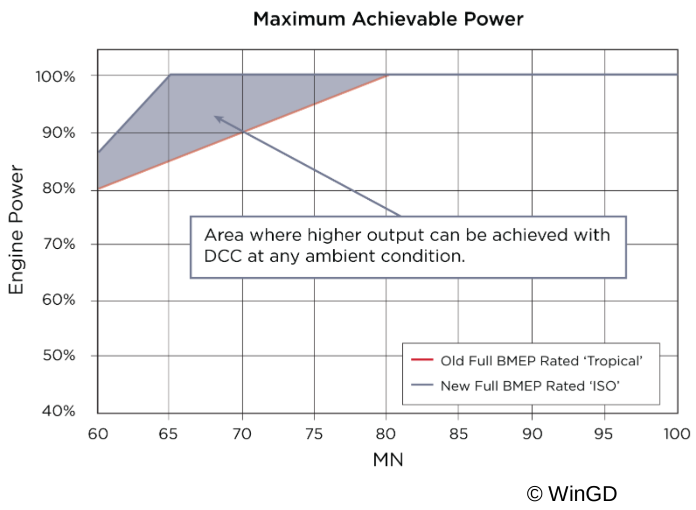


Figure 25: WinGD Dynamic Combustion Control

An engine's gas quality sensitivity is indicated by methane number, which is a measure of a gas fuel's resistance to engine knock. The higher the MN, the higher the resistance. MN influences the Otto combustion process but not Diesel combustion engines. When an X-DF engine is fueled with a low MN gas, the engine may encounter knock at high loads due to the increased amount of fuel, and the higher combustion temperatures involved at such loads. In order to prevent knock the engine may therefore be derated. WinGD are continually developing their products and we can see from Figure 25 that 100% of MCR is now available down to a MN of 65, which covers all typically available natural gas compositions. Where the gas quality variations are large then a reduction in power output and/or increased quantities of fuel oil amounts injected with the gas can be used to avoid engine knock. Under such conditions the engine control system allows the engine to only reach approximately 80%-90% of its maximum rating. Ambient conditions can also cause engine knocking. The WinGD 'Dynamic Combustion Control' (DCC) system, which injects additional diesel fuel as the engine approaches knock, is an example of engine control system mapping to counteract such gas quality or ambient conditions that can lead to engine knock. The DCC system can inject up to 15% diesel above 75% engine load and where greater stability is required, for example heavy seas (Figure 25).

It is recommended to refer to the engine manufacturers specifications for minimum acceptable MN for each engine type. Most engine manufacturers provide online MN calculator tools to assess the suitability of the natural gas composition to their engine.

For Otto cycle DF and single gas fuel engines driving generators, the transient response is one of those characteristics that needs to be carefully matched to the application, since auxiliary DF and gas engine transient response is generally not as good as diesel engines. CIMAC published a position paper in April 2011[68] to clarify the transient response behavior of gas engines. Figure 26 indicates typical response characteristics for Otto cycle gas engines compared to diesel engines and also shows the differences between the different gas engine types and their respective BMEPs. Load steps need to be significantly smaller for gas engines and recovery times are longer. The use of engine design features such as variable geometry turbochargers can greatly improve the transient response and low load operation, and as the CIMAC paper implies, careful assessment is the key to appropriate application matching. High pressure gas injection Diesel engines such as the MAN ME-GI deliver the same power and load acceptance characteristics in gas or diesel modes. Transient response is not a show stopper but it is an issue that needs to be considered, and in the case of generator sets requires careful matching of the vessel loads and Power Management System (PMS). IACS UR M3[69] was revised in November 2018 to increase the number of load steps permitted to be applied in reaching 100% MCR, which can help high BMEP engines and gas engines meet the IACS and Class frequency response requirements.

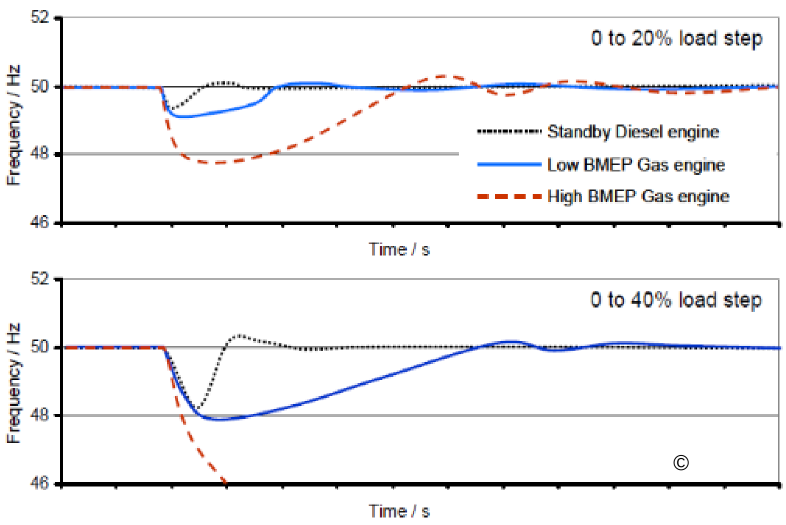


Figure 26: Diesel and Gas Engine Transient Response Characteristics

In summary, from Table 8 we can see that the HP DF engines are not sensitive to MN, gas quality or ambient conditions, have the same power density and transient response as the oil engine, and are not knock limited engines in the way the Otto engines are. However, the Otto engines are Tier III NOx compliant without exhaust aftertreatment and can counteract problems with gas quality and knock, to an extent, on a real time basis, by the engine control system.

Methane slip is currently an unregulated gaseous emission and can be significant for the Otto engines while negligible with the HP process. However, as we see from the 'Emissions Profiles and Environmental Compliance' section of this advisory, methane emissions are now on the IMO radar to introduce future limits as part of the GHG reduction strategy. Both engine concepts are SOx compliant when using sulfur compliant fuel for the pilot fuel.

Table 8: Otto vs Diesel Slow Speed 2-Stroke DF Engine Comparison

	Low Pressure	High Pressure
Gas mode cycle type	Otto	Diesel
Main engine manufacturers	Winterthur Gas and Diesel (WinGD) 'X-DF'	MAN Energy Solutions MAN B&W 'ME-GI'
Gas injection	Through cylinder wall above scavenge port with gas admission valves during commencement of compression stroke	Through cylinder head with separate gas injector(s) once pilot has ignited
Gas supply pressure	<13 bar	300 bar
Liquid pilot % @MCR	0.5 – 1.0	3.0 – 5.0 (0.5%-1.5% for Mk.2)
Liquid pilot % @30% MCR	~1.0	3.0 – 5.0
BMEP [bar]	17.3	19.0 – 21.5
Power density	Up to 15% lower	Equivalent to Diesel
Min load for DF Mode [%]	5	~10
IMO NOx Compliance	Tier II (oil mode) Tier III (gas mode)	Tier II (oil mode) Tier II (gas mode)
Methane Number/gas quality sensitive	Yes	No
Methane slip	Yes	No
Knock/misfire sensitive	Yes	No

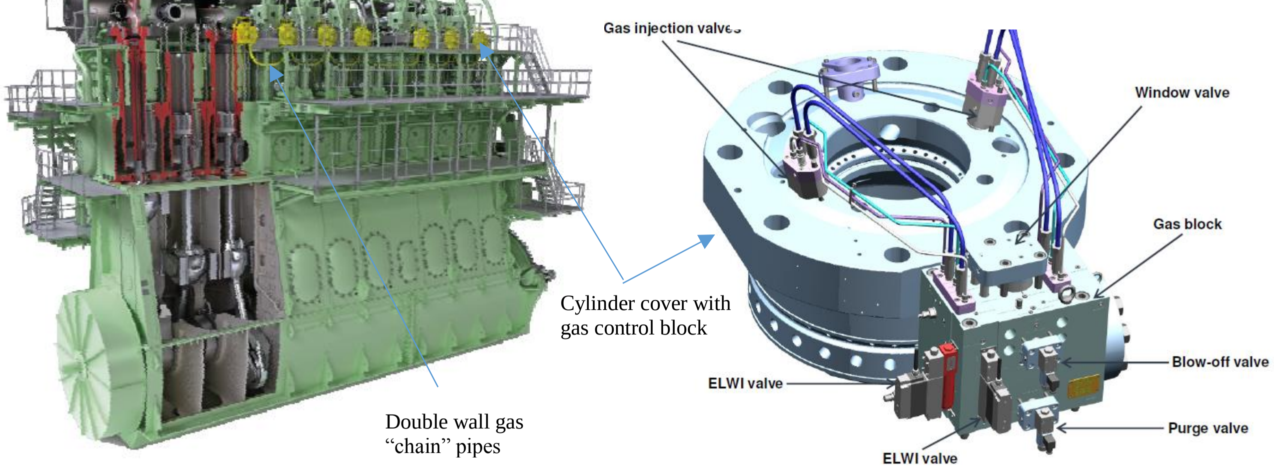
KEY COMPONENTS AND ENGINE CONVERSION

The ability of a diesel engine to be easily converted to a DF engine in the future can also be important, for example if an owner is selecting a 'Ready' notation in preparation for converting the ship to burn natural gas or another low flashpoint fuel at some point after vessel delivery.

In the case of Otto engines, because of the lower BMEPs that are achievable, there may be a need to install a bigger engine, or more cylinders, than for the conventional diesel engine. To counteract some of the loss of power, and lower BMEP from the Otto process DF engines, it is frequent practice for the engine designer to increase the cylinder bore size of the DF engine. This takes advantage of the strength of crankcases, crankshafts, connecting rods, etc. that have been designed for the higher firing pressures and higher BMEPs associated with diesel operation. For example, the Wärtsilä 50DF engine is based on the W46 diesel engine, the MAN 51/60DF engine is based on the 48/60 diesel engine, the Wärtsilä 34DF is based on the W32 diesel engine, etc. This means that if a significant derate of the diesel engine is not acceptable, and the Otto process is to be applied in gas mode, then the engine modifications may include re-machining of crankcases and the fitting of larger cylinder liners and pistons; this has already been done on some existing vessel conversions. Alternatively, it could be a case of specifying a higher power DF engine than needed initially, with the engine operating on diesel until such time as the ship is ready to be converted.

For engines converting to the HP gas injection Diesel combustion cycle the process can be simpler, primarily because there is no change to engine MCR (Maximum Continuous Rating) or bore sizes. However, as detailed elsewhere, there are greater complexities with the FGSS. The basic components that would be changed to convert to gas operation would be cylinder heads, on-engine gas injection equipment and piping, and engine control systems, together with auxiliary equipment such as Gas Valve Trains (GVT), hydraulic sealing systems and nitrogen purging equipment. Key base engine gas components for the MAN ME-GI and WinGD X-DF engines are shown in Figures 27 and 28.

Figure 27: MAN ME-GI Engine



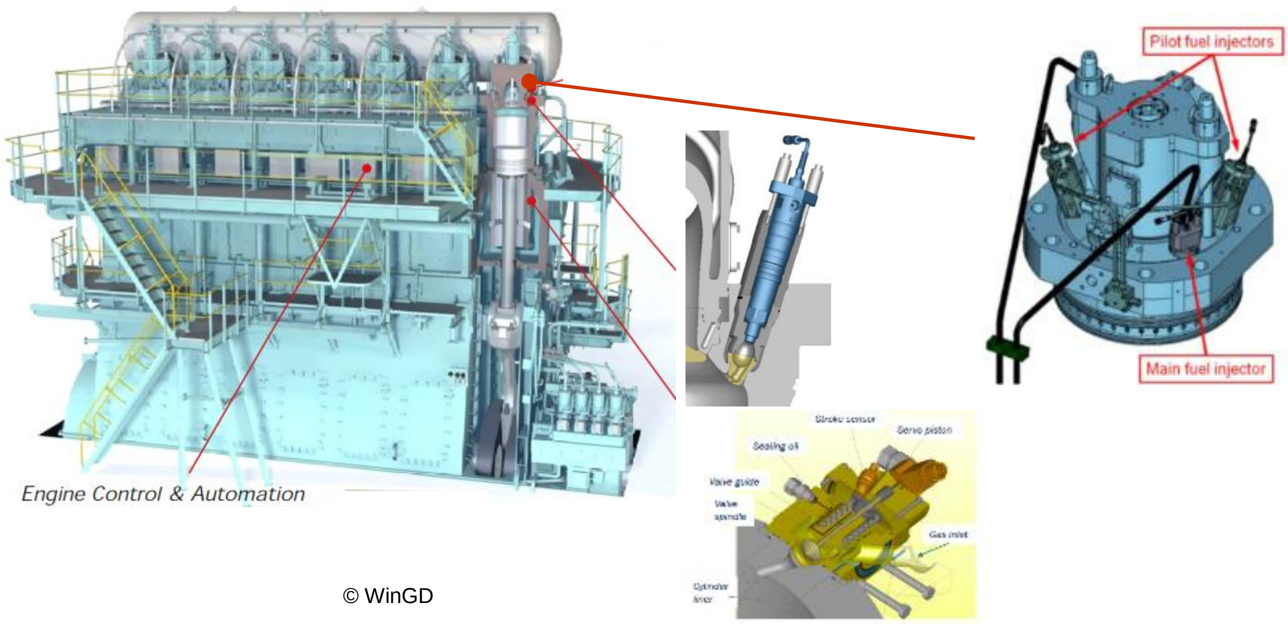
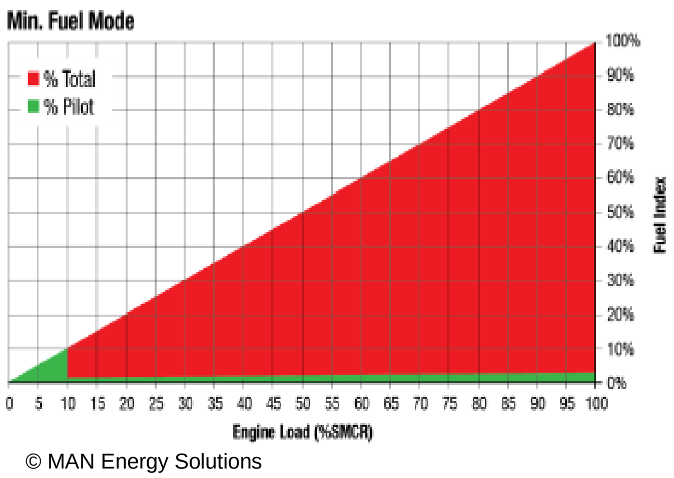


Figure 28: WinGD X-DF Engine

GAS MODE LIMITATIONS, FUEL SHARING AND AUXILIARY CONTROL DEVICES

Pure gas engines normally utilize a spark ignition system to initiate combustion. For DF engines, combustion is initiated by injecting a small amount of conventional pilot fuel oil. This can be by the normal fuel injection equipment or by a dedicated pilot injector. The quantity of pilot fuel injected will vary by engine type and the fuel injection equipment adopted, with quantities from 0.5-5% being typical. Historically DF engines could only operate on gas above specified minimum load points, but performance has improved over the past 15 years with lower minimum loads and smaller pilot quantities being applied and engines being capable of being started and stopped in gas mode. Figure 29 shows the minimum fuel quantities for the MAN ME-GI engine and the WinGD X-DF engine. For MAN, application of gas mode above 10% engine load and with a minimum pilot fuel quantity of 3% throughout the load range is shown. The latest 'Mk.2' version is offered with pilot fuel quantities of approximately 1-1.5%. For WinGD smaller pilot quantities are possible with gas mode available over the whole load range.



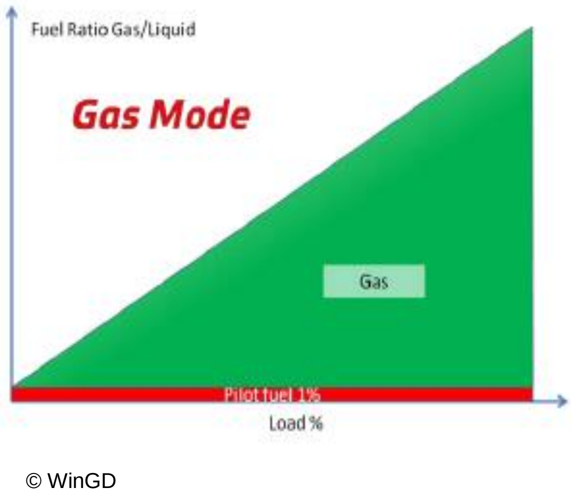
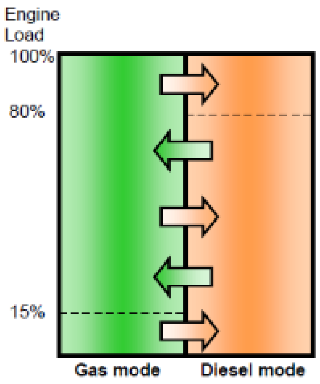


Figure 29: MAN and WinGD Minimum Fuel Modes

There are other limitations that may be applicable depending on the engine type and combustion process. Figure 30 shows the general limits for Wärtsilä DF engines, with transition to gas mode being possible at all loads below 80%. Most DF engines are limited to 100% engine load in gas mode and will revert to oil mode under a safety trip at loads above 100%. Similarly, high transient loads may cause a trip to oil mode unless some additional feature, such as the WinGD DCC is activated.

Figure 30: Fuel Mode Switching



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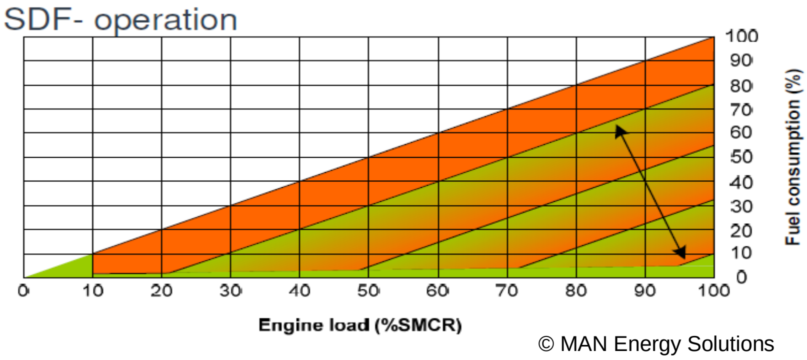
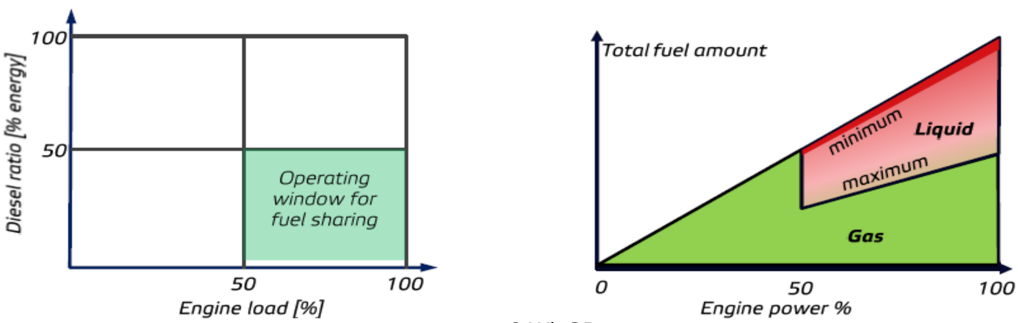
The HP Diesel combustion engines can vary the fuel split between fuel oil and gas over a wide load range, i.e. mixed fuel capability, with the MAN range shown in Figure 31. The LP Otto engines typically inject the smallest pilot fuel quantity possible just to initiate combustion, so operate almost as pure gas engines in gas mode, except where optional 'Fuel Sharing' or 'Fuel mixing' modes are applied. The 'Fuel Sharing' range for WinGD X-DF engines is also shown in Figure 31. Where separate pilot injection systems are used, these will be operable in these mixed fuel modes with gas quantities being reduced and the conventional fuel injection system making up the remainder of injected fuel to meet the load demand. The load range for the 'Fuel Sharing' mode offered for Wärtsilä DF engines is also shown in Figure 31. As can be seen (and this is linked to the application of the Otto combustion process) the fuel mix range is not as wide as for the Diesel combustion process engines, and the best compromise of available range has to be determined for each engine type and in consideration of additional parameters such as smoke. The fuel sharing modes are mainly applied on gas carriers where there can be a need to vary the amount of fuel oil being consumed dependent on the quantities of available BOG. Due to the increased quantities of fuel oil being consumed these 'Fuel Sharing' modes will have higher NOx emissions and hence require exhaust emissions aftertreatment in all cases to meet IMO Tier III limits.

As outlined in the Environmental Compliance section of this advisory, although the IMO NOx certification is based on steady state, reference testbed testing at specified test cycle load points, all engine manufacturers must include details of all engine features that can affect NOx emissions and provide limitations to operation in gas mode. These features, known as Auxiliary Control Devices (ACD), such as DCC, low load limitations and auxiliary equipment restrictions, must be clearly defined in the approved engine Technical File. Further information on the ACD requirements for gas and DF engines can be found in IMO Circular MEPC.1/Circ.854[47].

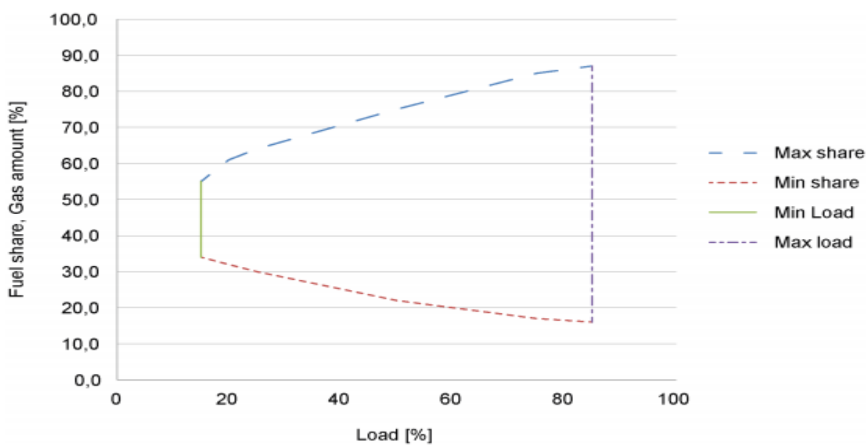
Figure 31: Mixed Mode DF Engine



© MAN Energy Solutions



© WinGD



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DUAL FUEL AND GAS ENGINE PORTFOLIO

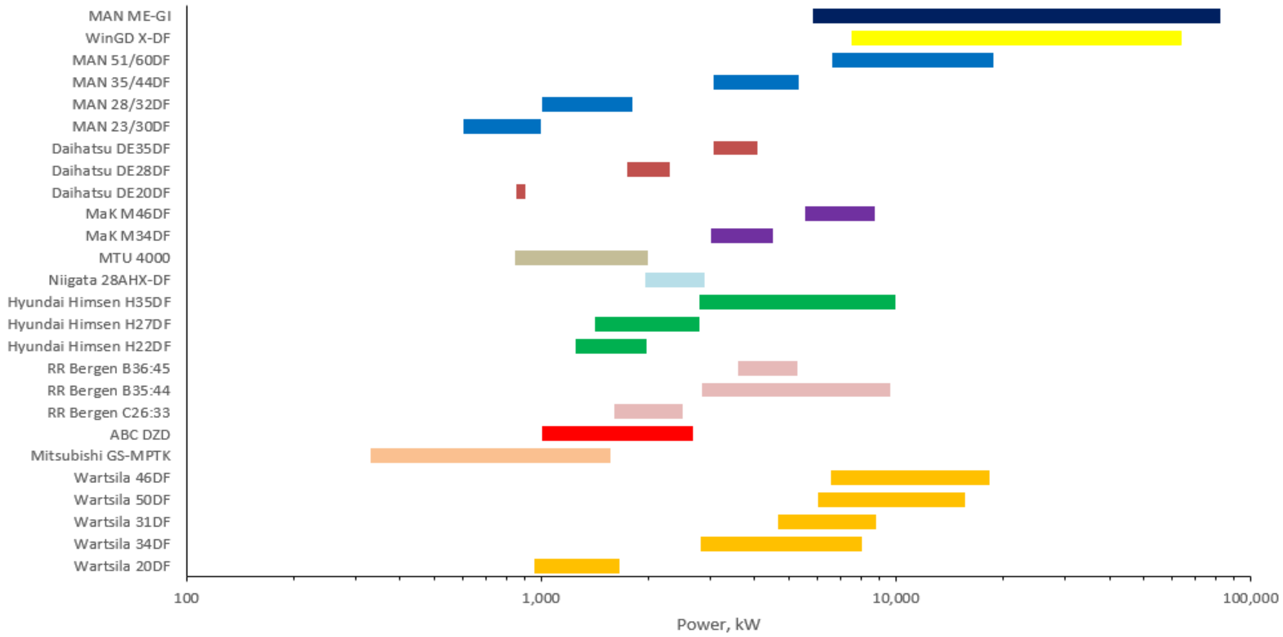
As highlighted above, although there have been HP Diesel DF 4-stroke engines designed and installed in offshore applications before, the trend for marine 4-stroke DF and gas engines is application of the Otto process in gas mode. Initially these engines were introduced as solutions for the diesel electric gas carriers and therefore typically had outputs in the 6-18MW range; e.g. the Wärtsilä 50DF and MAN 51/60DF engines. As the size and type of ships using gas as fuel has increased, so has the number of available marine gas and DF engines. The established marine engine suppliers have expanded their ranges and we have also seen other OEMs entering the market. There are still some gaps, or lack of competition, in some sizes and power ranges, notably below 1MW, however the engine types and power ranges now available is far greater than existed 10 years ago with all major marine engine suppliers now offering marine or gas DF engines – see Table 9.

© Courtesy of Wärtsilä 31DF

In most cases the engine OEM will also offer conversion of an existing diesel engine to the DF variant from their engine range. In the case of older engine designs, or where a DF product is not offered in the OEMs engine catalogue, it may be more practical to re-engine. This is a very case specific decision process.

There also remains the option to convert existing diesel engines by a third party. There are challenges with this route, for example intellectual property, warranty, liability and design approval status. However this has also been done on existing ships, and is also a route undertaken by some third parties in association with the OEM. For example, the low marine engine volumes may not be enough to justify OEM R&D investment, but a third party may be able to develop a cost effective solution from a land based engine or a marine diesel engine. We would recommend early engagement with the engine OEM and Class where such modifications are being considered.

Table 9: Marine DF and Gas Engines



SERVICE EXPERIENCE

For full details on the service experience with gas and DF engines in service we recommend contacting the engine designers. Many have made public some of their gas and methanol service experience and the early lessons they have learned. Frequently the engine designer is blamed for problems that originate outside their area of responsibility or control; system and fuel cleanliness are examples of this. However, as we might reasonably expect, there have also been many design, quality and operational lessons learnt with the early adopter experience that has driven revised specifications, design improvements and further enhancements; we are already seeing 'Mk 2' and 'Mk 3' designs incorporating such improvements.

With gas carrier expertise limited to a small number of designers, shipyards and equipment suppliers it is also not surprising that the rapid expansion to other ship types, sectors and shipyards, with no experience in building gas carriers or gas fueled ships, has also created problems. Gas fueled ships are significantly more complex than conventional ships.

However, as the industry matures and volumes increase, we can expect designs and quality to improve along with a reduction in lead times and costs.

ETHANE, METHANOL and LPG ENGINES

Both MAN and Wärtsilä have delivered ethane burning versions of their DF engines.

In the case of MAN Energy Solutions, this is by application of their established ME-GI high pressure slow speed 2-stroke engine specifically configured for burning ethane. The dual-fuel concept can be applied to all MAN low-speed diesel engines either ordered as an original unit or through retrofitting, subject to some practical and cost restrictions for the smaller bore end of their engine portfolio.

For predominantly methane natural gas applications, the ME-GI engine uses high pressure gas supplied at approximately 300-350bar. For ethane this is increased to approximately 450bar and the engine designation becomes 'ME-GIE'. As with the methane version, the high pressure gas can be supplied by a fuel supply system containing a multi stage compressor or by a lower energy demand cryogenic system utilizing a high pressure cryogenic pump and vaporizer. Engine systems and fuel supply arrangements for ethane are similar to methane, with the ethane ME-GIE engine using the same safety features as the ME-GI engine with double barriers for all fuel piping and equipment and sealing oil systems for the gas injectors. The specifications for gas piping materials, gas accumulator volumes and gas injectors are revised for the ME-GIE version, but safety and design concepts are the same. The engine designer also offers a generic engine variant capable of burning ethane or methane, and also LPG, a 'multi-fuel' engine. This may be particularly useful where gas carriers anticipate carrying a number of products, or where the engine could be used on oil tankers to consume VOCs with other fuels. The main components for an ethane ME-GIE installation with cryogenic HP fuel supply and pressurized tank are shown in Figure 32 and a multi fuel layout in Figure 33.

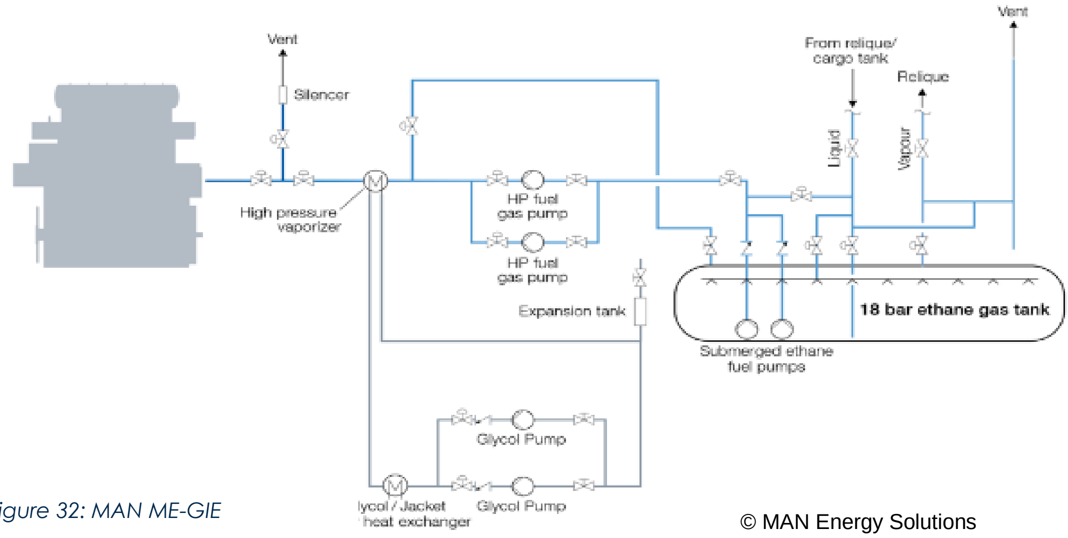


Figure 32: MAN ME-GIE

Wärtsilä also offers their established natural gas low pressure medium speed 4-stroke DF engine for burning ethane. As detailed above, this engine operates according to the Diesel combustion process in oil mode and according to the Otto combustion process in gas mode. The engine is therefore knock limited in gas mode and sensitive to gas quality and methane number. With ethane having a MN of approximately 43, the ethane variant of the engine therefore requires de-rating from the natural gas version. Even with the lowest permitted charge air receiver temperatures this could be in the region of a 25-40% derate compared to the diesel engine version.

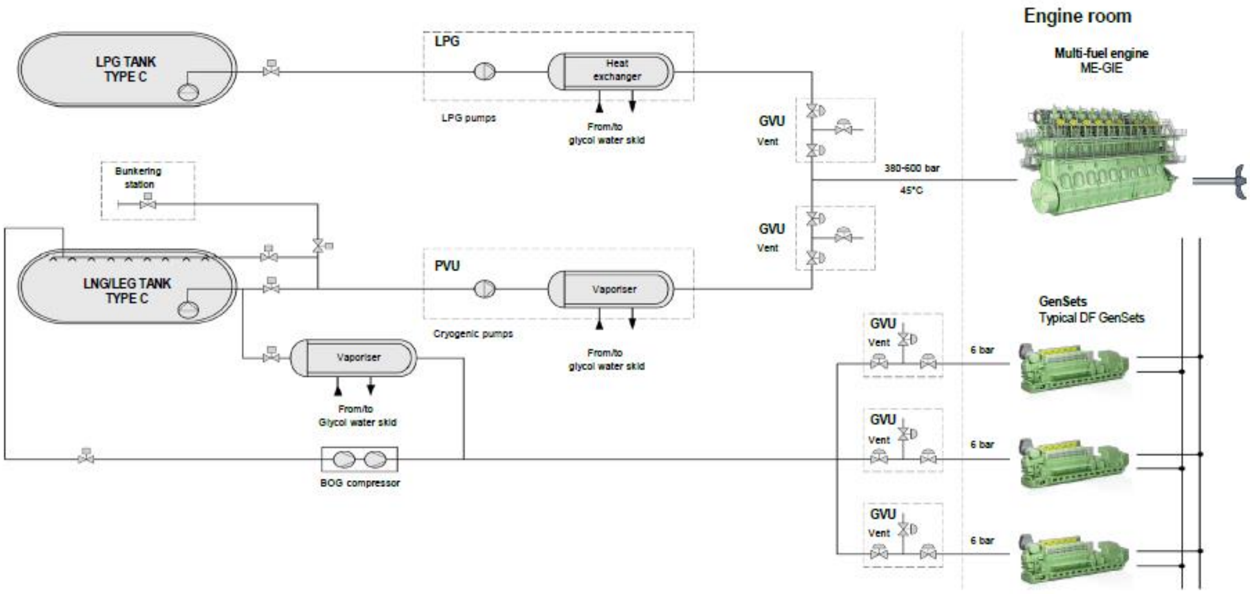


Figure 33: MAN Multi-Fuel Layout

Since some of the low flashpoint gases considered such as ethane and LPG are heavier than air, a leak would have the tendency to accumulate in the bilges or low sections of a space. Therefore special attention needs to be given to the ventilation and detection placement arrangements of double barrier concepts and machinery spaces using such fuels.

Appendix III contains a list of the ethane burning ships in operation, which are all gas carriers. As with the development of natural gas burning propulsion systems on LNGC, the development of ethane burning technologies is being developed on the ethylene/ethane/LPG and VLEC fleet.

Similarly, both MAN and Wärtsilä offer methanol burning engines. For this liquid fuel application both engine designers have adopted the HP Diesel combustion process for the burning of methanol.

The MAN engine is based on the ME-GI engine concept but instead of injecting high pressure gas the engine is designed to inject high pressure liquid fuels, similar to the injection of conventional fuel oils, through a dedicated liquid fuel injector. This engine designation is 'ME-LGI' and is designed for methanol, LPG, DME and other similar nominally liquid fuels at ambient or low pressure conditions such as ammonia. For methanol the engine has the designation 'ME-LGIM' and for LPG it has the designation 'ME-LGIP'.

The dual fuel combustion concept, i.e. the Diesel process in both oil and low flashpoint fuel modes, is the same as for the ME-GI engine and therefore the MCR and transient response performance is equivalent to the conventional oil fueled engine range and operates with no fuel slip. As with the ME-GI concept, the ME-LGI engine can burn methanol (or LPG or DME or ammonia) or fuel oil over a wide ratio depending on the operator preference, fuel availability and relative fuel cost.

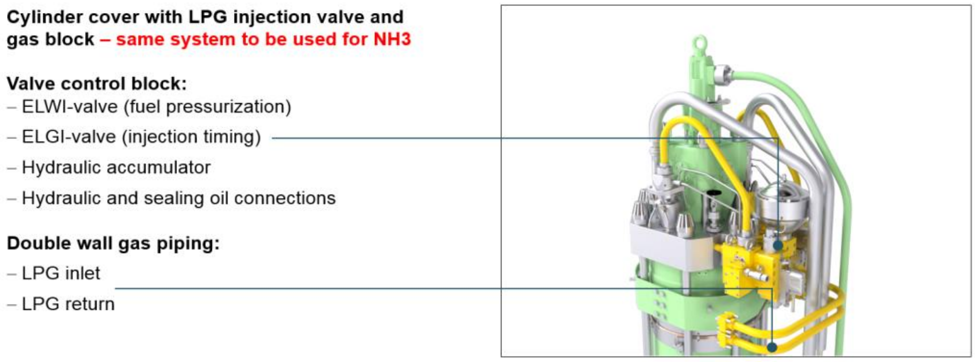
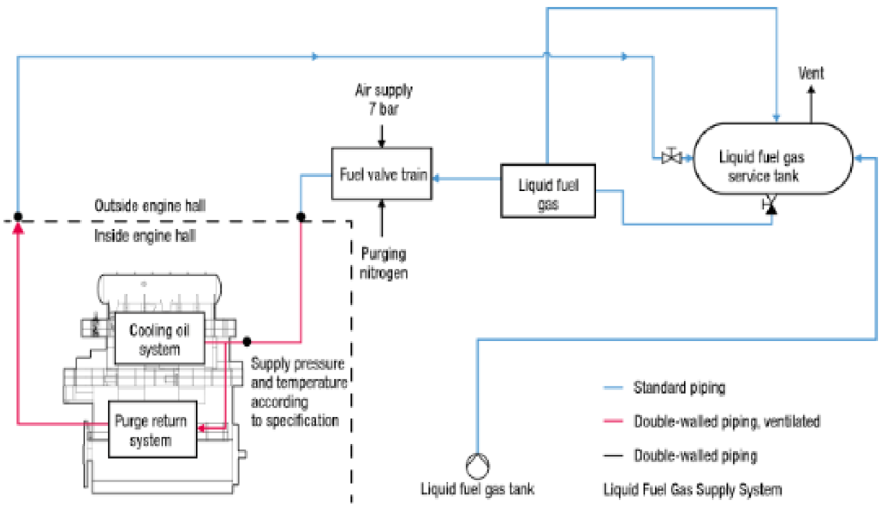


Figure 34: MAN ME-LGI Engine © MAN Energy Solutions

Operation on dual fuel requires the injection of both pilot oil fuel and the low flashpoint liquid fuel into the combustion chamber via different types of injectors arranged in the cylinder head, each with their own fuel supply system - see Figure 34. Pilot oil fuel quantities of 3-5% are typical. There would be minor differences between the low pressure fuel supply systems, depending on which fuel(s) the engine is designed to burn, but are nominally low pressure systems, similar to conventional liquid fuel systems and operate at approximately 8-40bar. This low pressure, low flashpoint fuel is supplied to the 'Fuel Booster Injection Valve' (FBIV) with the step up for high pressure liquid injection undertaken within the injector, as per conventional fuel injectors.

Figure 35: MAN ME-LGI Fuel Layout



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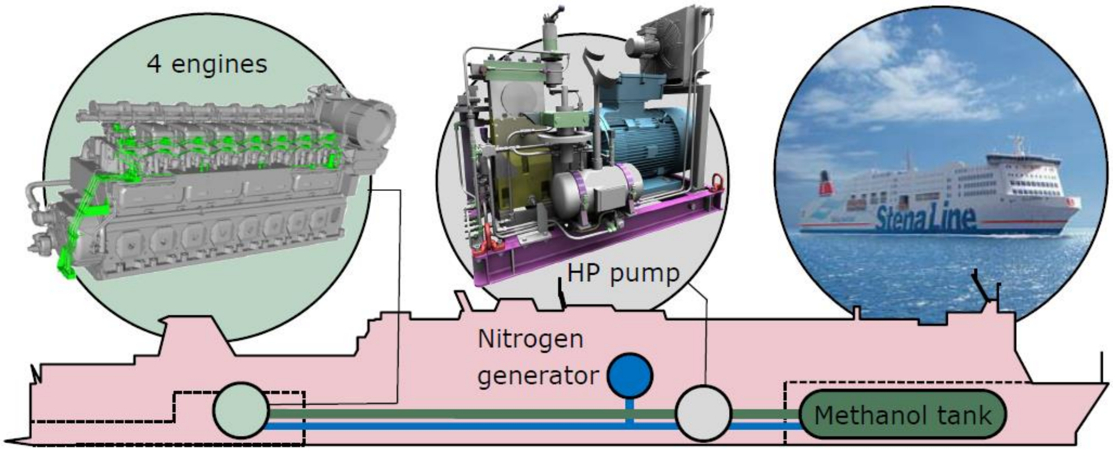
In the same way as the natural gas ME-GI engine, the ME-LGI low flashpoint fuel pipes are designed with double walls, with the outer shielding pipe designed as a measure to prevent leakage to the machinery spaces in the event of rupture of the inner fuel pipe. The double-wall piping system is designed so that every part is ventilated. Any leakage of fuel into the space between the inner and outer pipes will be extracted by the ventilation or drainage system and detected by the hydrocarbon sensors. Similarly, the ME-LGI uses the same principles of an injector sealing system to deliver sealing oil to the FBIV valves, thereby separating hydraulic control system oil and the fuel. Sealing oil pressures of 15-20 bar above fuel pressure are typical. An inert gas system to enable purging of the low flashpoint fuel system on the engine is also a necessary part of the fuel supply safety system. A generic schematic for the ME-LGI fuel systems is shown in Figure 35.

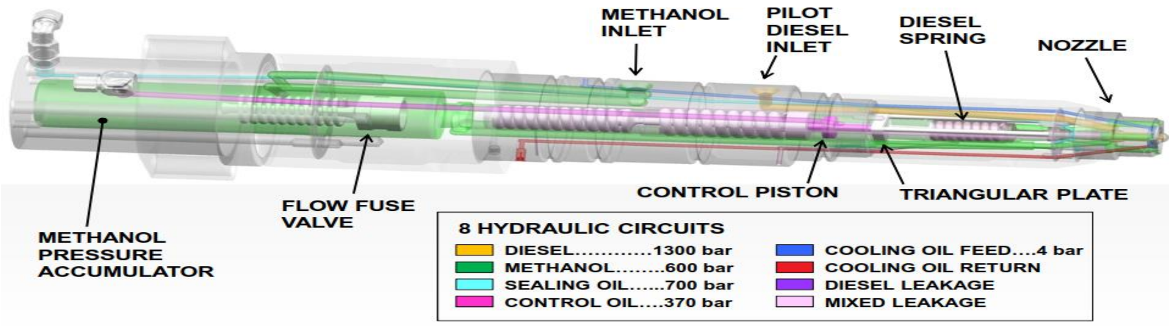
The Wärtsilä methanol burning engine technology has been successfully demonstrated on the *Stena Germanica* conversion. This retrofit included converting some of the ballast tanks for methanol fuel storage, the addition of a high pressure (600bar) fuel pump room, installation of the double wall fuel piping system with associated safety systems, and conversion of the 4-stroke medium speed engines for methanol combustion.



© Courtesy of Wärtsilä

The engine technology for the conversion is based on Wärtsilä's HP natural gas injection technology, historically deployed in offshore and land based engine applications. The high pressures in the methanol common rail system are generated by a dedicated HP fuel supply pump, located in the methanol fuel pump room, which incorporates its own methanol drain and nitrogen purge system. This off-engine fuel system was applied for the purposes of proof of concept, but is one of the systems that would likely be redesigned as an on-engine HP pump and rail arrangement for production engine designs. The engine modifications included a change of engine cylinder heads with the introduction of specially designed combined fuel oil and methanol injectors – see Figure 36. Operation of the injector is via a dedicated hydraulic control system, with the control oil also separated from the fuel system by a sealing oil system. Combustion is initiated with a pilot injection by conventional fuel oil. Operation indicates slightly improved efficiency over the diesel variant, expected SOx and PM reductions from the clean fuel and NOx reductions of 40-50%. The NOx reductions are not large enough to get to IMO Tier III levels, and thus would require exhaust aftertreatment, but Tier III could also be achievable without aftertreatment with design optimization and the blending of water with the methanol fuel.

Figure 36: Wärtsilä Methanol DF Injector



© Courtesy of Wärtsilä

Appendix III contains a list of the methanol burning ships already in operation. Methanol distribution and available engines are still some way behind natural gas, but the real world experience of large commercial marine ships demonstrates that methanol is a serious contender for a long term future marine fuel. Similarly, a number of LPG burning new construction and retrofit orders for MAN's ME-LGIP engine have also been placed and are expected to enter into service in 2020.

FURTHER CONSIDERATIONS - CYLINDER LUBRICATION

Cylinder lubrication is a consideration for all diesel engines but requires particular attention when using low flashpoint fuels that contain negligible sulfur content. The increasing BMEP, slower speeds and lower fuel sulfur content has made accurate control of cylinder oil even more essential to maintaining engines in an optimized condition and avoiding problems with cylinder cold corrosion or scuffing. Modern slow speed crosshead engines use electronic control systems to provide more accurate control of the oil feed rates than previous mechanical systems. This is important for control quantities, which may be approximately 0.6 g/kWh, but also for commercial reasons since these engines use a total loss system and cylinder oil can be significantly more expensive than fuel oil. Each of the major slow speed engine makers has their own brand name for the automated cylinder oil lubrication systems. For MAN engines the system is called Alpha ACC (Adaptive Cylinder-oil Control) and for Wärtsilä /WinGD it is the Pulse Lubrication System.

As with conventional diesel engines, the Total Base Number, or Base Number (TBN/BN) of the cylinder lube oils must be matched to the sulfur content of the fuel. The low BN oil specification suitable for gas operation is not suitable for extended operation on HFO or conventional fuel oils. Single lube oil operation may be possible if the sulfur content of fuels used is below 1.5%, but the latest manufacturers recommendations should be followed. Therefore, those ships with DF engines that operate for extended periods in both gas and fuel oil modes will be required to carry two separate cylinder oil grades. Oil switching would be concurrent with fuel switching and this can be automated through a system such as MAN's Automated Cylinder Oil Switching (ACOS) system – see Figure 37.

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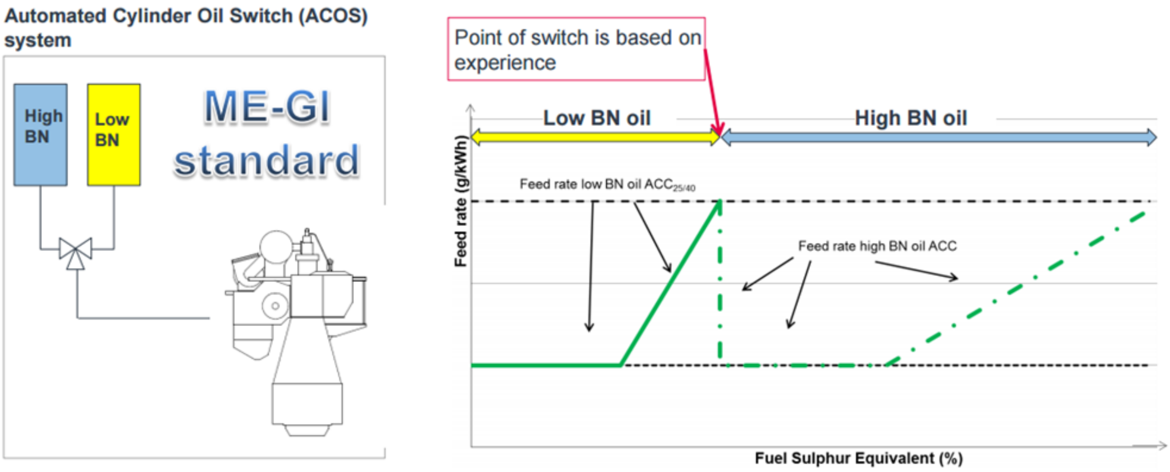
Figure 37: MAN Automated Cylinder Oil Switch



There are also now systems available that can automatically blend the correct oil specification dependent on fuel sulfur content, oil alkali content and engine load, such as the Automated Cylinder Oil Mixing (ACOM) system from MAN (see Figure 38) and WinGD who has now specified their 'iCAT' Integrated Cylinder Lubricant Auto Transfer system (see Figure 39) for all X-DF engines.. Incorporating these automatic switching, blending and dosing systems within the base engine control system can be essential to simplifying the use of low flashpoint fuels, while at the same time delivering fuel savings by keeping engines running in the most optimum condition and reducing repair and maintenance costs.

Figure 38: MAN Automated Cylinder Oil Mixing

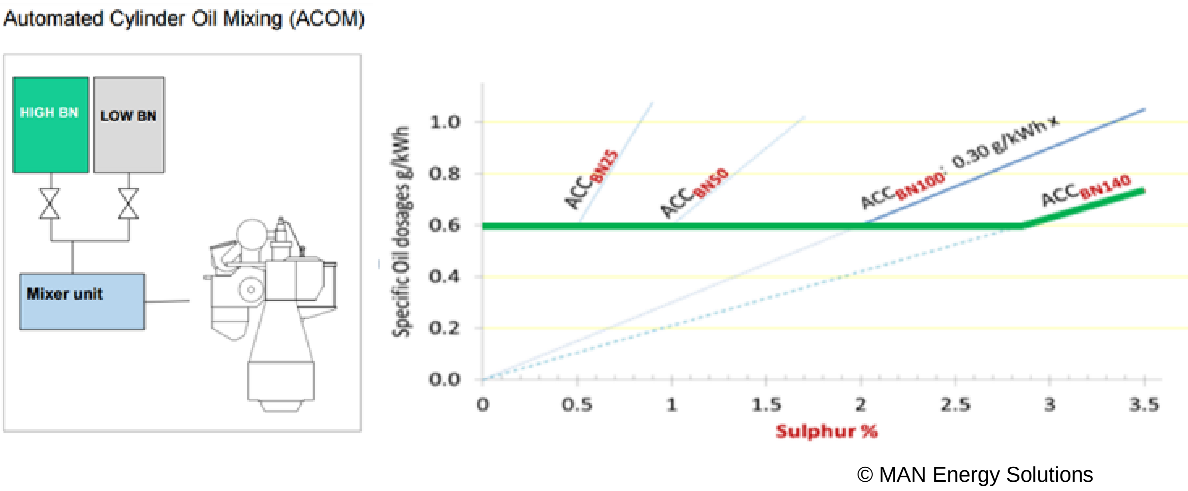
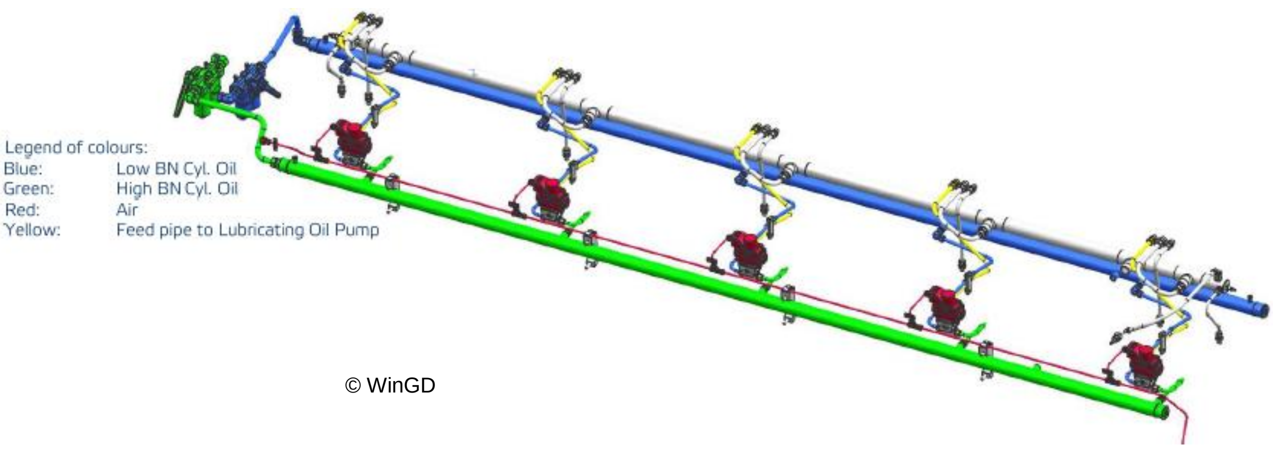


Figure 39: WinGD 'iCAT' Integrated Cylinder Lubricant Auto Transfer



CONCLUSIONS

The statutory and Classification requirements for the use of gas, or other low flashpoint fuels, are in place.

Technologies and equipment developed over many years on gas carriers for the carriage and burning of natural gas has evolved and been further developed for natural gas and other low flashpoint fuels.

There are challenges for all the low flashpoint fuels under consideration compared to conventional fuels from the technology, cost and supply perspectives. However, the bunkering infrastructure is developing and the number of vessels in service are increasing.

While the contribution of shipping to global CO_2 emissions is relatively low, the adoption of the initial IMO GHG reduction strategy demonstrates the IMO commitment to reduce the total annual GHG emissions from shipping, which means a game changing move to zero and low carbon marine fuels in the longer term.

The stage is therefore set for the marine industry to begin the transition to alternative fuels that deliver reduced gaseous and PM emissions together with GHG reductions. ABS can help with that transition.

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APPENDIX I: FUEL PROPERTIES

	MGO	HFO	Methane	Ethane	Propane	Butane
Chemical Composition			CH_4	C_2H_6	C_3H_8	C_4H_{10}
Boiling Point, deg.C 1bar	180-360	180-360	-162	-86	-42	-1
Density, kg/m^3 liquid	900	991	450	570	500	600
LHV, MJ/kg	42.7	40.2	48	47.8	46.3	45.7
Auto ignition temp, deg.C	250	250	600	515	450	372
Flash point, deg.C	>60	>60	-188	-135	-104	-60
Flammable Range, % vol in air	0.6-7.5%	0.6-7.5%	4.4-17%	2.9-13%	1.9-9.5%	1.5-8.5%
Energy density, MJ/lt	38.4	39.8	21.6	27.2	23.2	27.4
Volume comparison MGO	1	0.96	1.78	1.41	1.66	1.40
CO_2 factor, kg CO_2/kg fuel	3.206	3.114	2.750	2.927	3.000	3.030
Carbon content	0.8744	0.8493	0.7500	0.7989	0.8182	0.8264
CO_2, kg CO_2/kWh	0.2701	0.2787	0.2061	0.2205	0.2331	0.2385

	DME	Methanol	Ethanol	Hydrogen	Ammonia
Chemical Composition	C_2H_6O	CH_3OH	C_2H_5OH	H_2	NH_3
Boiling Point, deg.C 1bar	-25	65	78	-253	-33
Density, kg/m^3 liquid	670	790	790	76.9	696
LHV, MJ/kg	28.7	19.9	26.8	120.2	22.5
Auto ignition temp, deg.C	350	440	400	535	630
Flash point, deg.C	-41	9	12	-	132
Flammable Range, % vol in air	3.3-18%	6-26%	3.5-15%	4-77%	15-33.6%
Energy density, MJ/lt	19.2	15.7	21.2	9.2	15.7
Volume comparison MGO	2.00	2.44	1.82	4.16	2.45
CO_2 factor, kg CO_2/kg fuel	1.911	1.375	1.913	0	0
Carbon content	0.5214	0.3750	0.5217	0	0
CO_2, kg CO_2/kWh	0.2397	0.2486	0.2568	0	0

APPENDIX II: SAMPLE LNG BUNKER DELIVERY NOTE

LNG-BUNKER DELIVERY NOTE*
LNG AS FUEL FOR

SHIP NAME:_________________________ IMO NO.:_____________

Date of delivery:

1. LNG-Properties

Methane number **	--	
Lower calorific (heating) value	MJ/kg	
Higher calorific (heating) value	MJ/kg	
Wobbe Indices Ws / Wi	MJ/m^3	
Density	kg/m^3	
Pressure	MPa (abs)	
LNG temperature delivered	°C	
LNG temperature in storage tank(s)	°C	
Pressure in storage tank(s)	MPa (abs)	

2. LNG-Composition

Methane, CH_4	% (kg/kg)	
Ethane, C_2H_6	% (kg/kg)	
Propane, C_3H_8	% (kg/kg)	
Isobutane, i C_4H_{10}	% (kg/kg)	
N-Butane, n C_4H_{10}	% (kg/kg)	
Pentane, C_5H_{12}	% (kg/kg)	
Hexane, C_6H_{14}	% (kg/kg)	
Heptane, C_7H_{16}	% (kg/kg)	
Nitrogen, N_2	% (kg/kg)	
Sulphur, S	% (kg/kg)	
negligible<5ppm hydrogen sulphide (H_2S), hydrogen, ammonia, chlorine, fluorine, water		

3. Net Total delivered: _____________t, ___________________MJ _____________m³

Net Liquid delivery:______________GJ

4. Signature(s):

Supplier Company Name, contact details:________________________

Signature:___________________Place/Port ___________ date:_________________

Receiver:_____________________________

* *The LNG properties and composition allow the operator to act in accordance with the known properties of the gas and any operational limitations linked to that.*

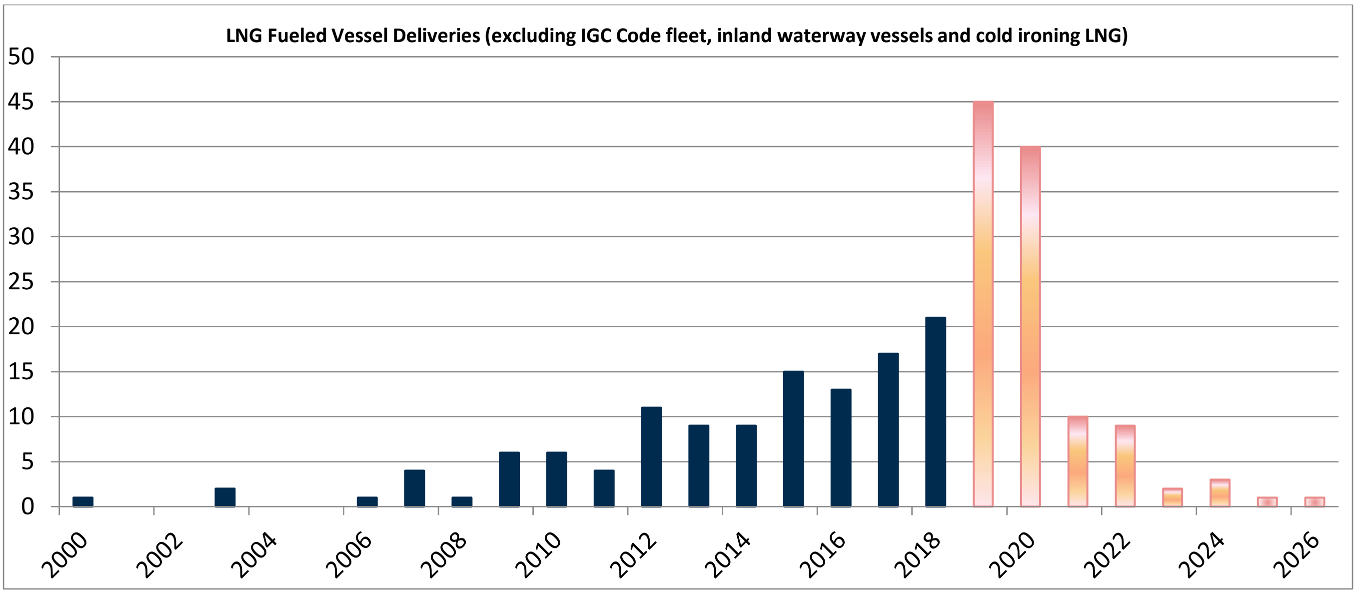
** *Preferably above 70 and referring to the used methane number calculation method in DIN EN 16726. This does not necessarily reflect the methane number that goes into the engine.*

APPENDIX III: LIST OF LNG AND OTHER LOW FLASHPOINT FUEL VESSELS IN SERVICE

LNG AS FUEL

Year	Name	Type	Year	Name	Type
2000	Glutra	Ferry	2013	Rem Leader	PSV
2003	Viking Energy	PSV	2013	Viking Grace	RoPax
2003	Stril Pioner	PSV	2013	Lodingen	Ferry
2006	Bergensfjord	Ferry	2013	Econuri	Ferry/Harbour vessel
2007	Stavangerfjord	Ferry	2013	Eidsvaag Pioneer	General cargo/fishfeed carrier
2007	Raunefjord	Ferry	2013	Stavangerfjord	RoPax
2007	Mastrafjord	Ferry	2013	Francisco	High Speed RoPax
2007	Fanafjord	Ferry	2013	Hai Yang Shi You 521	Tug
2008	Viking Queen	PSV	2013	Hardanger	RoPax
2009	Viking Lady	PSV	2014	Ryfylke	RoPax
2009	Moldefjord	Ferry	2014	Bergensfjord	RoPax
2009	Tidekongen	Ferry	2014	Borgoy	Tug
2009	Tideprinsen	Ferry	2014	Turva	Patrol Vessel
2009	Tidedronningen	Ferry	2014	Bokn	Tug
2009	Barentshav	Patrol Craft	2014	Rem Eir	PSV
2010	Bergen	Patrol Craft	2014	With Harvest	General cargo/fishfeed carrier
2010	Sortland	Patrol Craft	2014	With Marine	General cargo/fishfeed carrier
2010	Fannefjord	Ferry	2014	Siem Symphony	PSV
2010	Romsdalsfjord	Ferry	2015	F.A.Gauthier	RoPax
2010	Korsfjord	Ferry	2015	Helgoland	Ferry/cargo
2010	SelbjØrnsfjord	Ferry	2015	Prinsesse Isabella	RoPax
2011	Skandi Gamma	PSV	2015	Kvitnos	Cargo
2011	Boknafjord	Ferry	2015	Kvitbjorn	Cargo
2011	Bit Viking	Chemical Tanker	2015	Harvey Energy	OSV
2011	Normand Arctic	PSV	2015	Harvey Power	OSV
2012	Edoyfjord	Ferry	2015	Bergen Viking	Chemical Tanker
2012	Tresfjord	Ferry	2015	Ostfriesland	Ferry/cargo
2012	Viking Prince	PSV	2015	Hai Yang Shi You 525	Tug
2012	Olympic Energy	PSV	2015	Stril Barents	PSV
2012	Island Crusader	PSV	2015	Siem Pride	PSV
2012	Hoydal	General Cargo	2015	Sakigake	Tug
2012	Viking Princess	PSV	2015	Isla Bella	Container carrier
2012	Island Contender	PSV	2015	Greenland	Bulk carrier
2012	Landegode	Ferry	2016	Perla Del Caribe	Container carrier
2012	Vaeroy	Ferry	2016	Polaris	Ice breaker
2012	Baroy	Ferry	2016	Harvey Liberty	OSV

Year	Name	Type	Year	Name	Type
2016	Ternsund	Oil carrier	2018	Gagarin Prospect	Tanker
2016	Ternfjord	Oil carrier	2018	Lomonosov Prospect	Tanker
2016	Tern Sea	Oil carrier	2018	Mendeleev Prospect	Tanker
2016	Damia Desgagnes	Bitumen Tanker	2018	AIDAnova	Cruise
2016	Auto Eco	PCTC	2018	Boris Sokolov	Tanker
2016	Siem Thiima	PSV	2018	Containerships Nord	Container carrier
2016	Ireland	Bulk carrier	2018	Taino	Con-Ro
2016	Searoad Mersey II	Ferry	2018	Thun Eos	Oil/chemical tanker
2016	Hasvik	Ferry	2018	Elio	Ferry
2016	Bergsfjord	Ferry	2019	Ishin	Tug
2017	Fure West	Chemical Tanker	2019	Paul A. Desgagnes	Chemical/product tanker
2017	Seaspan Swift	Ferry	2019	Eagle Brasilia	Oil carrier
2017	Seaspan Reliant	Ferry	2019	Eagle Bintulu	Oil carrier
2017	Salish Orca	Ro-pax	2019	Rossi A. Desgagnes	Chemical/product tanker
2017	Tern Ocean	Oil carrier	2019	Fure Valo	Chemical/product tanker
2017	Salish Eagle	Ro-pax	2019	Thun Evolve	Chemical/product tanker
2017	Salish Raven	Ro-pax	2019	Samuel Prospect	Tanker
2017	Minerva	TSHD	2019	Vernadsky Prospect	Tanker
2017	Megastar	Fast Ferry	2019	Korolev Prospect	Tanker
2017	Harvey Freedom	OSV			
2017	Auto Energy	PCTC			
2017	Dux	Tug			
2017	Pax	Tug			
2017	Audux	Tug			
2017	Wes Amelie	Container carrier			
2017	Scheldt River	TSHD			
2017	Nyksund	General Cargo			
2018	Ilshin Green Iris	Bulk carrier			
2018	Harvey America	OSV			
2018	Mia Desgagnes	Chemical/product tanker			
2018	Gaia Desgagnes	Oil/chemical carrier			
2018	Spirit of British Columbia	Ro-Ro/Pass			
2018	Armand Imbeau II	RoPax			
2018	EL Coqui	Con-Ro			
2018	Living Stone	MPV/Cable-layer			
2018	KST Liberty	Tug			
2018	Haaga	Bulk Carrier			
2018	Viikki	Bulk Carrier			
2018	Maju Liberty	Tug			



ETHANE AS FUEL

Year	Name	Type	Year	Name	Type
2015	JS Ineos Insight	Gas carrier	2017	JS Ineos Intuition	Gas carrier
2015	JS Ineos Ingenuity	Gas carrier	2017	JS Ineos Invention	Gas carrier
2015	JS Ineos Intrepid	Gas carrier	2017	Gaschem Orca	Gas carrier
2016	JS Ineos Inspiration	Gas carrier	2018	Navigator Aurora	Gas carrier
2016	JS Ineos Innovation	Gas carrier			
2016	Gaschem Beluga	Gas carrier			
2017	JS Ineos Independence	Gas carrier			

METHANOL AS FUEL

Year	Name	Type	Year	Name	Type
2015	Stena Germanica	Ro-Pax	2016	Manchac Sun	Chemical/Oil Carrier
2016	Lindanger	Chemical/Oil Carrier	2016	Mari Boyle	Chemical/Oil Carrier
2016	Leikanger	Chemical/Oil Carrier	2016	Mari Jone	Chemical/Oil Carrier
2016	Cajun Sun	Chemical/Oil Carrier			
2016	Taranaki Sun	Chemical/Oil Carrier			

APPENDIX IV: LIST OF LNG BUNKER VESSELS IN SERVICE

Region	Location	Name	Capacity (m^3)
North America	Jacksonville, Florida	Clean Jacksonville	2,200
Europe	Port of Stockholm	Seagas	180
Europe	Port of Rotterdam	Cardissa	6,500
Europe	Zeebrugge	ENGIE Zeebrugge	5,100
Europe	North Sea / Baltic	Coralius	5, 800
Europe	Huelva, Spain	Oizmendi	600
Europe	Algeciras, Spain	Bunker Breeze	1,200
Europe	North Sea / Baltic	Kairos	7,500
Europe	Mediterranean/Atl antic	Coral Methane	7,500

APPENDIX V: ABS RULES AND GUIDES FOR GAS AND OTHER LOW FLASHPOINT FUELS

Publication Number	Title
1	Marine Vessel Rules; Part 5C Specific Vessel Types; Chapter 8 Vessels Intended to Carry Liquefied Gases in Bulk; Chapter 13 Vessels Using Gases or Other Low-Flashpoint Fuels
10	Steel Barges
97	Risk Assessment Applications for the Marine and Offshore Oil and Gas Industries
116	ABS Guidance Notes on Review and Approval of Novel Concepts
117	Risk Evaluations for the Classification of Marine-Related Facilities
138	Vessels Intended to Carry Compressed Natural Gases in Bulk
144	Liquefied Gas Carriers with Independent Tanks
210	LNG Fuel Ready Vessels
245	LNG Bunkering
271	LNG Regasification Vessels
287	Power Service for Marine and Offshore Applications
305	Guide for Liquified Gas Tank Barges with Remote Control and Monitoring of Essential Systems

APPENDIX VI: FREQUENTLY ASKED QUESTIONS

What are the Marine Vessel Rules? Is there a difference between the Marine Vessel Rules and the Steel Vessel Rules?

To address the duplication of requirements and to provide a set of Rules that are easier to navigate for both ABS and industry users, the ABS *Rules for Building and Classing Marine Vessels* (MVR) have been introduced to consolidate the following ABS Rule sets: *Rules for Building and Classing Steel Vessels*, *Rules for Building and Classing Steel Vessels Under 90 meters (295 feet) in Length*, and *Rules for Building and Classing Offshore Support Vessels*. The technical content is not changing, the consolidation is for administrative reorganization purposes only. The MVR become mandatory as of 1 January 2020.

All current and archived ABS Rules, Guides and Guidance Notes can be downloaded free of charge at www.eagle.org.

What are the statutory safety requirements for using natural gas or other low flashpoint fuels?

SOLAS has historically prohibited the use of low-flashpoint fuel oils less than 60˚C, except for emergency generator use. With the adoption of the 'International Code of Safety for Ships Using Gases or Other Low-Flashpoint Fuels' (IGF Code), IMO has introduced a mandatory safety code for all ship types, other than gas carriers subject to the IGC Code, that introduces a framework and requirements under SOLAS for burning fuels with a flashpoint less than 60˚C. For gas carriers, the use of natural gas as a fuel is permitted by application of Chapter 16 of the IGC Code. With the adoption of the revised IGC Code in 2014, a new section 16.9 for 'Alternative fuels and technologies' was introduced permitting the burning of cargoes other than natural gas, provided they are not identified as toxic products. With the adoption of the IGF Code and 2016 IGC Code, IMO has therefore established the regulatory safety requirements and framework for the use of natural gas and other low flashpoint fuels on all ship types. Both of these Codes are embedded in the ABS Rules under Part 5C, Chapters 8 and 13 for the IGC and IGF Codes respectively. Additional vessel requirements may also be applicable through the flag Administration of the ship, and additional national and local regulations regarding bunkering would be applicable.

What is LNG?

Liquefied natural gas, or LNG, is natural gas that has been supercooled to minus 162 degrees Celsius. At that temperature it condenses into a liquid. When in liquid form, natural gas reduces in volume up to 600 times from its gaseous state, which makes it feasible to transport over long distances. The critical temperature for LNG is minus 82 degrees Celsius and is carried in appropriately designed fuel containment systems as a boiling liquid. LNG is odorless, colorless, non-corrosive and non-toxic. The composition of natural gas varies depending on the geographic source, but typical compositions are predominantly Methane (94%) with Ethane (4.7%), Propane (0.8%) and Nitrogen (0.3%). The density of LNG is in the range of 410-500 kg/m^3 with a typical (low) calorific value of 49.5 MJ/kg.

What ship-types are suited for LNG or other low flashpoint fuels?

In principle, any vessel type can adopt LNG or other low flashpoint fuels. However, every ship type, size, operating profile and trading region will offer its own unique challenges. Therefore, each vessel will need to be evaluated for the specific challenges related to the arrangement of the alternative fuel storage tanks, equipment and systems. For example, locating LNG fuel tanks and fuel preparation equipment may be less challenging on tankers compared to other vessel types, because of the availability of deck space that means the additional equipment may not impact cargo capacity or normal ship operations.

What are the space challenges with storage of LNG or other low flashpoint fuels compared to conventional liquid fuels?

The packaging of LNG and other low flashpoint fuels by comparison to conventional liquid fuels is a challenge for most vessels and particularly with respect to retrofit conversions. While the direct volume ratio for equivalent energy content indicates a ratio of approximately 1.6:1 for LNG, the additional space requirements required as a result of using (typically) Type C tanks and associated fuel processing spaces makes the real world volume ratio between 2 and 4 times that of conventional fuels. Methanol has similar challenges having approximately half the specific energy of HFO. This means a compromise has to be reached with respect to needing a larger vessel, or reduced range, or more frequent bunkering, or reduced cargo space, or a combination of those features to optimize the design and minimize this penalty. Therefore most designs will need to be assessed on a case-by-case basis considering the vessel type, operating profile, trading areas etc. to see if a practical, cost effective solution can be achieved.

Can low flashpoint fuel tanks be located adjacent to accommodation spaces, service spaces or control stations?

During the development of the IGF Code, IMO determined at BLG 16 in February 2012 that low flashpoint fuel tank arrangements should not be excluded from being located adjacent to accommodation spaces. However, a risk based approach would be required to be applied to assess the hazards of each particular installation. For the use of LNG as a fuel, the IGF Code has a reduced scope of risk assessment due to the detailed prescriptive requirements contained in part A-1. Section 4.2.2 of the IGF Code details the specific parts of the IGF Code that are to be considered for risk assessment, and this includes reference to fuel containment systems under 6.4.1.1 of the IGF Code. ABS' understanding of the intention of that specific risk assessment requirement is to capture novel fuel containment systems within a risk assessment, but also evaluate any fuel containment features that deviate from the Code requirements and to assess the proposed arrangement of LNG tanks in all cases. Furthermore, there may be flag Administration requirements, for example, USCG Policy letter No. 01-12 CH-1[24] requires additional items from those identified by 4.2.2. of the IGF Code to be considered in the risk assessment. These include gas fuel storage tanks located below or directly adjacent to accommodation spaces, service spaces or control stations Therefore locating low flashpoint fuels below accommodation areas is possible, subject to satisfactory to consideration by the vessel specific risk assessment.

Can a vessel be prepared for later retrofit of LNG as fuel? What does ‘LNG Ready’ mean?

The ABS *Guide for LNG Ready Vessels* provides guidance to shipowners and shipbuilders preparing a ship design to be ready for using LNG as a fuel. It helps evaluate that a vessel has been designed intentionally with feasible LNG fuel conversion in mind and that it has physical features that make it suitable for such conversion in the future.

The ABS guide defines 3 'LNG Fuel Ready Levels':

Level 1 – Concept Design Approval, or Approval-in-Principle (AIP), that includes Record Comment. This is a high-level evaluation of the geometry and structural arrangements of the vessel, the safety elements associated with tank location and that the hazardous areas can be accommodated in compliance with the requirements.

Level 2 – General Design Approval, confirming compliance of the design with the applicable rules and regulations at the time of review with the purpose of providing the owner with an approved design package that can be used at the time of conversion. It is categorized into different groups to identify parts of the complete design. The level of the design details to be reviewed for each system would be general. Detailed information such as particular equipment manufacturers and installations are not required except for the gas consumers.

Level 3 – Detailed Design Approval & Installation of equipment. This level incorporates both the Class approval of detailed drawings and installation of specified equipment on board the ship. Upon completion of the installation to the Surveyor's satisfaction, the vessel will be eligible for the class notation "LNG Ready" with descriptive letters introduced in the Record listing the parts of the system that have been installed in accordance with approved plans and to the satisfaction of the Surveyor prior to delivery of the vessel.

What are the flag Administration or port state policies for the use of LNG as fuel and LNG bunkering?

Not all flag administrations have a formal policy for adoption of the IGF Code, or to provide any additional requirements, however the amendments to SOLAS to make the IGF Code mandatory means that all flag Administrations signatory to SOLAS are to apply the IGF Code to the applicable internationally trading ships over 500GT. Some administrations, such as the USCG & Transport Canada, have established policies for adoption of the IGF Code. It is important to reach out as early as possible to Class and regulators for any prospective LNG or low flashpoint fuel project to determine the applicable ship and port operation safety and environmental regulation. In addition to the IMO developed IGF Code, there have also been many industry initiatives that have helped develop technical specifications, standards and best practices to support the development of the LNG bunkering infrastructure and provide regulatory frameworks for port authorities, bunker suppliers and other stakeholders. Specifically, the ISO 20519:2017[13] standard covering the LNG bunkering transfer systems, the ISO/TS 18683:2015[14] LNG supply guidelines, the IACS LNG bunkering guidelines[21] and the USCG policy letters[26, 27] all provide important LNG bunkering references that may be applied. As a RO for the majority of the worlds flag Administrations, and with a global presence, ABS can facilitate communication with the flags and port authorities to verify the specific requirements.

What are the typical LNG bunkering options?

There are three main methods to bunker LNG to a vessel, tank-to-vessel (from a land bulk storage tank), truck-to-vessel, vessel-to-vessel. There is also a further recognized technique that involves the transfer of LNG by transferring portable LNG tanks to the vessel. In this latter case, the portable LNG tanks are effectively loaded as (hazardous) cargo but when onboard must be secured and connected as if they are a permanent LNG fuel storage tank. The coupling and uncoupling of these tanks to the vessel fuel supply, vent and safety systems is considered bunkering. Further guidance is provided in the ABS *LNG Bunkering: Technical and Operational Advisory* and *Bunkering of Liquefied Natural Gas-Fueled Marine Vessels in North America* publications.

Will bunkering LNG interfere with our normal cargo operations and can we bunker at the same time, i.e. undertake Simultaneous Operations (SIMOPS)?

The bunkering of LNG poses additional risks that need to be evaluated and addressed and typically leads to the establishment of a number of safety zones around the bunkering station. There are a number of standards, guidelines and publications that address LNG bunkering, such as the ISO 20519:2017[(13)] standard covering the LNG bunkering transfer systems, the ISO/TS 18683:2015[(14)] LNG supply guidelines, the IACS LNG bunkering guidelines[(21)] together with the SGMF publications Safety Guidelines – Bunkering[(50)], Bunkering of Ships with LNG[(51)], Simultaneous Operations during LNG Bunkering[(52)] and Recommendation of controlled zones during LNG bunkering[(53)]. Those that address SIMOPS specifically require a risk assessment to be conducted. The main safety zones that are established for LNG bunkering are the hazardous area zone, safety zone and marine exclusion zone, with wider areas defined as the monitoring and security area and external zone. The hazardous zones are typically defined by IEC standards and the extent of the safety zone will be defined by the bunkering risk assessment based on the arrangements, physical features and maximum credible release. This risk assessment process and the extent of the safety zone may therefore have some impact on where cargo operations can be undertaken during bunkering. Consideration to the bunker station location and cargo operations at an early design stage can help to facilitate application of SIMOPS and reduce the limitations on cargo operations.

What is methane slip?

Methane slip is a general term used for the direct emission of methane to the atmosphere during production of natural gas for energy purposes, but also used to describe the emission of methane to the atmosphere during the operation of natural gas fueled ships. Methane is a potent global warming gas, according to the UN IPCC 5th Assessment Report, methane is categorized with a GWP of 84 times that of CO_2 on a 20 year basis and 28 times that of CO_2 on a 100 year basis. Safety system actions, such as triggering an engine to trip from gas mode operation to oil mode operation, normal changeover operations between fuel modes, fuel tank relief valve operation, fuel supply line purging and bunkering are all sources of operational methane slip for gas fueled ships. However, one of the most significant emissions of methane for gas fueled ships is that direct to the exhaust from the passage of unburned hydrocarbons to the exhaust stream from low pressure Otto process gas and DF engines. This is inherent with Otto cycle gas or DF engines and originates from incomplete combustion, valve overlap and combustion chamber crevice volumes. There are scientific studies that indicate using natural gas as a fuel can have an overall lower CO_2 footprint than conventional fuels, but there are also studies that indicate the opposite. At present this emission is not regulated. However, the IMO initial GHG reduction strategy adopted at MEPC in April 2018 has pushed the issue of marine GHG emissions to the front of the agenda. IMO has indicated that the workplan will consider and analyze measures to address emissions of methane and develop robust lifecycle GHG/carbon intensity guidelines for all types of fuels. Consideration of the full production and use chain, from well-to-funnel, therefore becomes critical to assessing the overall GHG footprint of any fuel to be considered. It is important to note that methane slip to the exhaust is not an issue for HP engines using the Diesel combustion process. Furthermore, other fuels being considered, such as methanol, LPG and ethane are not considered global warming gases.

What natural gas and other low flashpoint fuel engines are ABS approved?

ABS has a long association with all of the major engine OEMs and has been engaged in the approval of the gas, dual fuel and alternative fuel engines available on the market. The latest list of ABS type approved engines can be found on the ABS website through the ABS Type Approval database at:
https://ww2.eagle.org/en/Products-and-Services/type-approval.html

How do we proceed with crew training for LNG fueled ships?

The STCW Convention and Code were amended in 2015 to add specific training requirements and certification for IGF Code seafarers. These amendments describe the required competence, knowledge, understanding and proficiencies for basic and advanced training. While Administrations are yet to develop their own detailed routes to proficiency certification, ABS has worked extensively in North America with the USCG and Transport Canada, and in partnership with United States Maritime Resource Center (USMRC), to develop training courses for gas fueled ships that meet the requirements of the STCW Convention. Training courses can be tailored to the shipowners requirements but as a minimum include a combination of classroom training, fuel containment and fuel supply system simulation, bunkering simulation and practical fire-fighting exercises. Owners and operators should therefore engage with ABS and their Administration to confirm which specific training is required and what they may wish to provide specifically for their crew members, as relevant to their own fleet. Once this has been established the training programme and venue(s) can be organized by ABS specialist groups, such as Advanced Solutions, to incorporate the necessary mix of classroom, simulator and fire-fighting training necessary to meet the STCW and client requirements using ABS experienced and qualified instructors.

LIST OF ACRONYMS AND ABBREVIATIONS

ABS	American Bureau of Shipping
ACC	Adaptive Cylinder-oil Control
ACD	Auxiliary Control Device
ACOM	Automatic Cylinder Oil Mixing
ACOS	Automatic Cylinder Oil Switching
AFR	Air/Fuel Ratio
AIP	Approval In Principle
ALARP	As Low As Reasonably Practical
BDN	Bunker Delivery Note
BMEP	Brake Mean Effective Pressure
BOG	Boil Off Gas
CCC	Carriage of Cargoes and Containers (IMO)
CFR	Code of Federal Regulations
CIMAC	International Council on Combustion Engines
CNG	Compressed Natural Gas
CO	Carbon Monoxide
CO_2	Carbon Dioxide
DCC	Dynamic Combustion Control
DME	DiMethyl Ether
ECA	Emission Control Area
EEA	Exhaust Emission Abatement
EEDI	Energy Efficiency Design Index
EGCS	Exhaust Gas Cleaning System
EIAPPC	Engine International Air Pollution Prevention Certificate
EMSA	European Maritime Safety Agency
EPA	Environmental Protection Agency
ESD	Emergency Shutdown
EU	European Union
FBIV	Fuel Booster Injection Valve
FGSS	Fuel Gas Supply System
FMEA	Failure Mode and Effects Analysis
GFS	Gas Fueled Ship
GGS	Global Gas Solutions
GHG	Green House Gas
GISIS	Global Integrated Ship Information System (IMO)
GVT	Gas Valve Train
GVU	Gas Valve Unit
GWP	Global Warming Potential
HAZID	Hazard Identification Studies
HAZOP	Hazard and Operability Study
HC	Hydrocarbon
HFO	Heavy Fuel Oil
IACS	International Association of Classification Societies
IEA	International Energy Agency
IEC	International Electrotechnical Commission
IEEC	International Energy Efficiency Certificate
IGC	International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IMO)
IGF	International Code of Safety for Ships Using Gases or other Low-Flashpoint Fuels (IMO)
IMO	International Maritime Organization
ISO	International Organization for Standardization
LL	Loading Limit
LNG	Liquified Natural Gas
LNGC	Liquified Natural Gas Carrier
LPG	Liquified Petroleum Gas
MARPOL	Marine Pollution (IMO)
MCR	Maximum Continuous Rating
MDO	Marine Diesel Oil
ME-GI	MAN engine identifier – M series Electronic Gas Injection
MEPC	Marine Environment Protection Committee (IMO)
MGO	Marine Gas Oil
MN	Methane Number
MSC	Maritime Safety Committee (IMO)
MSSE	Marine Safety & Security Executive
MVR	Marine Vessel Rules
NIST	National Institute of Standards and Technology
NMA	Norwegian Maritime Authority
NMHC	Non-methane Hydrocarbon
NOx	Nitrogen Oxides
NPV	Net Present Value
NTC	NOx Technical Code
OEM	Original Equipment Manufacturer
PBU	Pressure Build Up
PM	Particulate Matter
PMS	Power Management System
PN	Particle Number
PPM	Parts Per Million
PVU	Pump Vaporizer Unit
ROI	Return On Investment
SCR	Selective Catalytic Reduction
SDS	Safety Data Sheet
SECA	SOx Emission Control Area
SEEMP	Ship Energy Efficiency Management Plan
SGMF	Society for Gas as a Marine Fuel
SIMOPS	Simultaneous Operations
SOLAS	International Convention for the Safety of Life at Sea, 1974, as amended (IMO)
SOx	Sulfur Oxides
STCW	Standards of Training, Certification and Watchkeeping for seafarers
SVR	Steel Vessel Rules
TBN	Total Base Number
TCS	Tank Connection Space
THC	Total Hydrocarbon
ToR	Terms of Reference
UI	Unified Interpretation
UNFCCC	United Nations Framework Convention on Climate Change
UR	Unified Requirement
USCG	United States Coast Guard
USMRC	United States Maritime Resource Center
VLEC	Very Large Ethane Carrier
VOC	Volatile Organic Compound
WinGD	Winterthur Gas and Diesel

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