NATIONAL TECHNICAL UNIVERSITY OF ATHENS

School of Naval Architecture and Marine Engineering

Post graduate program:
"MARINE AND NAUTICAL TECHNOLOGY AND SCIENCE"

Post graduate thesis with title:

Environmental Challenges in shipping industry meeting the Air Emissions requirements. Techno economic analysis of the current solutions (LNG as Fuel, Scrubbers, MGO)

George D. Kiadimos

Athens, January 2017

Supervisor: Dr. Nikolaos P. Ventikos (Ass. Professor)

NATIONAL TECHNICAL UNIVERSITY OF ATHENS

School of Naval Architecture and Marine Engineering

Post graduate program:
"MARINE AND NAUTICAL TECHNOLOGY AND SCIENCE"

Post graduate thesis with title:

Environmental Challenges in shipping industry meeting the Air Emissions requirements. Techno economic analysis of the current solutions (LNG as Fuel, Scrubbers, MGO)

George D. Kiadimos

Supervisor: Dr. Nikolaos P. Ventikos (Ass. Professor)

Has been approved by three members of the committee dated

Nikolaos P. Ventikos, Ass. Professor……………………………………

George Zaraphonitis, Ass. Professor…………………………………….

Dimitris V. Lyridis, Ass. Professor………………………………………

Athens, January 2017

Abstract

Due to the recent decision of the International Maritime Organization (IMO), the regulatory authority for international shipping, during its Marine Environment Protection Committee (MEPC), meeting for its 70th session in London set the implementation of a global sulphur cap of 0.50% m/m (mass/mass) in 2020, triggered the global Shipping community to adopt to the new progressive stricter regulations in order to control emissions from ships, including Sulphur oxides (SOx) and nitrous oxides (NOx) - which present major risks to both the environment and human health. All these new stricter requirements will force the Ship-owners and Operator to invest in new technologies on board especially for the existing vessels in order to enable the ships to meet the Air Emission requirements.

The intention of this post graduate thesis is to provide a useful tool with the pros and the cons of the investment and retrofit of the new technologies such as using gas as a fuel or the usage of the exhaust gas cleaning systems or "scrubbers", which "clean" the emissions before they are released into the atmosphere, in comparison with the continuation of using of low-Sulphur compliant fuel oil, from both economic and technical point of view.

The first chapter analyses the current and forthcoming Air Emissions requirement such as Annex VI to the International Convention for the prevention of Pollution from ships (MARPOL Convention), US/EPA Air Emissions requirements and Regulation (EU) 2015/757 monitoring, reporting and verification of carbon dioxide (CO2) emissions from maritime transport (MRV).

The Second chapter provides the economic incentives for EU and US-EPA sub financial programs in order to attract the Ship-owners to invest into the new technologies and help them to the decision of making the first step toward to the new stricter Environmental requirements Era.

Within the Third Chapter is providing a perspective real case scenario of the modification of a ROPAX vessel of a retrofit a dual fuel system engine for using LNG as fuel. Actually, it is provided a thorough technical review in accordance with Class piping rules, Gas Fueled Ship Rules and IGF Code. The LNG Retrofit Design, obtain the notation "Approval in Principle" or AIP. All Statutory critical requirements will

deeply analysed together with relevant solutions so that this retrofitting endeavour can be accomplished. Cost analysis approach offered captured from a relevant project in a Korean Shipyard.

The Forth chapter provides a real case scenario of retrofitting an existing tanker with all the three alternative methods, LNG as fuel and Scrubbers against of the continuation of the usage of MGO. A full economic and technical report is providing giving all the needs to the Owners and relevant costs.

It is underlined that both case retrofitting Scenarios include all relevant drawings references to the specific Rules and Regulations and from the statutory aspects. In addition, besides the Techno-economic analysis of the current Solutions, a reasoned estimation payback time of the three possible investments is provided.

At the end, the arising conclusions of the modifications offered, together with the technical difficulties of the referred projects. Financial analysis, payback time and days that will need for each proposal will be offered with relevant comments.

Acknowledgement

I would like to thank my thesis advisor Dr. Assistant Professor Nikolaos P. Ventikos of the School of Naval Architecture and Marine Engineering /Laboratory for Maritime Transport at National Technical University of Athens, for the assignment of this thesis and our nice collaboration.

Finally, I must express my very profound gratitude to my family and to my colleagues of my current job (Marine Technical Support Specialist at Lloyd’s Register) for providing me with unfailing support and continuous encouragement throughout my years of this Master degree and through the process of researching and writing this thesis. This accomplishment would not have been possible without them.

Thank you.

Author

George D. Kiadimos

Tables of contents

Tables of contents

Table of Figures

Table of Figures

Table of Tables

Table of Tables

Abbreviations:

Abbreviations:

EC: European Commission

ECA: Emission Control Area

EFTA: European Free Trade Association

GHG: Green House Gases

GISIS: Global Integrated Shipping Information System

HFO: Heavy fuel oil

IMO: International Maritime Organization

INEA: Innovation and Networks Executive Agency

LBG: LIQUEFIED BIO-GAS

MEPC: MARINE ENVIRONMENT PROTECTION COMMITTEE

MGO: MARINE GAS OIL

MOS: MOTORWAYS OF THE SEA (ΘΑΛΆΣΣΙΕΣ ΑΡΤΗΡΊΕΣ)

OEM: ORIGINAL EQUIPMENT MANUFACTURER

PM: PARTICULATE MATTERS

SECA: SULFUR EMISSION CONTROL AREA

SCR: SELECTIVE CATALYTIC REDUCTION

VECS: VAPOUR EMISSIONS CONTROL SYSTEM

VOC: VOLATILE ORGANIC

Chapter 1

Current & forthcoming regulations regarding the ECA, SECA, MRV, Sox, Nox and the regulatory framework.

1. CURRENT & FORTHCOMING REGULATIONS REGARDING THE ECA, SECA, MRV, SOX, NOX AND THE REGULATORY FRAMEWORK.

1.1. Environmental: Emission Control Areas (ECA, SECA)

The emission control areas established under MARPOL Annex VI for SOx are: the Baltic Sea area, the North Sea area, the North American area (covering designated coastal areas off the United States and Canada) and the United States Caribbean Sea area (around Puerto Rico and the United States Virgin Islands).

ECA established to limit SOx and particulate matter emissions, 1.50% m/m prior to 1 July 2010, 1.00% m/m on and after 1 July 2010, 0.10% m/m on and after 1 January 2015. Outside the emission control areas, the current limit for Sulphur content of fuel oil is 3.50%, falling to 0.50% m/m on and after 1 January 2020. The 2020 date is subject to a review, to be completed by 2018, as to the availability of the required fuel oil. Depending on the outcome of the review, this date could be deferred to 1 January 2025.

Ships may also meet the SOx requirements by using gas as a fuel or an approved equivalent method, for example, exhaust gas cleaning systems or "scrubbers" which will be analyzed further in the relevant section of this post graduate thesis.

SO_x and particulate matter emission controls apply to all fuel oil, as defined in regulation 2.9, combustion equipment and devices onboard and therefore include both main and all auxiliary engines together with items such boilers and inert gas generators. These controls divide between those applicable inside Emission Control Areas (ECA) established to limit the emission of SO_x and particulate matter and those applicable outside such areas and are primarily achieved by limiting the maximum Sulphur content of the fuel oils as loaded, bunkered, and subsequently used onboard.

1.1.1 Emission Standards: SOx/NOx Limits for the big Country Areas:

Summary of current MARPOL limits: Outside ECAs : SOX 3.5%m/m (since 1/01/2012), NOX Three Tier Scheme Within ECAS: Three Tier Scheme, Tier III (Only for North America ECA and US Caribbean Sea ECA)

1.1.1.1 Current limits for United States:

Federal law Regulations: The Act to Prevent Pollution from Ships (APPS): Annex VI of MARPOL is enacted in the US by APPS. The EPA has the authority to enforce Annex VI with the cooperation of USCG (through the ship inspections, examinations and investigations) Code of Federal Regulations. Title 40: Protection of Environment. Part 1043 Control of NOx, SOx and PM Emissions form marine Engines and Vessels subject to the MARPOL Protocol.

The Clean Air Act • The Final Rule published on April 30, 2010: extends the ECA to the internal waters.

Areas - North America Emission Control Area: on 26th March 2010 IMO designated as an ECA, waters off the North American coasts. • US Caribbean Emission Control Area: on 15th July 2011 IMO designated as an ECA, waters off the coasts of Puerto Rico and the US Virgin Islands by ECA amendments MEPC.202(62) For this area, the effective date of the first phase fuel sulphur standard (1%) is 2014 and the second phase (0.1%) begins in 2015. Stringent NOx engine standards begin in 2016 (Tier III). Steamships operating in the North American and USA Caribbean Sea ECAs are exempted from compliance with the Regulation 14 (SOx) through 31/12/2014. • Great Lakes: Vessels which operate within and outside the Great Lakes must comply with the provisions of 40 CFR 1043. Great Lakes Vessels (vessels operating exclusively in the Great Lakes, both US and foreign flagged) may be exempted by EPA according to a separate waiver under interim provisions described in 40 CFR 1043.95 (c) if no acceptable fuel is available. Steamships operating on the Great Lakes are subject to a separate waiver under 40 CFR 1043.95 (a) when they were propelled by steam engines and operated within the Great Lakes before 30th October 2009 and operate exclusively within the Great Lakes.

The convenience of the designation of new ECA areas such as Pacific US territories, smaller Hawaiian Islands and Western Alaska is currently being examined.

1.1.2 California

Ocean-Going Vessel (OGV) Fuel regulation limited the maximum fuel sulphur for both marine gas oil (DMA) and marine diesel oil (DMB) to 0.1% m/m. Therefore, vessels visiting California ports have to comply with both the California OGV Fuel Regulation and the North American Emission area. Besides, the California OGV Fuel

Regulation encompasses a noncompliance Fee Provision by which if a vessel is unable to find a compliant fuel, a fee may be paid instead. These requirements set in the California OGV Fuel Regulation won't apply if the US adopts and enforces requirements that achieve equivalent emissions reductions. Furthermore, the California Air Resources Board will allow the use of alternative emissions control technologies such as exhaust gas cleaning devices as stated under the ECA Regulation.

1.1.3 Canada

Regulations for Vessel Air Emissions apply to vessels over 400 gross tonnage operating in Canada.

Regulations

• Some requirements are in place under Vessel Pollution and Dangerous Chemicals Regulations (The Regulations)

• New implementations are now in place under The Regulations Amending the Vessel Pollution and Dangerous Chemicals Regulations (The Amendments) published 8/05/2013.

Emissions Standards

• Sulphur Oxides = Marpol I) For Vessels inside the NA-ECA and throughout Canadian waters south of 60ºN, the current limit (since 1/07/2010) is 1% but it will be 0.10% after 1/01/2015. II) For Vessels outside the NA-ECA, north of 60ºN and including Hudson's Bay, James Bay and Ungava Bay, the current limit is 3.50% (since 1/01/2012) but it will be 0.50% after 1/01/2020

• Nitrogen Oxides = Marpol (Annex VI + NOx Technical Code 2008) The NOx limits apply to engines installed on vessels that have power ratings over 130 kilowatts as described in table below. If a vessel undergoes a major conversion or a new engine, substantially different from the old one, is installed the current standard would apply.

1. Tier I

Engines installed on vessels built between December 31, 1999 to December 31, 2010 17.0 g/kWh when n is less than 130 rpm; 45n (-0.2) g/kWh when n is 130 or more but less than 2,000 rpm; 9.8 g/kWh when n is 2,000

2. Tier II

1. Engines installed on vessels built after December 31, 2010
2. 14.4 g/kWh when n is less than 130 rpm; 44 · n(-0.23) g/kWh when n is 130 or more but less than 2,000 rpm; 7.7 g/kWh when n is

3. Tier III

1. Engines installed on vessels built after January 1, 2016, that operate in ECAs
2. 3.4 g/kWh when n is less than 130 rpm; 9 · n (-0.2) g/kWh when n is 130 or more but less than 2,000 rpm; and 2.0 g/kWh when n is

1.1.4 China

Regulations

• Country Party Annex VI Marpol

• No Specific provisions regulating emissions from ships.

Air Pollution

• Air Pollution Control Ordinance 10/04/2014

• Air Pollution Control (Marine Light Diesel) Regulation 01/04/2014 introduces a new Sulphur content cap of 0.05% for the locally supplied marine light diesel (MLD). Hong Kong Environmental Protection Department has required all ocean-going vessels (OGVs to use low Sulphur fuel, defined in the new legislation as fuel with Sulphur content not exceeding 0.5% by weight, when at berth in Hong Kong waters. All OGVs must initiate fuel switch upon arrival at berth, complete the switch to low Sulphur fuel within one hour, and then use low Sulphur fuel throughout the berthing period until one hour after departure. Hong Kong government has declared its long-term intention to set up an Emissions Control Area for ships in the Pearl River Delta. Meanwhile, since 2011 vessels have been participating in an industry-led scheme (Far Winds Charter) by which they switch voluntarily to low Sulphur fuel (0.5% Sulphur content or less) when at-berth in Hong Kong until December 2014. 17 major freight liners have signed up to this initiative: Maersk Line, Evergreen, OOCL, Yang Ming (Taiwan), APL, CMA CGM, COSCO, MOL, Hapag Lloyd, Hanjin, Hyundai, NYK, Hamburg Sud, Alianca, Hoegh, Crystal Cruises, Prestige Cruise Holdings.

1.1.5 Australia

Regulations

• Australia: Country Party MARPOL Annex VI

Summary of Discharge Standards for Ships and smaller vessels operating in Australian waters: MARPOL and local requirements (This table applies to all vessels)

Vessel/Voyage type/Area	Sub-Category	Discharge Conditions
All vessels	Ozone-depleting substance	Prohibited
	Nitrogen Oxides	• Operation of diesel engines >130kW prohibited unless engine is certified to meet prescribed emission standards • New Engines: • Tier I – 17 g/kW from 1 January 2000 • Tier II – 14.4 g/kW from 1 January 2011 • Tier III – 3.4 g/kW from 1 January 2016 Existing Engines (installed on ship on or between 1 January 1990 to 1 January 2000) • 17g/kW for diesel engine with power output >5000kW and displacement per cylinder => 90 litres • Approved method by Administration
	Sulphur Oxides	• Sulphur content of fuel oil not to exceed 4.5%** • From 1 January 2012, sulphur content of fuel oil not to exceed 3.5% • From 1 January 2020 sulphur content if fuel oil not to exceed 0.5%* ** Fuel oil to be purchased from a registered supplier Note: Feasibility review to be completed 2018
	Incinerators	• Incinerators installed after 1 January 2000 must be type approved and certified to meet prescribed emission standards. • Do not use within port limits

Table 1: MARPOL and local requirements Australia

(http://www.ukpandi.com/)

1.1.6 Turkey

Regulations • Country Party MARPOL Annex VI

Specific Requirements Since the 1st January 2012, new regulations on Sulphur content limits of marine fuels are in place:

• Sulphur content in marine fuels shall not exceed 0.1% by mass in all vessels arriving at Turkish ports and all inland waterway vessels sailing on Turkish inland waters.

• Sulphur content in marine fuels shall not exceed 1.5% in all passenger vessels providing regular services in areas covered by Turkey's marine jurisdiction. These limitations apply to berthed or anchored Ships within the boundaries of any port and staying at berth or at anchor for more than two hours. However, they won't apply to vessels passing the Turkish Straits without calling to any Turkish Port, if their transiting process does not exceed two hours.

1.1.7 France

French Transport Code, Article L 1431-3 comprises a new CO_2 reporting requirement by which foreign ship owners need to provide information to their French customers, either cargo interests or passengers, of the mass of CO2 when calling at French Ports. The mass of emitted CO2 is calculated by multiplying the fuel consumed during the voyage with the relevant emission factors published by the French Authorities. The emission factors provide the quantity of CO2 produced in kilograms for both the "operating phase" and the "upstream phase" for each kilogram of fuel used (fuel oil, diesel, LNG and LPG). The total quantity is expressed as a mass in either grams (g), kilograms (kg) or tonnes (t) of CO2 corresponding to the actual service provided to cargo interests or passengers respectively. In terms of goods, the provision of this information to cargo interests may be given either prior to or after the voyage depending on the agreement between the parties, but in any event must be provided within two months of the voyage being completed. For passengers, the information must be provided prior to the ticket being purchased, or if no ticket is issued, no later than completion of the passenger's voyage. North America control Area comprises the French islands: Saint Pierre and Miquelon archipelago, therefore the more stringent limits applied to them.

1.1.8 Finland

Finland is preparing stricter provisions on sulphur emissions from shipping to come into force by the beginning of 2015. Finnish Transport Safety Agency (Trafi), the Finnish Border Guard and the police will all monitor emissions from shipping. The price difference between high- and low-sulphur fuels – gains are considered as 'illegal financial gains' therefore, the violators must forfeit to the government. Such penalties are considered more tangible than fines or other punishments and would also apply to shipping companies. The cost impact of such a measure will only be known after the provisions come into force and when the price of low-sulphur fuel becomes clear. Traffic has estimated that if ships use only low-sulphur fuel, the provisions will increase Finland's maritime transport costs by around €460 million/year, and by €120 million/year if scrubbers are installed in ships.

1.2. The MRV Regulation: Regulation (EU) 2015/757 monitoring, reporting and verification of carbon dioxide (CO2) emissions from maritime transport, entered into force on 1st July 2015.

This means that by 31st August 2017, ship owners and operators of vessels sailing in the EU and exceeding 5,000 GT are required to submit a Monitoring Plan (MP) detailing the procedures in place to monitor and report the fuel consumption, carbon emissions, and transport work on all voyages to, from and between European ports.

1.2.1. How this starts why and how will be implemented?

In 2010, the United Nations Framework Convention on Climate Change (UNFCCC), recognized that global warming must not exceed pre-industrial levels by more than 2 degrees centigrade and, in order to do so, this would require GHG emissions reductions of 50% less than 1990 levels by 2050. In committing to this, the EU stated that it would consider further action on shipping GHGs should there be no international agreement and possibly implement a regional market-based measure (MBM) if the IMO failed to introduce an international scheme.

In late 2012 the EU stated that it would no longer seek to do this and the focus from the EU is now to take steps towards setting up the MRV framework which could provide the first step towards achieving their absolute emissions reductions.

On 28 June 2013, the European Commission published its finalized proposal for a European Union (EU) regulation on Monitoring, Reporting and Verification (MRV) of CO_2 emissions from ships. The regulation, No.525/2013, is introduced further to the EU's Climate and Energy Package, adopted on 23 April 2009, which seeks international agreement including emission reduction targets through the IMO or the UNFCCC.

The regulation will apply to certain vessels conducting voyages into, out of and between EU ports and will annual reporting of their CO_2 emissions in line with a verified monitoring plan. The purpose of the regulation is to provide reliable information on greenhouse gas (GHG) emissions within maritime transport. As a first step the regulation is intended to focus on, and establish, CO_2 emissions which will then allow the EU to define reduction targets associated with this and finally the means to achieve those reduction targets, as appropriate.

1.2.2. How will it be implemented?

The EC plan a phased approach to regulating CO_2 from shipping as follows:

Phase 1: Implement MRV and establish CO_2 emissions from maritime transport.

Phase 2: Establish an agreed global energy efficiency standard as part of the regulation.

Phase: 3: Identify whether the efficiency standards are achieving the EU's desired absolute CO_2 emissions reductions and what else should be done e.g. introduction of an MBM.

1.2.3. How does it apply?

The regulation will apply to all ships greater than 5,000 GRT undertaking one or more voyages into, out of and between EU ports and will require per-voyage and yearly monitoring of CO_2 emissions, as well as other parameters including energy efficiency metrics.

Annually, 'companies' (DOC holder) must provide an emissions report for the previous calendar year's activity. In addition, this will include the technical efficiency of the ship (the Energy Efficiency Design Index (EEDI) or the Estimated Index Value (EIV) in accordance with IMO Resolution MEPC.215 (63), where applicable).

1.2.4. When does reporting requests?

Reporting periods are defined over a calendar year. At present the EC acknowledges that further clarification is required in regard to the precise closing date of the current reporting period and whether this should occur at the end of the previous voyage, at the exact point mid-voyage that coincides with the actual date/time of the end of the reporting period or the end of the current voyage.

To simplify the preparation of monitoring plans, reporting and verification of emissions and other climate relevant information, electronic templates will be provided by the EC. The following timescales have been proposed as part of the regulation:

- 31 August 2017 – Monitoring plan to be prepared and submitted for verification
- 1 January 2018 – Commence per-voyage monitoring
- 2019 onwards – By 31 April each year, submit a verified emission report to the EC and relevant flag state.
- 30 June 2019 onwards – Ships will need to carry a valid document of compliance relating to the relevant reporting period.
- 30 June each year – EC will make each ship's emissions reports publicly available including information specific to that ship, its fuel consumption,

CO_2 emissions, technical efficiency (EEDI or EIV as appropriate) along with other parameters.

1.2.5. How will it work?

Each company will be required to produce a monitoring plan which will be used to monitor data on a per voyage basis and yearly basis for all voyages conducted into, out of and between EU ports. The requirements for monitoring on a per-voyage basis and on a yearly basis are shown in the table below.

Per-voyage monitoring	Yearly monitoring
Port of departure and port of arrival including the date and hour of departure and arrival	Aggregated CO_2 emissions from all voyages between, departed from and to ports under a Member State's jurisdiction CO_2 emissions which occurred within ports under a Member State's jurisdiction at berth
Amount and emission factor for each type of fuel consumed in total and differentiated between fuel used inside and outside emission control areas	
CO_2 emitted Total CO_2 emitted	CO_2 emitted Total CO_2 emitted
Distance travelled Total distance travelled	Distance travelled Total distance travelled
Time spent at sea Total time spent at sea	Time spent at sea Total time spent at sea
Transport work Total transport work	Transport work Total transport work
Cargo carried Average energy efficiency	Cargo carried Average energy efficiency

Table 2: What to do table_(Source LR MRV Co2, Special Consideration 2013)

1.2.6. How do we monitor CO2?

CO_2 emissions will be either calculated based on fuel consumption and use of appropriate emissions factors for the fuel type being consumed, or by direct emissions monitoring, with a back-calculation of the fuel consumption using the relevant emissions factor. As part of the monitoring plan, companies will be able to choose one of four methods for monitoring fuel consumption:

1. The use of Bunker Fuel Delivery Notes;
2. Bunker fuel tank monitoring
3. Flow meters for applicable combustion processes
4. Direct emission measurements.

These methods are goal-based and allow for an improving scale of accuracy of monitoring. Where fuel consumption is measured in units of volume, the density of that fuel also needs to be determined, either through the bunker delivery note or onboard measurement systems according to the regulation. Presently, there is no legal requirement for a user to determine quality and make-up of fuel and in this regard, options for introducing standard values of density or owner-supplied values which have been verified and independently tested have been suggested to the EC.

1.2.7. What happening to IMO and this can be interactive with the MRV.

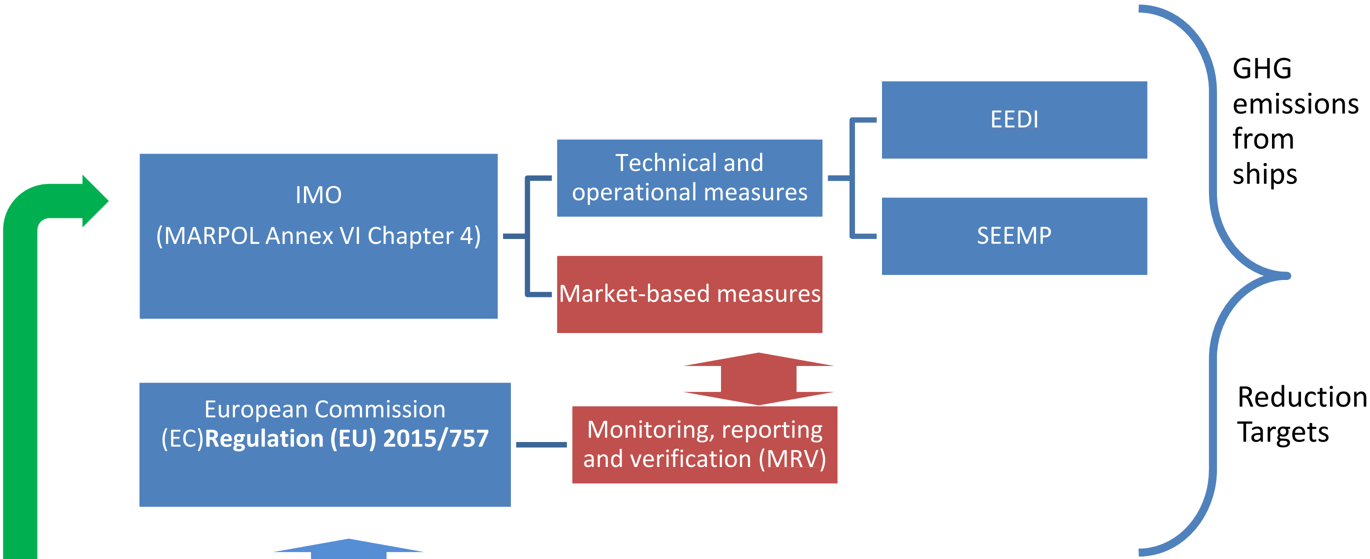
IMO Data Collection System (DCS)

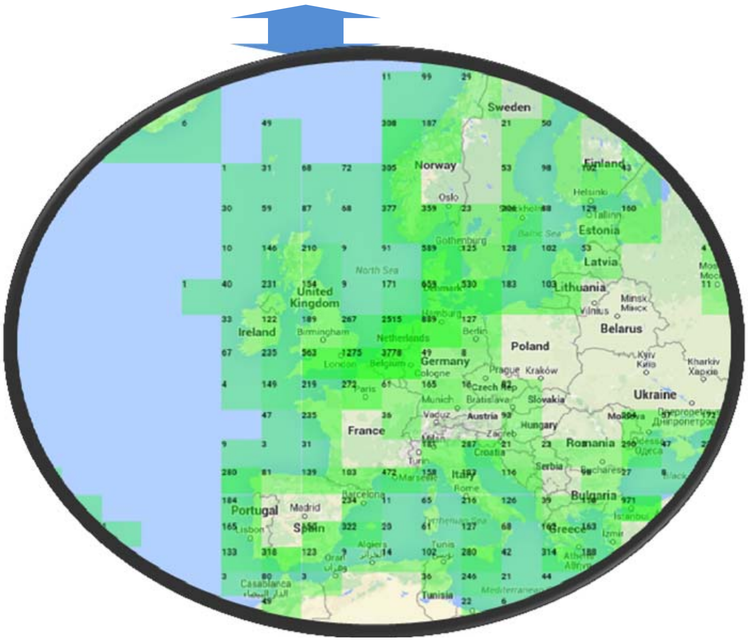
Amendments to Chapter 4 of MARPOL Annex VI adopted which establish a new requirement for all ships of 5000 GT and above on international voyages to collect data related to fuel consumption. Beginning on January 1, 2019, the following information is to be collected during the calendar year, from January 1 until December 31:

- Fuel consumption data for each type of fuel used onboard the ship (HFO, MGO, LNG, etc.)
- Distance travelled while the ship is underway; and
- Service hours while the ship is underway.

This maybe is an initial movement of the IMO towards to MRV. Since IMO adopted mandatory requirements for ships of 5000gt and above to collect consumption data for each type of fuel oil they use in order to provide information for future decisions on additional measures to reduce shipping’s greenhouse gas emissions.

1.2.8. Shipping GHG emissions now regulated and where all these requirements are leading.





EU Member State jurisdiction:

- **Includes time at sea and at berth excluding anchoring**
- **All ships >5,000GT**
- **Regardless of flag**
- **Commercial voyages**

Figure 1: EU members MRV jurisdiction

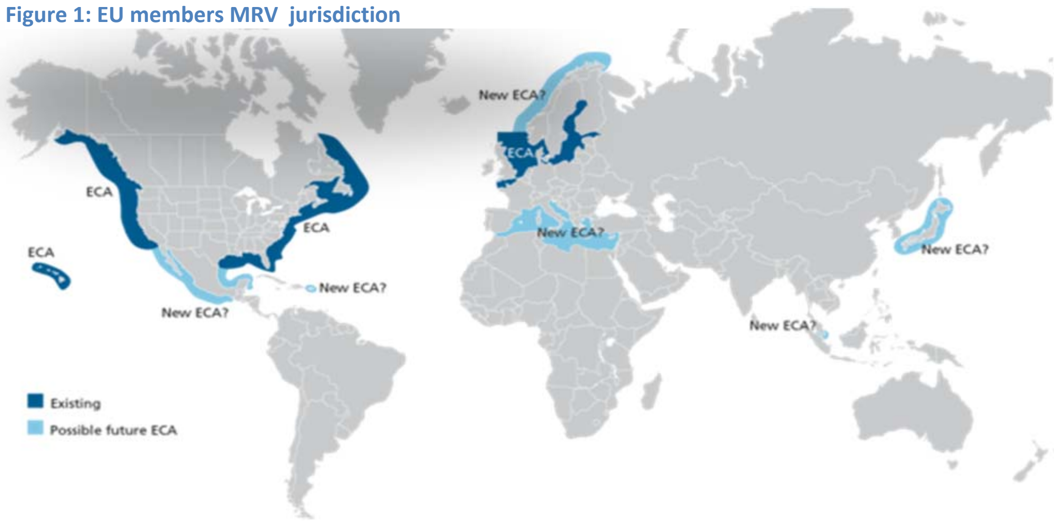


Figure 2: Existing and possible ECA Areas

- **MARPOL Annex VI Chapter 4** (since Jan 2013) – Energy Efficiency Design Index (new ships only) and Ship Energy Efficiency Management Plans (new and existing ships) =>MARPOL ANNEX VI Regulation 4 – Equivalent measures An Administration may allow any fitting, material, appliance or apparatus to be fitted in a ship or other procedures, alternative fuel oils, or compliance methods used as an alternative to that required by this Annex if such methods are at least as effective in terms of emissions reductions as that required by this Annex This means the Administration (and not the ship) have to acknowledge that: – technologies have equivalent efficiency in terms of SOx, PM and NOx. –they do not harm the environment –they operate within the requirements of the IMO guidelines
- **EEDI** is a design index, primarily applicable to new ships for controlling CO2 emissions: EEDI = g CO2 / tonne.nm
- **SEEMP** is a ship specific management plan to be maintained and kept on board. Focus on operational and technical efficiency improvements (use of EEOI as a very coarse metric)
- On 28 April, 2015, the European Council approved the new shipping regulation on the monitoring, reporting and verification of CO2 emissions, as part of its overall strategy to reduce greenhouse gas emissions by 2050. The regulation entered into force on 1 July, 2015.

1.2.9. Compliance techniques for NOx and SOx – common challenges and Technical Options in case of Modification.

There are a number of ways to comply with Sox and NOx requirements, each of one presents different technical and operational challenges. We will provide a guidance trying to analyze the pros and cons together providing an understanding of the different compliance options and the practical challenges of implementing them on board the ships. We can either work by lowering SOx and NOx emissions at source, `using low-Sulphur fuel to reduce SOx or manipulating the combustion process to reduce NOx. Another compliance technique is to low SOx and NOx emission levels by treating the exhaust gas after combustion. In this guidance, we refer to them as exhaust gas treatment systems (EGTS). Treatment systems include ‘scrubbers for SOx and selective catalytic reduction (SCR) for NOx.

LNG is low in Sulphur and easily combusted in engines and boilers using mature and reliable technology. Gas engines are widely used in land-based industry and have been used in LNG carriers for many years. The IMO is developing a new code for gas as fuel – the IGF Code – but until this enters into force there is uncertainty over the legal framework for operators and designers to work within. LR and other Class societies have published class rules for gas-fueled ships.

Wholesale LNG prices are generally lower than RFO prices, but a lack of marine supply facilities means LNG may be more expensive than RFO once delivery costs are taken into account. In some markets, LNG prices are indexed to oil prices and can match them even before supply costs are added. Known gas reserves have steadily increased. International Energy Agency data shows they increased more than threefold between 1975 and 2010, and gas prices have become very attractive in some markets as a result of this abundance, particularly in North America. Where LNG supply infrastructure is in place,

LNG is expected to become very financially attractive as a marine fuel.

Converting existing ships to alternative fuels such as LNG is possible, and there is a lot of interest in this area in the North American market. However, conversions are expensive and technically challenging. Challenges include installing the fuel tank and containment systems, gas zoning and engine conversion. Another method of Compliance is the solution of Gas as fuel.

Fuel type is critical to engine NOx emissions performance. While the difference in NOx emissions between residual and distillate fuels is not dramatic, some of the alternative fuels listed in 3.3 can reduce NOx to a level where Tier III compliance can be achieved. Fuels such as natural gas (stored on-board as LNG or potentially compressed natural gas) can achieve Tier III NOx levels. However, this depends on the engine design; not all gas engines can achieve Tier III. Some of these design considerations include.

1.2.10. Compliance Techniques for compliance techniques for SOx

MARPOL Annex VI Regulation 14 limits fuel Sulphur content. Several low-Sulphur fuels are available including low-Sulphur distillate oil, ‘hybrid’ fuel oil, liquefied natural gas (LNG), liquefied petroleum gas (LPG), biofuels, dimethyl ether (DME), ethane and methanol. Residual fuel oil (RFO) can also be de-sulphurised. These are primary compliance techniques as they lower SOx emissions at source.

1.2.11. The science of SOx

SOx derive directly from fuel Sulphur content. The Sulphur is oxidized in the combustion chamber, forming principally Sulphur dioxide (SO2) and Sulphur trioxide (SO3), typically in a ratio of 15:1. The use of alkaline lubricants to protect the engine surfaces from corrosion converts a small (and relatively insignificant) proportion of the SOx to calcium sulphate. The Sulphur emissions from the engine are essentially proportional to the Sulphur content of the fuel.

1.2.12. Low- Sulphur distillate oil

Due to the nature of crude oil and refinery operations, RFO meeting the 0.10% Sulphur limit is not expected to be widely available. So it is anticipated that low-Sulphur distillate oil (LSDO) will generally be used to comply. It is also the simplest way to comply.

LSDO will normally consist of marine diesel oil (MDO) or marine gas oil (MGO); the terms MGO and MDO have no precise definition other than that both are distillates and therefore do not require heating before injection, whereas RFO, whatever the grade, does require heating. The ISO standard 8216:2010 categorizes MGO and MDO as distillate marine (DM) grades. Within this guidance, MGO refers to the ISO 8217:2012 DMA and DMZ grades while MDO corresponds to the ISO 8217:2012 DMB grades.

LDSO is traditionally considered a trouble-free fuel but it is not entirely without risk. There are some technical challenges, particularly if converting existing ships from residual fuel. Equipment and systems will need to be suitable for use with LSDO, and may need to be modified. However, these engineering modifications are minor compared to those needed for other Sox compliance options.

Most of the Classification Societies offers the optional ‘DIST’ descriptive note to recognize ships that apply best practice beyond minimal class rule requirements for fuel oil systems.

The availability of LSDO is an industry concern. There has been a tightening of distillate fuel supplies as a result of EU requirements for ultra-low Sulphur automotive fuels and an increasing demand in emerging markets. In 2009, CONCAWE a estimated that a USD 50 billion investment in refineries was needed to meet European automotive and industrial demand for distillates, with a further USD 17.5 billion investment needed to meet potential additional demand from shipping.

Little of this investment has been in Europe and in fact Europe has been losing refining capacity. There is significant investment in upgrading refineries outside of Europe, for example in Russia. This may offset expected shortfalls. The IMO will review LSDO availability in 2018 to see whether the 2020 global Sulphur limit reduction is achievable. At the time of writing, LSDO is typically 300 US dollars per tonne more expensive than 380 centistokes (cSt) RFO, and while long-term fuel cost forecasting is notoriously unreliable it is generally accepted that it will remain significantly more expensive than RFO.

Some things which you should consider if using LSDO to comply with Regulation 14 are listed here, and are based on ISO 8217:2012:

Contamination

The 0.10% Sulphur limit means that low-Sulphur distillates could easily become non-compliant if contaminated with higher Sulphur fuels. Therefore, it is essential to strictly segregate low-Sulphur and other fuels.

Viscosity

Distillates generally have a viscosity in the range 2.0-5.0 cSt at 40 C; however, it is expected in the future that these fuels will tend towards lower viscosities. The DMA and DMB grades are currently limited to a minimum viscosity of 2.0 cSt at 40oC.

Cold flow

Cold flow is a property often overlooked by ships. Fuel cold flow properties are controlled by setting a limit on the pour point (the lowest temperature at which a fuel will continue to flow). However, given that wax crystals form at temperatures above the pour point, fuels that meet the limits can still be challenging when operating in colder regions. Wax particles can rapidly block filters, potentially plugging them completely. Temperatures of 22°C or more may be needed to ensure trouble free operation. Ships operating in warmer operating zones will not generally suffer these problems but ships transiting from warm to cold zones need to be aware of them.

Lubricity

Distillates are more likely to have lower lubricity than residual fuel oils. Therefore, they may not provide the required boundary lubricating performance. High-pressure fuel pumps and other equipment should be checked to see if they have any minimum lubricity requirements for the fuel being used.

Fuel seepage

Converting RFO systems to LSDO may result in seepage of fuel from pipe flanges, equipment seams and other fittings (such as pressure gauges and other sensors) because of the searching' nature of LSDO. This may only become apparent after a period of time as accumulated material is removed by the cleaning action of the distillate.

Sludge formation

If you plan to switch between different fuels according to whether or not the ship is in an ECA-SOx, there is a risk that incompatible fuels will result in the formation of excessive quantities of sludge. This can disrupt the combustion process and the functioning of fuel oil treatment, service systems and associated equipment. Mixing of significant quantities of fuel should be avoided. During fuel change-over between residual fuel and distillate, the fuel system, including fuel pumps, will be subject to a significant change in temperature as a result of the need to heat the residual fuel to maintain viscosity at the correct levels for the engine. This temperature change will be approximately 100°C; therefore the change-over procedure is critical to prevent machinery seizure, machinery wear, micro-seizure and loss of performance. The fuel changeover procedure should be in accordance with the instructions of the engine manufacturer. Typically, unless stated otherwise by the engine manufacturer, a maximum rate of temperature change is 2°C per minute for two-stroke slow speed engines and 4°C per minute for other engines.

Ignition and combustion

RFO and LSDO have different ignition and combustion characteristics. An engine set up for RFO can experience a number of issues if operated on LSDO:

Deposition may be caused within the cylinder and inlet/exhaust valves. This reduces the life expectancy of piston rings, liners and valves.

Fuel valves may require increased maintenance to counter the effects of using LSDO.

In some cases, fuel valves may need to be changed to an alternative material specification based on the manufacturer's advice. The reduced viscosity of distillates may result in worn high-pressure fuel pumps being unable to deliver sufficient fuel to the fuel valves to maintain engine power output. This may result in excessive fuel leakage and engine failure, and may also present difficulties in starting the engine.

Other implications include:

On two-stroke engines, the lower Sulphur content of LSDO will reduce the rate of acidic corrosion of the cylinder liner.

The Sulphur in high-Sulphur fuels has a positive effect on piston ring/liner wear because controlled acid corrosion prevents polishing of the liner and helps to maintain an open graphite structure on the liner face to promote a hydrodynamic oil film between the rings and liner.

Finally, the cylinder oil base number must be suitable for the fuel in use:

If the cylinder oil base number is too high relative to the acidity of fuel, there is a risk of hard alkaline deposition to cylinder liners, which can cause polishing and accelerated wear.

— If it is too low, the rate of acidic corrosion of the liner may be too high, resulting in accelerated wear.

Finally, the cylinder oil base number must be suitable for the fuel in use:

If the cylinder oil base number is too high relative to the acidity of fuel, there is a risk of hard alkaline deposition to cylinder liners, which can cause polishing and accelerated wear.

If it is too low, the rate of acidic corrosion of the liner may be too high, resulting in accelerated wears.

Converting boiler and incinerator burners

Converting boiler and incinerator burners presents particular challenges. Specific RFO and distillate burner tips should be fitted to burners which are intended to operate on both residual fuel and distillate, and the tips must be changed over as required. Steam atomizer supply to burners will usually need to be shut off when using distillate to avoid heating the fuel in those designs where the steam supply surrounds the core fuel oil supply (concentric gun type). There are certain burner types where the steam supply is carried in a separate channel away from the fuel supply (parallel gun type), thereby avoiding the risk of fuel over heating. Transfer between fuels is likely to result in some smoke formation if no remedial action is taken to control combustion. Fuel and air systems are controlled by automatic boiler control, automatic combustion control or burner management systems, all of which may require modification. The burner manufacturer and combustion control system manufacturer should be consulted to determine the extent of any modifications required.

Procedures and training

Operational procedures and appropriate crew training are critical to the safe and reliable change-over between residual and distillate fuels. These procedures should be incorporated within the onboard Safety Management System (SMS) and operators are responsible for ensuring these procedures are in place and that crews are suitably trained.

Sea trials

Full sea trials in safe navigational waters are recommended to test machinery systems operating continuously on distillate –in particular to test maneuverability of the engines.

Alternative low-Sulphur fuels

Hybrid fuels

To meet the increasing demand for 0.10% Sulphur marine fuel, several suppliers have developed new low-Sulphur 'hybrid' fuels that are claimed to be more cost-effective than conventional distillate fuels like MGO. They are called hybrids because they combine properties of distillate and residual marine fuels. Typically, they have lower viscosity and density, and better ignition and combustion properties, than conventional RFO.

An expanding range of hybrid fuels is being marketed to the shipping sector. They are generally categorized as heavy distillates requiring heating, but some are actually RFO-based products, often derived from existing refinery side streams, and their price will be driven by marine market conditions and competition for base stocks from other industrial sectors. This is a rapidly evolving sector with great potential. Because of the wide range of products in development and the relatively early stage of their development, this guidance doesn't cover hybrid fuels in detail, but some factors to consider include:

- compatibility with other fuels, particularly residual fuels
- fuel segregation
- pour point, viscosity and heating requirements
- low density variations that may require separator plant adjustment.

Positive characteristics of hybrid fuels include their improved combustion characteristics and low levels of metals and ash, in particular abrasive catalytic fines.

1.2.13. Biofuels

There are also biofuels which are low in Sulphur; the most common are Fatty Acid Methyl Ester (FAME) types derived from vegetable oils. Second and third generation biofuels are expected to address some of the societal concerns relating to the supply of FAME-type fuels. Biofuels are generally very similar to petroleum distillate oils. There are materials compatibility and storage issues related to the use of biofuels.

1.2.14. LNG (Liquid Natural Gas)

The LNG is low in Sulphur and easily combusted in engines and boilers using mature and reliable technology. Gas engines are widely used in land-based industry and have been used in LNG carriers for many years. The IMO has developed new code for gas as fuel – the IGF Code – but until this enters into force there is uncertainty over the legal framework for operators and designers to work within. LR as lead Class Society has published class rules for gas-fuelled ships which will be applied further below.

Wholesale LNG prices are generally lower than RFO prices, but a lack of marine supply facilities means LNG may be more expensive than RFO once delivery costs are taken into account. In some markets, LNG prices are indexed to oil prices and can match them even before supply costs are added. Known gas reserves have steadily increased. International Energy Agency data shows they increased more than threefold between 1975 and 2010, and gas prices have become very attractive in some markets as a result of this abundance, particularly in North America. Where LNG supply infrastructure is in place, LNG is expected to become very financially attractive as a marine fuel.

Converting existing ships to alternative fuels such as LNG is possible, and there is a lot of interest in this area in the North American market. However, conversions are expensive and technically challenging. Challenges include installing the fuel tank and containment systems, gas zoning and engine conversion.

1.2.15. Other alternative fuels

Other alternative fuels include liquefied petroleum gas (LPG) and methanol. While shipping Market currently expects the use of LPG as a marine fuel to be limited to niche markets, such as LPG carriers using cargo to provide fuel, it is expected that methanol will establish a place in the market and already working on several methanol projects. Many Classification Societies have published provisional rules for methanol-fueled ships and the IMO is working on incorporating methanol into the draft IGF Code.

1.3. Compliance techniques for NOx

All current marine engines can easily achieve Tier II compliance. Tier III compliance, however, will require significant changes to the engine using either the complex primary techniques discussed in this section or by using secondary exhaust gas treatment systems.

1.3.1. The science of NOx

The formation of NOx is complex. NOx is the collective term for Nitrogen dioxide (NO2) and Nitrous Oxide (NO). Nitrous Oxide is not NOx.

Nitrogen is a natural element in the atmosphere and is also found in the chemical structure of some fuels. During the fuel combustion process, NOx is formed in the cylinder in three ways:

- thermal formation, as a result of the reaction between atmospheric nitrogen and oxygen at high temperatures
- fuel formation, as a result of the reaction between nitrogen in the fuel and oxygen
- Prompt formation, as a result of complex reactions with hydrocarbons and atmospheric nitrogen.

NOx is formed both at the initial stage of combustion in very high temperatures and later in the combustion process after a longer dwell time in the combustion chamber. Therefore, the formation of NOx requires both high temperatures and exposure time.

The major component of NOx on exit from the ship is nitric oxide, which readily oxidizes in the atmosphere.

The proportion of nitric oxide attributable to thermal and fuel formation depends on the combustion conditions, which in turn are determined by the combustion unit type, configuration and operation, together with the fuel's grade and composition.

Prompt formation can exceed thermal formation under certain conditions where combustion temperatures are low, residence time is short and combustion conditions are fuel-rich.

Lowering the temperature of the combustion process reduces NOx but also reduces engine efficiency. Theoretical ideal heat engine efficiency is represented by the Carnot cycle, where heat efficiency is a function of the ratio maximum temperature to minimum temperature. Marine engines are not Carnot engines but efficiency is still related to the temperature differential across the cycle. Reducing the compression ratio by adjusting engine valve opening and closing, adding water to fuel or charge air or applying high-pressure super charging can reduce maximum combustion temperature. Lower combustion temperatures and lower combustion, atmospheric oxygen and nitrogen levels are the main approaches to reducing NOx emissions.

1.4. Gas as fuel system

Fuel type is critical to engine NOx emissions performance. While the difference in NOx emissions between residual and distillate fuels is not dramatic, some of the alternative fuels listed in 3.3 can reduce NOx to a level where Tier III compliance can be achieved. Fuels such as natural gas (stored on-board as LNG or potentially compressed natural gas) can achieve Tier III NOx levels. However, this depends on the engine design; not all gas engines can achieve Tier III. Some of these design considerations include:

Thermal cycle

NOx performance is linked to the thermal cycle of the engine. A pure gas Otto or Miller cycle engine can achieve Tier III emissions levels relatively easily. A gas diesel cycle engine using oil pilot ignition for the gas cannot, despite having lower NOx emissions than conventional oil-fuelled engines.

Methane slip

Pure gas Otto and Miller cycle engines are associated with methane slipb. Methane has much higher global warming potential than carbon dioxide; as societal concerns over greenhouse gas emissions increase, methane is expected to become a more prominent part of the marine emissions debate.

Dual fuel engines

Under the NOx Technical Code, dual fuel engines (engines that use liquid fuel to ignite the gas) and engines that use liquid fuel are required to be tested and certified at the highest liquid-to-gas fuel ratio. This ratio will change with the engine design.

In accordance with this, an engine can be certified as either a dual fuel or a gas engine. If certified as a gas engine, it will be Tier III compliant when operating on

gas, but not when operating on liquid fuel. The operator will only be able to use liquid fuel during an emergency or failure, reducing operational flexibility.
B: b “Methane slip is when gas leaks unburned through the engine. Methane has a GWP100 (100-year global warming potential), which is 25x higher than CO2. If [ ] methane slip isn’t controlled, environmental benefits to using natural gas are reduced.” Source: http://en.wikipedia.org/wiki/Marine_LNG_Engine

1.5. Exhaust gas recirculation

Exhaust gas recirculation (EGR) is a mature technology, used in automotive engines for several decades. Exhaust gas is feedback into the cylinder air intake, lowering oxygen and increasing CO2, which has a higher specific heat capacity than air.
This slows combustion and reduces temperature, lowering NOx. The EGR fan can adjust the amount of exhaust gas that is recirculated (the EGR ratio).
The main components of an EGR system are shown in Figure 4, and comprise:
a high-pressure exhaust gas scrubber fitted before the engine turbocharger
A cooler to further reduce the temperature of the recirculated gas
A water mist catcher (WMC) to remove entrained water droplets
A high-pressure blower to increase recirculated gas pressure before reintroduction to the engine scavenge air automated valves for isolating the system.
The main wash water components of the scrubber are typical of a closed loop SOx scrubber system (see section 5.1.2 on page 18) and comprise:

- a buffer tank with fresh water make-up
- a sodium hydroxide dosing device
- a circulating pump
- a water treatment plant with sludge collection.

1.6. MAN Diesel & Turbo EGR systems

MAN Diesel & Turbo has tested its own EGR systems on two-stroke engines.
A first generation MAN EGR system was trialed on board M.V. Alexander Maersk. Initial issues with materials [4] required material upgrades and improved sodium hydroxide dosage because of iron and sodium sulphate deposits in the main engine air coolers, and corrosion of EGR system components including the cooler casing and blower.

MAN's second generation EGR system is shown in Figure 5. This integrates the engine, scrubber, cooler, water mist catcher and blower into a single unit. It is designed to be fitted in the same way as a charge air cooler. With 40% recirculation, this

EGR can potentially reduce NOx to Tier III levels on a two-stroke low-speed marine engine, and increased fuel consumption, carbon monoxide (CO) emissions and PM emissions resulting from reduced combustion efficiency are manageable with engine adjustments.

MAN also report that specific fuel consumption is improved when using EGR to reduce NOx to Tier II levels, when compared with using engine adjustments to achieve the same level of emissions, particularly at part load. While most attention has focused on using the MAN EGR system for slow-speed engines, high-speed and medium-speed engine manufacturers are also considering EGR NOx abatement technology.

1.7. CO and PM emissions

EGR systems can cause higher CO and PM emissions. CO emissions can be controlled by adding water to the fuel. However, adding water can reduce fuel efficiency and increase PM. Increasing turbocharger and fuel injection pressure can help to reduce the PM emissions.

There is a balance to be struck between EGR ratio and water addition to achieve an optimum balance between NOx, CO, PM and fuel efficiency.

1.8. Fuel emulsification

Fuel emulsification has been recognized as an effective way of reducing NOx emissions for many years. Forming a stable and homogeneous emulsion can be challenging (particularly with distillate fuels) but it can be done. While achieving Tier III compliance using emulsification alone is proving to be challenging, it could be used with other techniques such as mild EGR or high-pressure super charging to achieve Tier III. Given that emulsification systems affect the composition of fuel it is important to ensure that the resulting emulsified mixture is suitable for combustion machinery and that measures are in place to prevent the emulsification system exceeding the allowable fuel parameters for machinery.

1.9. High-pressure supercharging

Since combustion temperatures are related to the compression ratio of internal combustion engines, reducing this compression ratio can lower temperature and reduce NOx. This can be achieved by high-pressure supercharging using multi-stage turbochargers and by applying the Miller thermal cycle. In a Miller engine, the air inlet valves remain open for much longer than in a Diesel or Otto engine, with the result that typically only 70-80% of the upward piston stroke is compressing the charge air or pre-mixed charge air and fuel. While this is unlikely to achieve Tier III emissions compliance by itself, it can be used in conjunction with other techniques. Although high-pressure supercharging improves emissions performance, it has high energy demand. If using turbochargers, this will significantly reduce the energy which is available for waste heat recovery systems. This is potentially quite important for ships with a high heating load. Clearly the supercharging system will be more complex and more expensive, particularly where multi-stage devices are used and these will require more complex charge air cooling arrangements. If the compression ratio is lowered too much, there may be problems with engine operability.

Figure 3: A two-stroke EGR system arrangement (image courtesy of MAN Diesel & Turbo)

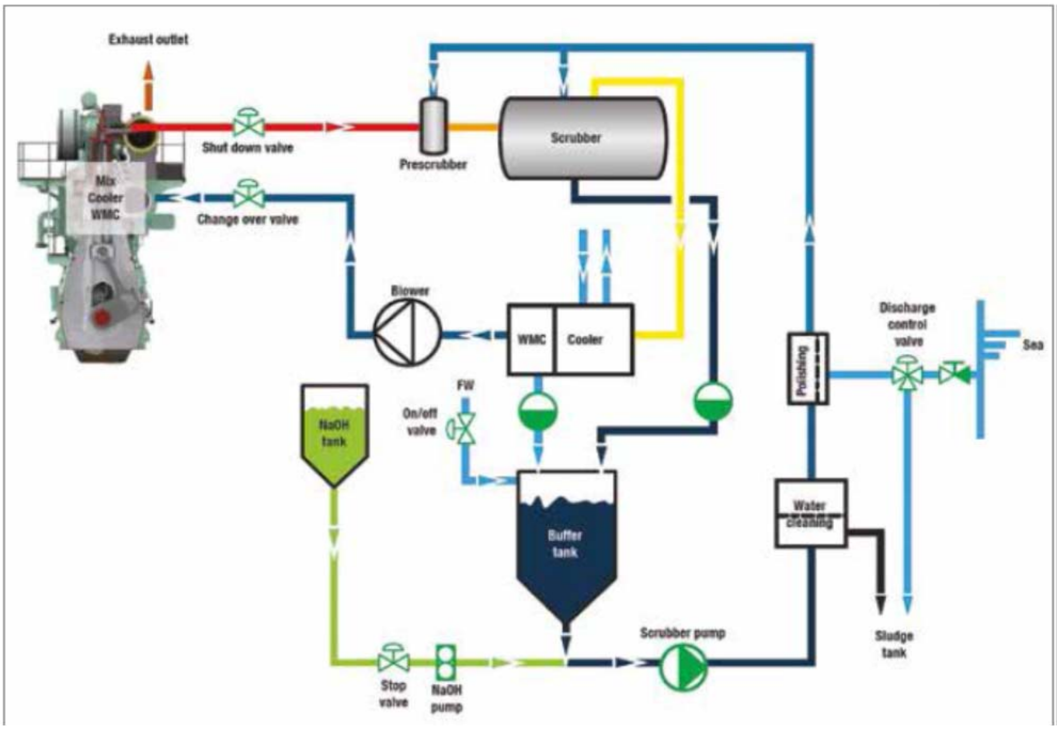


Figure 4: A two-stroke EGR system arrangement (Source_courtesy of MAN Diesel & Turbo)

1.10. Secondary compliance techniques for SOx

Operators can use exhaust gas treatment systems as an alternative way to comply with the SOx emissions limits, if permitted.

Currently the market for marine exhaust gas cleaning technology is dominated by SOx scrubbers. A less mature technology option is non-thermal plasma (NTP).

There are two main types of SOx scrubber:

wet scrubbers that use water (seawater or fresh water) as the scrubbing medium; and dry scrubbers that use a dry chemical.

Both wet and dry scrubbing technologies are established and mature and have been used in industries such as electricity generation for many years.

1.10.1. Open loop scrubbers

Open loop scrubbers pump seawater into the scrubber and discharge the wash water back to the sea. A simple open loop scrubber is shown in Figure 6.

In an open loop system, sulphur oxides (SOx) are removed from the exhaust gas in a series of conventional chemical reactions; these vary according to the particular technology used but typical chemistry is:

$SO_2 + H_2O \Rightarrow H_2SO_3$ (sulphurous acid) $\Rightarrow H + HSO_3$ (bisulphite)

HSO_3 (bisulphite) $\Rightarrow H + SO_3$ (sulphite)

SO_3 (sulphite) + . $O_2 \Rightarrow SO_4$ (sulphate)

The sulphate is discharged to sea. Wash water is not recirculated. A typical wash water flow rate in an open loop system is 45m3/MWh. Open loop systems are sensitive to local washwater controls and are associated with higher parasitic loads but do not normally need alkaline additives and are simple.

1.10.2. Closed loop scrubbers

Closed loop scrubbers circulate fresh water in a closed loop, 'bleeding off' contaminants to keep the wash water clean. A closed loop arrangement is shown in Figure 3. SOx and particulates are removed from the exhaust gas as the wash water dissolves them. Dissolved SOx forms sulphuric and sulphurous acids; a series of chemical conversions results in these acids being converted to sulphite and bisulphite, generating excess hydrogen ions and acidity. This acidity is neutralized by alkaline carbonates and bicarbonates in the sea water – a process known as pH buffering. Many marine systems use sodium hydroxided for pH buffering.

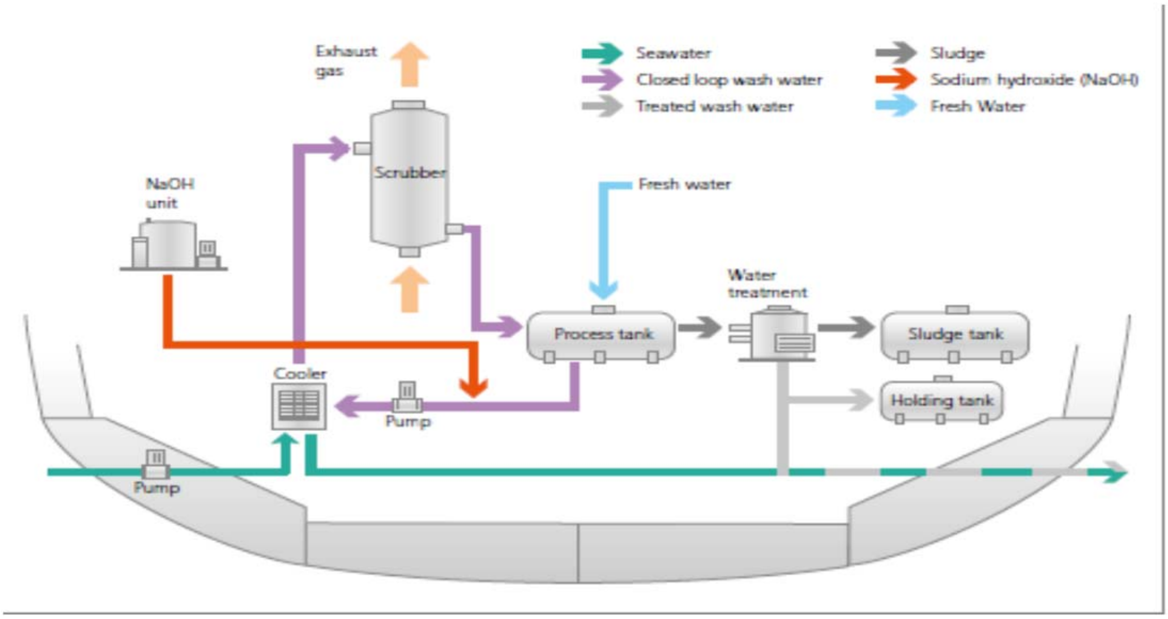


Figure 5: A closed loop scrubber arrangement

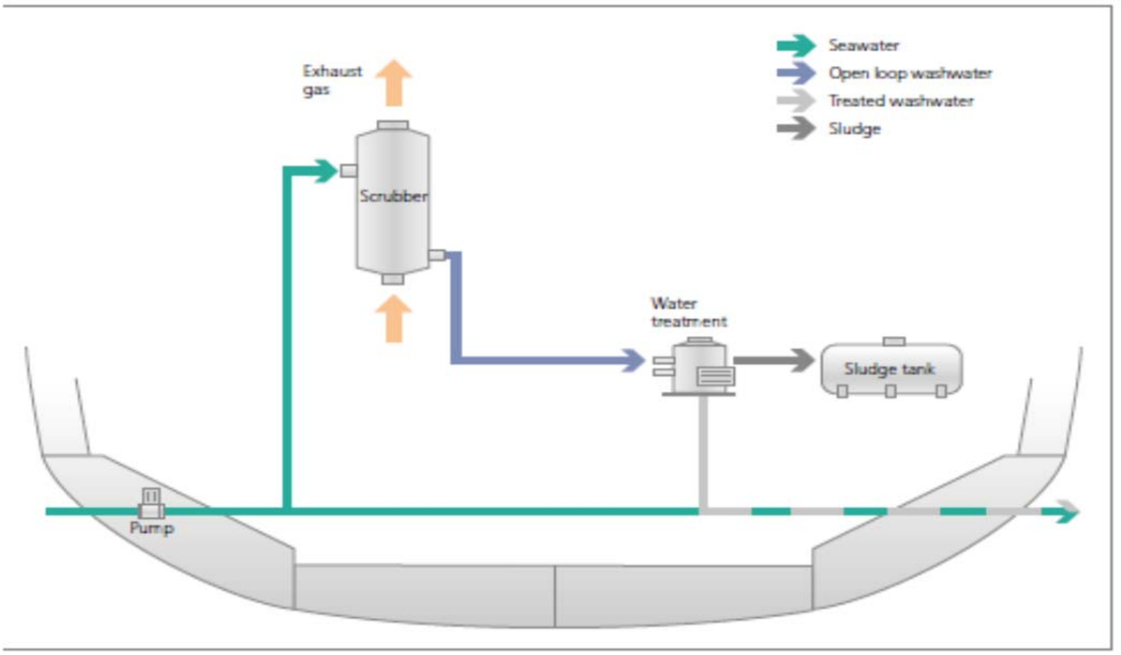


Figure 6: An open loop scrubber arrangement

Sodium hydroxide

Closed loop systems typically consume sodium hydroxide in a 50% aqueous solution. The dosage rate is approximately 15 litres/MWh of scrubbed engine power. The choice of materials for pipework, fittings and tanks is an important consideration as sodium hydroxide is corrosive to aluminum, brass, bronze, tin, zinc (including galvanized coatings) and glass. Sodium hydroxide is usually delivered by road tanker at a transportation temperature of around 40°C. The temperature when pumping must be above 20°C, as the viscosity rapidly rises below this temperature. However, it should not be above 50°C to prevent corrosion cracking of mild steel pipework, although stainless steel is resistant at higher temperatures. Onboard storage temperature is therefore between 20°C and 50°C. If onboard temperature is regulated by cooling water systems, the risk of a heat transfer coil failing (leading to cross contamination of the cooling system with sodium hydroxide) should be noted. Sodium hydroxide has a pH of 14 and is hazardous. It can cause severe skin burns, respiratory damage and eye injury. Robust procedures are required for handling sodium hydroxide, including use of appropriate personal protective equipment (PPE) if there is risk of exposure. Reference should be made to material safety datasheets (MSDS).
Alternative alkaline additives such as magnesium oxide and sodium bi-carbonate may be used which are less hazardous than sodium hydroxide.

1.10.3. Wash water in closed loop systems

Closed loop systems discharge small quantities of treated wash water to reduce the concentration of sodium sulphate. If sodium sulphate is left uncontrolled, crystals will form and lead to progressive degradation of the wash water system?
Information from scrubber manufacturers suggests that the wash water discharge rate is approximately 0.1 m3/MWhe. The rate of fresh water replenishment to the system not only depends on the discharge to sea but also on losses to the exhaust through evaporation and via the washwater treatment plant. The rate of evaporation is influenced by exhaust and scrubbing water temperatures, which in turn are governed by factors such as engine load and the temperature of the seawater supply to the system coolers. Some of the water vapour incorporated within the exhaust may be captured after the scrubber and reused to reduce fresh water consumption.
If a wash water holding tank is added, closed loop systems can operate in zero discharge mode for a period of time (the exact length of time depends on the size of

the holding tank). This flexibility is ideally suited to operation in areas where there is sensitivity to wash water discharges, such as ports and estuaries, removing the risk that coastal states and harbor authorities may not accept the use of scrubbing despite the IMO MEPC 184(59) Guidelines allowing open loop systems. Closed loop systems operate with lower parasitic electrical loads due to lower wash water flows. Closed loop systems require more tankage than open loop systems. A process or buffer tank is required in the scrubbing water circulation system, a holding tank is required for zero discharge mode (size dependent on ship requirements) and loading facilities, storage tanks and dosing equipment are required for sodium hydroxide.

Operation in fresh water.

The alkalinity and pH buffering of sodium hydroxide reduces water flow compared to open loop systems and removes sensitivity to seawater carbonate and bicarbonate levels. Control of pH by dosing with sodium hydroxide enables the washwater circulation rate, and therefore power consumption, to be about half that of open loop systems at approximately 20 m3/MWh and between 0.5 – 1% of the power of the engine being scrubbed. Closed loop systems can also be operated when the ship is operating in enclosed waters where the alkalinity would be too low for open loop operation.

1.10.4. Hybrid scrubbers

Hybrid scrubbers can operate in either open loop or closed loop mode. This provides the flexibility to operate in closed loop mode (including zero discharge mode) where the water alkalinity is insufficient or where there is sensitivity to, or regulation of, wash water discharge, and in open loop mode without consuming sodium hydroxide at all other times. This offers advantages in the sodium hydroxide is only used when necessary, reducing handling, storage and associated costs. And freshwater consumption is also reduced. There are also hybrid systems that can operate in open and closed loop mode simultaneously.

Although hybrid scrubbing is the preferred option for many operators, mitigating the uncertainty over the acceptance of open loop systems while retaining the simplicity of open loop operation where allowed, hybrid scrubbers are more complex.

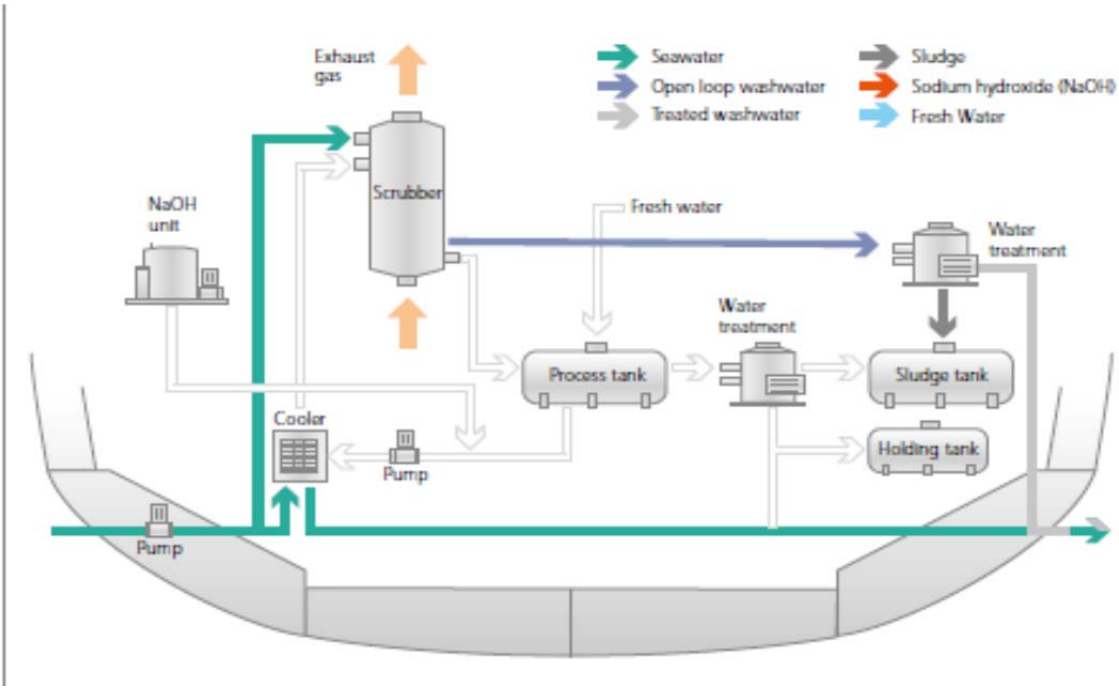


Figure 7 : A hybrid Sox scrubbing system, operating in open loop mode

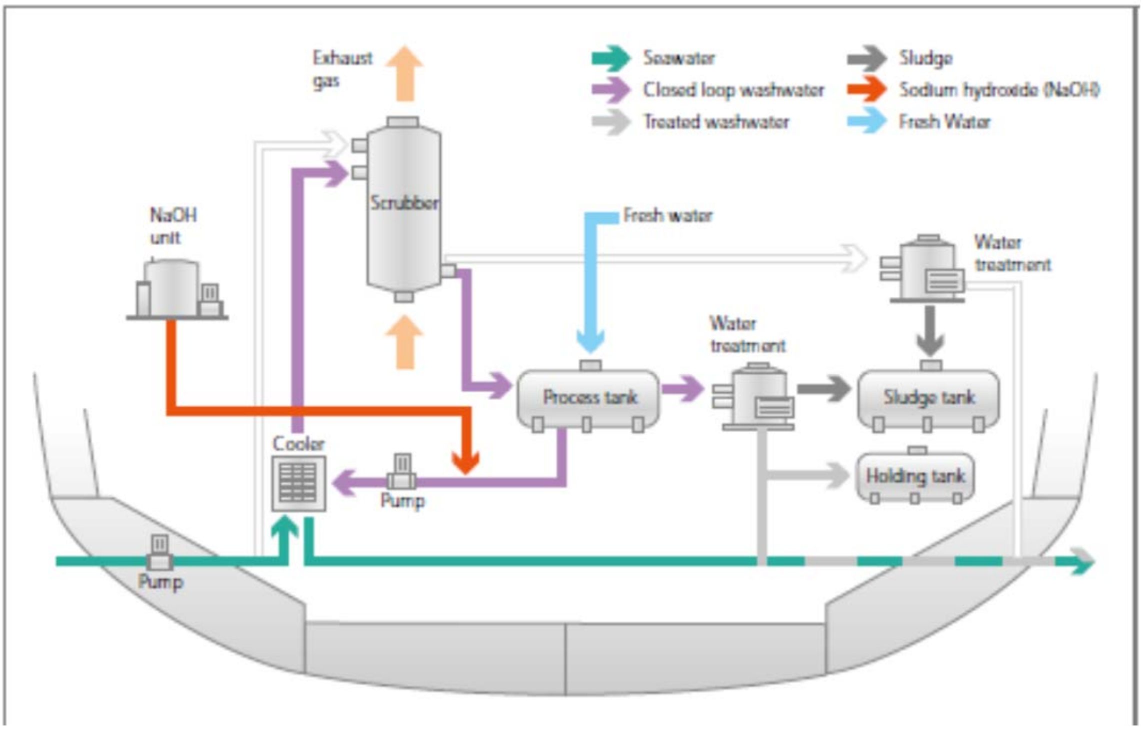


Figure 8 : A hybrid Sox scrubbing system, operating in closed loop mode

1.11. Common challenges of wet scrubbing

Service experience shows that wet SOx scrubbers can achieve emissions reductions of over 99%, the equivalent emissions of 0.10% sulphur fuel with all marine fuels. The technology is simple, claimed parasitic loads are relatively low (manufacturers estimate 0.5% of installed power for closed loop systems or 1.5% for open loop systems) and the return on investment time is short, potentially less than one year if operating in an ECA constantly. Retrofitting older vessels is relatively easy; some systems fit within the uptake space occupied by the engine silencer.
Wet scrubbing does present challenges, however, and these are outlined here:

1.12. Backpressure

Wet scrubbing causes higher exhaust back pressure, typically 1000 – 2000Pa. Reverse flow of water can flood the engine and boiler. Exhaust gas leaves the scrubber at approximately 60°C so waste heat recovery systems and selective catalytic reduction units (SCR) will be fitted before the scrubber in order to be effective. Waste heat recovery units already operate in acidic exhaust gas and temperature is above dew point when running. However, if an SCR is fitted, catalyst materials and geometry should be suitable for such exhaust gas or a high-pressure SCR should be used.

1.13. Stability review

Scrubber towers add top weight, affecting ship stability. Additional tanks are required, consuming hull volume and increasing deadweight, increasing fairway dues and reducing overall ship efficiency. Engine room flooding can occur if a pipe fails. Wet scrubbers can generate a visible plume of water vapour at the funnel and there have also been problems with particulates being emitted from the funnel and deposited onto ships’ after decks. Washwater is highly aerated after being sprayed through nozzles and mixing with exhaust gas. This can cause frothing and foaming on the sea surface if the wash water is discharged overboard.

1.14. Corrosion of materials and pipework

Washwater in wet SOx scrubbers is highly corrosive and the scrubber components that come into contact with it should be constructed of suitable corrosion-resistant materials. Glass reinforced epoxy (GRE) piping has been used successfully in a number of installations. GRE piping is lightweight, which makes it easier to handle during retrofits, but its reduced rigidity makes it necessary to install appropriate bracketing – in excess of that required for steel pipe. The relevant Class Rules should be followed, for example use of steel transition pieces fitted with suitable closing devices where GRE piping passes through watertight bulkheads. GRE piping close to the scrubber must also be protected from exposure to hot exhaust gases.

Experience indicates that coated steel piping may not be suitable as it can suffer rapid localized corrosion typically at welds and flanges, where there is an increased risk of breakdown of the coating. Stainless steel 316L may also be subject to rapid corrosion, particularly in open loop systems using seawater, which has a moderately high temperature after scrubbing and a low pH. In these cases, nickel alloys with a higher pitting resistance equivalence number (PREN) may be used.

Typically, it is not necessary to change the materials of the exhaust duct and systems downstream of a wet SOx scrubber if the exhaust gas temperature is kept above the dew point. If this is not the case, corrosion-resistant materials should be used.

During class approval (see section 7.8.2), the materials used in the construction of the SOx scrubber and its associated systems, including chemical storage and handling systems, will be reviewed for compliance with class Rules.

1.15. Particulate matter and soot removal

Some systems use particulate matter and soot removal devices before the scrubbing tower to simplify wash water conditioning and make polycyclic aromatic hydrocarbon (PAH) discharge compliance easier. This may negate the need for a washwater treatment system, making this an attractive option. However, these devices add complexity, and soot handling and disposal can be problematic. Disposing it as hazardous industrial waste is expensive and rigorous work safety controls are needed to protect the crew from long-term exposure to harmful substances. If a soot removal device fails, the ship will need a conventional washwater treatment system to operate in open loop mode. If a conventional washwater treatment system is fitted, it negates the advantages of having a soot removal device.

1.16. Wash water discharge to sea

One of the principal challenges associated with wet scrubbing is handling the washwater discharge. Wet scrubbers clean a wide range of pollutants out of exhaust gas, in addition to SOx, which affect washwater composition. Unless there are controls to govern wash water discharge to sea there is a possibility of pollution shift from air to water, negating the environmental benefits of exhaust gas cleaning. In an open loop system the wash water goes into the sea. Closed loop systems require bleed off; unless the ship is provided with very large collecting tanks or the ship is in a position to discharge holding tanks to shore reception facilities frequently, this bleed off will also go into the sea.

The IMO MEPC.184(59) Guidelines place emission limits on washwater discharge, but do not contain any geographical restrictions; providing the emission limit values are satisfied, they allow for exhaust gas cleaning systems to operate while discharging washwater to sea with no further restrictions. They do not reference open or closed loop modes; the controls apply to all wet scrubbers. In the US, the Environmental Protection Agency (EPA) has put in place Vessel General Permit (VGP) requirements for discharges incidental to the normal operation of ships. Ships with exhaust gas cleaning systems must have a VGP in order to

discharge SOx scrubber washwater. These requirements are broadly equivalent to those of the IMO MEPC.184 (59) Guidelines but a significant exception is that the washwater must meet a pH limit of 6.5 at the point of discharge to sea. The permit requirements apply to "waters of the United States, including the contiguous zone or ocean".

There are further complications when using wet scrubbers within the North Sea and Baltic ECA because of the interaction between the European Water Framework and Sulphur Directives. Despite European requirements for scrubbers also being generally aligned with the IMO MEPC.184(59) requirements (with the exception that continuous emissions monitoring is mandatory) it is not yet clear if coastal states and local authorities will impose more stringent controls on washwater discharge.

However, we are seeing many references to restrictions on open loop systems. This is creating uncertainty for some operators, and a perceived risk that wet scrubbing will not be a viable solution if they are not allowed to use these systems in littoral and inshore waters. This problem is not limited to open loop systems and will also affect closed loop systems. To date, most concerns appear to relate to the acidity of washwater discharges although this is not the only emission limit for the washwater. There have also been concerns about contaminants which are not monitored, such as heavy metals, and the potential for them to accumulate in sediment on the bed of closed docks and other areas with limited water exchange.

Washwater emission parameters and monitoring.

The IMO MEPC.184 (59) Guidelines require three washwater parameters to be continuously monitored if discharged to sea:

Acidity (pH)

The pH must be limited to 6.5 at the ship's side at rest, with a maximum difference of 2 pH units when the ship is manoeuvring or in transit; or

the pH is to meet a limit of 6.5 measured four meters from the ship's side. This must be continuously monitored and the monitoring data recorded and retained.

Turbidity

The washwater treatment system should minimize suspended particulate matter, including heavy metals and ash, and the maximum turbidity in washwater is limited to 25 FNU (formazin nephlometric units) or 25 NTU (nephlometric turbidity units) or equivalent units, above the inlet water turbidity, and are to be continuously monitored. However, during periods of high inlet turbidity, the precision of the measurement device and the time lapse between inlet measurement and outlet measurement make using a difference limit unreliable. Therefore, all turbidity difference readings should be a rolling average over a 15-minute period to a maximum of 25 FNU. For the purposes of this criteria the turbidity

in the wash water should be measured downstream of the water treatment equipment but upstream of washwater dilution (or other reactant dosing) before discharge. For a 15 minute period in any 12 hour period, the continuous turbidity discharge limit may be exceeded by 20%.

Polycyclic aromatic hydrocarbons (PAH)

The maximum PAH concentration in the washwater must not be greater than 50 μg/L PAHphe (phenanthrene equivalence) above the inlet water PAH concentration and is to be continuously monitored. The PAH concentration in the washwater should be measured downstream of the water treatment equipment, but upstream of any washwater dilution or other reactant dosing unit, if used, before discharge. The 50 µg/L limit is normalized for a wash water flow rate through the EGC unit of 45 t/MWh where the MW refers to the MCR or 80% of the power rating of the fuel oil combustion unit. This limit would have to be adjusted upward for lower wash water flow rates per MWh, and vice-versa, according to a table provided in section 10.1.3.3 of the IMO MEPC.184 (59) guidelines. For a 15 minute period in any 12 hour period, the continuous PAH phe concentration limit may exceed the limit described above by up to 100%.

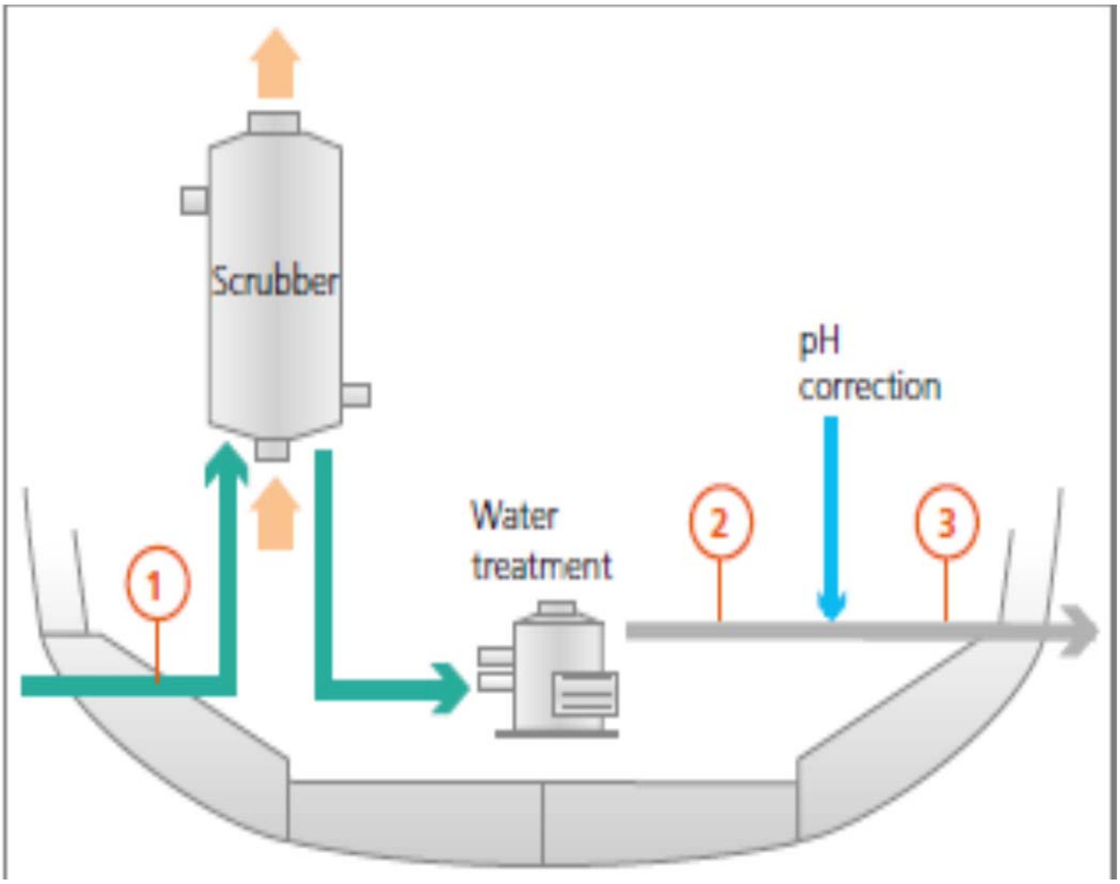


Figure 9: Washwater instrumentation

Figure 7 shows the position of instruments that can be fitted to an open loop system for the monitoring of water quality at the system inlet and the point of overboard discharge. The wash water instrumentation shown is:

Point 1 wash water system inlet

- pH
- PAH
- turbidity
- salinity (optional)

- Point 2 (after wash water treatment plant and before any pH correction)
  - PAH
  - turbidity
- Point 3 (before discharge after any pH correction)
  - ph.

The position, care, calibration and survey requirements for wash water monitoring instruments must be contained within an approved Onboard Monitoring Manual (OMM). Further information is included in Appendix B1. Short periods of instrument downtime are allowed for maintenance and cleaning but only when the ship is not in ports, harbours or estuaries. This may have commercial implications if there are tasks that have to be undertaken at sea requiring attendance by the manufacturer or specialists. There are also some requirements for wash water discharge which are not subject to continuous monitoring. The wash water treatment system should prevent the discharge of nitrates beyond that associated with a 12% removal of NOx from the exhaust, or beyond 60 mg/l normalized for wash water discharge rate of 45 tons/MWh, whichever is greater. This does not have to be continuously monitored and is verified by periodic extractive sampling. An assessment of the wash water is required for technologies which make use of chemicals, additives, preparations or create relevant chemicals in situ. The assessment could take into account relevant guidelines such as IMO Resolution MEPC.126 (53) – Procedure for Approval of Ballast Water Management Systems That Make Use of Active Substances (G9) and if necessary additional wash water discharges criteria should be established.

There appears to be some confusion in the industry regarding wash water and waste residue sludge produced by scrubbers. Wash water refers to water that, while contaminated with various substances, is allowed to be discharged to sea subject to the controls given in the IMO MEPC.184 (59) Guidelines. Waste residue sludge results from conditioning the wash water to remove contaminants and comply with the MEPC.184 (59) wash water discharge limits. This sludge is a pollutant and cannot be discharged to sea. It must be transferred to an appropriate waste reception facility for processing and disposal in an environmentally responsible way. The composition of wash water and sludge will vary because of variations in the materials entrained within the fuel. Wet scrubbing will dissolve SOx. In addition, gaseous volatile organic compounds will condense into the wash water and solids and incombustibles will be washed out of the exhaust gas into the wash water.

1.17. Environmental impacts of wash water.

The environmental impact of wash water discharge has been studied in a number of technical papers. These have primarily focused on the effects of wash water acidity, reflecting concerns about ocean acidification. Various papers have found the effects of wash water discharge on ocean acidification to be negligible. A study by University College London found that acidic jets discharged into an alkaline environment, as per wash water discharges from exhaust gas cleaning systems, can be safely absorbed by the sea with a negligible effect on acidification.

On the other hand, a study led by Chalmers University found that shipping is a major contributor to ocean acidification. However, this study focused on precipitation following gaseous emissions of SOx and NOx; given that exhaust gas cleaning will remove the overwhelming majority of SOx from exhaust gas, this will greatly reduce acidic precipitation. This is an important consideration; while LR does not advocate or support pollution shift, existing SOx emissions result in acidic precipitation and also the carbon reductions associated with scrubbing will have a significant positive impact on acidic precipitation.

Wash water treatment.

The technology and techniques used for wash water treatment are influenced by the overboard discharge rate. The low discharge rate of closed loop systems (0.1 m3/MWh) enables use of centrifugal separators (similar to those used for fuel and lubricating oil) or multi-stage oily water separators. Wartsila’s wash water treatment plant (shown in Figure 8) is an example of the latter.

Figure 11: Wash water treatment system with GRE piping

For open loop systems with a higher discharge rate (≈45 m3/MWh), cyclonic separation is appropriate. This technique is widely used in onshore and offshore industry and may also be encountered in ships' ballast water treatment systems. The heavy fractions are moved outward and downward to the outlet (underflow) at the bottom of the device. The light fractions move toward the central axis and upward to the outlet (overflow) at the top of the device. A hydro cyclone is a tapered device that converts velocity of a liquid into a rotary motion. It does this by means of a tangential inlet or inlets near its top. This causes the entire contents to spin, creating centrifugal force in the liquid.

Hydrocyclones can either consist of a single vessel or a 'nest' of hydrocyclone 'liners' within a vessel (see Figure 11). The latter, which may be either horizontally or vertically orientated, is arranged with a plate (similar to a tube plate in a cooler) at each end. The overflow plate holds the overflow end of each liner in place while the underflow plate holds the underflow ends.

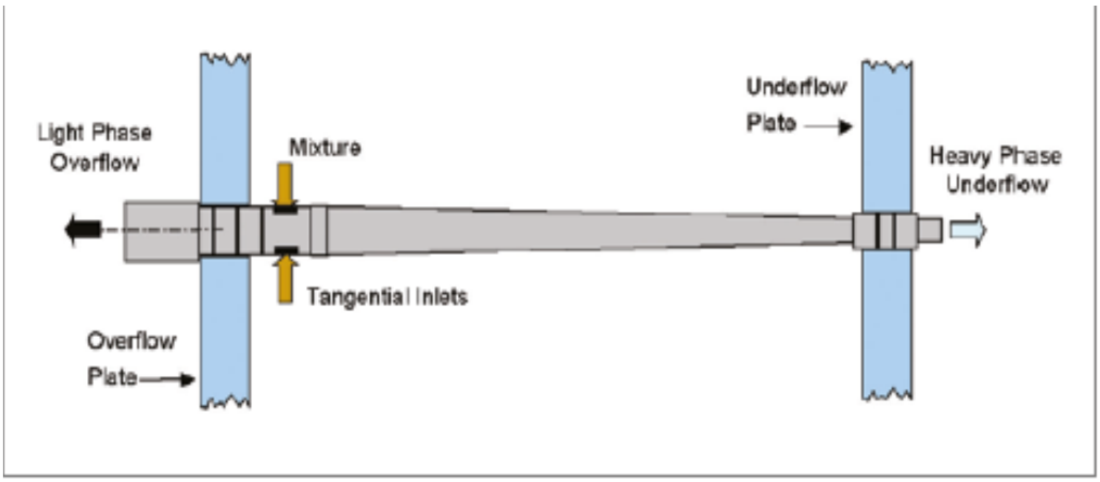


Figure 12: A hydrocyclone liner

Depending on design, hydrocodone's can separate solids from liquid, or liquids of Differing densities. Combinations can therefore be used to separate both particulate matter and hydrocarbons from wash water. The velocity of the wash water is either imparted by a pump or by the height of the scrubber above the wash water plant in the engine room, if sufficient. In US submissions to the IMO supporting the introduction of the North American ECA [5], test data showed PM10 emissions being dependent on fuel sulphur levels, with emission rates of 0.23 g/kWh with distillate fuel (0.24% sulphur content) and 1.35 g/kWh with residual fuel (2.46% Sulphur content) – which compared closely with the findings of LR's Marine Exhaust Emissions Research Programme. If a scrubber removes 70% of the particulate matter, then approximately 500kg of sludge may be expected for every 100 tones (t) of residual fuel consumed by a diesel engine. This is dependent on removal rate at the scrubber and the efficiency of the wash water treatment, both in removing PM and not including excess water. Wet Sox scrubber manufacturers typically recommend a sludge tank of around 0.5m3/MW of scrubbed engine power. Residue removed from SOx scrubber wash water must be stored on board, landed ashore and disposed of appropriately; itis not permitted to incinerate it or discharge it to sea.

1.18. Dry scrubbing

Dry scrubbers use a dry reactant – calcium hydroxide – to remove SOx from exhaust gas. The calcium hydroxide reacts with SOx and oxygen or water to give calcium sulphate and water. Dry scrubbing is widely used in land-based industry. A difference between marine and land-based systems is that marine systems use granulated calcium hydroxide rather than a powdered form. Injecting powdered calcium hydroxide into baghouse filters offers responsive control to changes in Sox levels but is very bulky. In contrast, granulated calcium hydroxide systems have no controllability, operating with a pre-set cleaning efficiency which is typically set at 85% maximum continuous rating (MCR) at the highest Sulphur content of the fuel being used. The only marine dry scrubber supplier has sadly gone out of business but they demonstrated an efficiency of 99% SOx removal with 4.5%mm Sulphur fuel.

There is no risk of flooding or reverse flow with dry systems; the reaction is exothermic and installation is upstream of SCR and waste heat recovery units. The SCR operates with clean gas and waste heat recovery systems can use cheaper, less corrosion resistant materials. Parasitic load is insignificant and retrofitting is possible. Size and weight are key considerations for dry scrubbers. A 20MW dry unit weighs 211 tonnes, compared to an equivalent wet scrubber, which weighs around 10 tonnes. Dry scrubbers also have a bigger footprint compared to wet scrubbers. Large storage tanks are required for the granulated calcium hydroxide, and equal amounts of spent calcium sulphate granulate are produced. Couple Systems advised that 16Kg/MWh of granulate was produced when operating with high Sulphur residual fuel. An 18MW engine would consume 288Kg/hour of granulate with a density of 800Kg/m3, equating to 8.6m3 per day for both new and spent granulate. The cost-effectiveness of a dry scrubber relates strongly to how much time a ship spends in an ECA. Currently there is very limited availability of dry scrubbers compared to the proliferation of wet scrubber designs and suppliers. Figure 10 shows a typical dry SOx scrubber. It has the following main components:

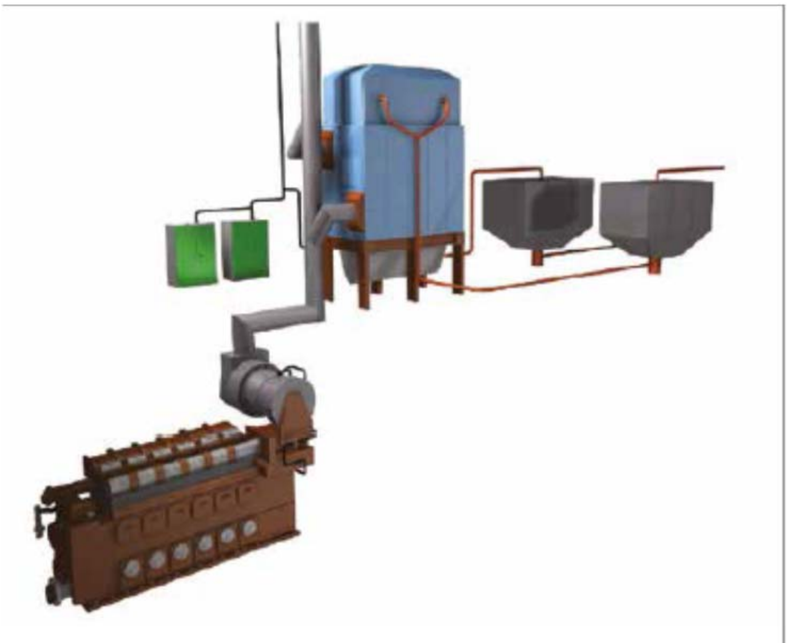


Figure 13 Couple Systems dry SOx scrubber for marine use (image courtesy of Couple Systems)

A scrubber unit

A scrubber unit, in this case known as an ‘absorber’, which brings the exhaust gas from one or more combustion units into contact with calcium hydroxide granules. Unlike the majority of wet scrubbers, the exhaust gas entry is perpendicular to the vertical downward flow of the scrubbing medium. No heat is removed from the exhaust gas during scrubbing (in fact the reaction is exothermic and releases heat) so dry scrubbers can be positioned before waste heat recovery and SCR equipment.

A granule supply silo and screw conveyor for discharge, positioned at the top and bottom of the absorber respectively. A pneumatic conveyor system enables granules to be transported from and returned to onboard storage facilities. The use of flexible pipework facilitates the storage of granules at various locations on board.

A scrubber control and emission monitoring system. Removal of the used granules and any exhaust-related particulate matter is an automated process and may either be continuous or intermittent to ensure the correct flow of fresh granules under gravity down through the absorber.

Dry scrubbers typically operate at exhaust temperatures between 240°C and 450°C. Calcium hydroxide granules are between two and eight millimeters in diameter (see Figure 13) with a very high surface area to maximize contact with the exhaust gas.

Within the absorber, the calcium hydroxide granules ($Ca(OH)_2$) react with Sulphur oxides to form gypsum ($CaSO_4 \cdot 2H_2O$). Details of the chemical reactions can be found in Appendix D1.3. Trials on a 3.6MW engine using up to 1.80% Sulphur content fuel are reported to have shown a 99% and 80% reduction in SO_2 and particulate matter emissions respectively. It should be noted that the PM reduction was tested according to DIN51402 whereby particulate is captured on a filter of silica fibre material.

The filter is then assessed either visually or by photometer, which compares the intensity of reflected light with that from the original light source, enabling a smoke number to be derived by a standard conversion procedure.

Figure 14: Calcium hydroxide granules(image courtesy of Couple Systems)

To reduce SOx emissions to those equivalent to fuel with a 0.10% Sulphur content, a typical marine engine using residual fuel with a 2.70% Sulphur content would consume calcium hydroxide granules at a rate of 40 kg/MWh and, based on a density of 800kg/m3, the volume of granulate required would be approximately 0.05 m3/MWh (i.e., a 20MW engine would require approximately 19 tonnes of granulate per day with a volume of 24m3). Electrical power consumption is lower than for wet systems at approximately 0.15 – 0.20% of the power of the engine being scrubbed.

Unlike wet scrubbers, dry scrubbers have no requirement for wash water treatment systems and their associated pipework, tankage, instrumentation and controls. This simplifies installation and operation, and makes dry scrubbers ideally suited to areas where there is increased sensitivity regarding discharges to sea. However, as with closed loop operation of a wet system, there is a need for storage and handling of consumables. Used granules must also be stored before disposal ashore. The scrubber manufacturer may be able to co-ordinate the logistics of supplying, removing and disposing of granulate.

Calcium hydroxide is classed as harmful to eyes and skin and the inhalation of dust should be avoided. Although calcium hydroxide has hazardous properties, it is considerably less hazardous than 50% aqueous sodium hydroxide solutions typically used in wet scrubbing systems. It should be kept dry and away from contact with acids. It is also important that used granules remain dry, and fully contained storage and handling systems are therefore an advantage. If a ship's own storage is used, advice should be taken as to appropriate alkali-resistant coatings.

While dry scrubbing does not reduce NOx emissions by itself, it is ideally suited for use in conjunction with selective catalytic reduction (SCR) systems (see section 6.1, page 32) which require hot exhaust gas to attain an operating temperature of above 300°C.

1.19. Non thermal plasma

Unlike wet and dry scrubbing, which achieve de-sulphurisation through a series of conventional chemical reactions, non-thermal plasma (NTP) works by breaking the molecular bond between Sulphur and oxygen, achieved through molecular excitation. NTP has the potential to treat multiple pollutants and is not restricted to SOx abatement. It can be applied in a variety of ways including systems reliant on high voltage electrical apparatus or ionizing beam lasers. NTP systems may incorporate wet or dry elements to convert and condition the free elements created by the dissociation of pollutants. These may include wet scrubbing, baghouse filters and electro-static precipitators.

There has been limited interest in applying NTP to shipping. Unlike wet and dry scrubbing, which are fundamentally simple, NTP needs to achieve the molecular excitation, which can involve expensive apparatus. The proprietary nature of such apparatus makes in-service support difficult if the supplier ends product support. If used with wet or dry techniques for conditioning the free elements created by breaking the molecular bonds of pollutants, the energy demand, complexity and space demands may be similar to that of a wet or dry scrubber.

1.20. Comparing SOx scrubber technologies

1.20.1. Operation in fresh water

Alkalinity or the buffering capacity of seawater is a key parameter for the effective operation of wet open loop Sox scrubbers (including hybrid SOx scrubbers when operating in open loop mode). When exhaust gas is mixed with seawater inside the scrubber, Sulphur oxides are dissolved, increasing the acidity and lowering the pH of the wash water. Alkalinity is a measure of the ability to resist changes in pH; in seawater, alkalinity is naturally provided by bicarbonates, carbonates, borates and anions of other ‘salts’ in more minor quantities. It is not the sodium chloride content of seawater that facilitates scrubbing. Hence, salinity (a measure of all salts present) only indirectly indicates that sufficient alkalinity is present.

Some natural fresh water can be highly alkaline and suitable for scrubbing, although efficiency may be reduced. The water in the Great Lakes and areas within the Baltic Sea does not have sufficient alkalinity to support the operation of wet, open loop SOx scrubbers. Closed loop wet SOx scrubbers (including hybrid SOx scrubbers operating in closed loop mode) and dry SOx do not use sea water as their scrubbing medium and are therefore unaffected by the properties of the sea water in which they operate.

1.20.2. Operation without discharge to sea

The high wash water discharge rate (≈45m3/MWh) of open loop systems (and hybrid systems in open loop mode) means that when operating they have to discharge wash water into the sea continuously. The much lower discharge rate (0.1m3/MWh) of closed loop systems (and hybrid systems operating in closed loop mode) means that it is possible to retain wash water to be discharged on board for a limited period of time (i.e., operate in zero discharge mode). Dry SOx scrubbers have no discharge to sea. Given the uncertainty surrounding the acceptability of discharging wash water to sea, this is a critical consideration.

1.20.3. Weight

The filled dry SOx scrubber unit for a 20 MW engine is heavier (≈200 tonnes) than comparable exhaust capacity wet scrubbers (30-55 tonnes). However, the overall weight of wet and dry systems may be similar once the wash water systems, such as the processing tank, holding tank and chemical storage, are taken into account. As most of the weight of the dry scrubber system is installed relatively high up in the ship, the impact of the system on the vertical centre of gravity (VCG) of the ship is likely to be greater than for wet SOx scrubbers, where many of the components may be lower down. When installing a SOx scrubber on an existing ship, the resulting change in lightship weight and/or VCG may necessitate the revision of the ship's stability manuals.

1.20.4. Power consumption

The wash water flow rate in an open loop SOx scrubber is higher (≈45m3/MWh) than a closed loop SOx scrubber (≈20m3/MWh) because the buffering capacity of seawater is less than the buffering capacity of fresh water dosed with sodium hydroxide. Consequently, open loop SOx scrubbers require larger pumps and have higher power requirements.

The power requirement of dry SOx scrubber systems is mainly associated with a screw conveyor that moves the calcium hydroxide granules through the scrubber unit (known as an absorber). The power required is therefore significantly less than for wet SOx scrubbers.

The energy consumption associated with SOx scrubbers does not adversely impact a ship's attained Energy Efficiency Design Index (EEDI) value as, for almost all conventional cargo ships, the auxiliary power consumption will be calculated as a fixed proportion of the installed main engine power, and is unrelated to the actual auxiliary power consumption. However, if the installation of the system reduces cargo carrying capacity then the EEDI will be affected. The energy consumption will affect any operational energy efficiency key performance indicators (KPIs) that include actual energy consumption of auxiliary systems, such as the Energy Efficiency Operational Indicator (EEOI).

1.20.5. Compatibility with waste heat recovery units and SCR systems

All wet SOx scrubbers significantly cool the exhaust gas. Therefore, they are not suitable for installation before a waste heat recovery unit. For the same reason, it would not be possible to install a wet SOx scrubber before an SCR system unless a re heater was fitted after the wet scrubber to raise the exhaust gas temperature back up to around 300°C – the temperature required for SCR systems to work effectively. Dry SOx scrubbers do not cool the exhaust gas so they are suitable for installation before both waste heat recovery units and SCR systems.

1.20.6. Particulate matter (PM) removal

The SOx scrubbers can be an effective means of reducing PM (see section A1.5 in Appendix A1), both indirectly by removal of SOx and by direct mechanical cleaning when particles come into direct contact with either wash water or chemical granules. SOx scrubber manufacturers typically claim between 70% and 90% removal rates.
The sulphates, which make a significant contribution to PM, are formed post-combustion in the exhaust plume. Oxidation of SO2, followed by further oxidation and condensation processes, contributes to the growth of complex particles after the cylinder and the majority of sulphates form in reactions after release from the stack.
The IMO Exhaust Gas Cleaning System Guidelines require monitoring of the SO2 to CO2 ratio in the exhaust gas but do not require PM monitoring as this is not necessary to demonstrate equivalence with fuel sulphur content limit. The in-service measurement of particulate matter can be challenging; methods involving weighing deposits on filters are difficult to measure continuously on board. Ship operators should note that the 'wet' method for collecting PM on filters contained in ISO 8178j includes sulphates and any incompletely burned hydrocarbons, whereas the 'hot/dry' technique contained in ISO 9096k does not. Significantly different results will therefore be obtained from the same engine operating under the same conditions consuming the same fuel, with ISO 8178 tests reporting a greater mass of particulate. Scrubber manufacturers have used differing methodologies during their trials, which make it difficult to compare like-for-like the PM reduction performance of various scrubbers.

1.20.7. Visible smoke

Smoke is a collection of airborne solid and liquid particulates and gases, together with entrained air. Visible smoke from combustion devices on ships is largely comprised of black carbon, heavy metals from the ash content, and water vapour.
Some countries impose 'smoke' control measures on shipping in their coastal waters. For example, within three miles of the Alaska coastline, visible emissions, excluding condensed water vapour, must not reduce visibility through the exhaust of a marine vessel by more than 20 percent. Short defined periods of increased emissions are, however, permitted in port, at anchor or when manoeuvring [8]. A visible plume may also be undesirable for commercial reasons.
All SOx scrubbers reduce the black carbon and ash from the exhaust but wet SOx scrubbers may increase the water vapour content in the exhaust stream, resulting in a highly visible white plume unless the exhaust is kept well above the dew point (see Figure 14). This plume is not smoke but there is a risk that local authorities may assume it to be smoke. Wet Sox scrubber manufacturers can provide de-plume devices but operators should be aware that these may not be part of the standard system and may be offered as optional extras.

1.20.8. Attenuation of engine noise

SOx scrubbers are commonly installed in the place of the silencer when converting existing ships. Equipment manufacturers have differing views on the attenuation that their equipment might provide. For wet SOx scrubbers this attenuation may change depending on whether or not the SOx scrubber is in operation, although some designs attenuate noise effectively in both conditions. For some operators, particularly cruise ship and ropax operators, the option of combining a SOx scrubber with the engine silencer, and incorporating a scrubber within the footprint allocated to a silencer in the uptake area, is critical

1.22. Secondary compliance techniques for NOx

The mechanisms which form NOx and the primary techniques to reduce NOx have been covered in previous section. Some of these primary techniques, such as using alternative fuels, have significant additional engineering requirements for safe storage, handling and use of fuels, while others can reduce engine efficiency. Secondary techniques are therefore potentially very attractive in avoiding engine efficiency penalties and the complexities of designing and installing an alternative fuels package.

1.22.1. Selective catalytic reduction

Selective catalytic reduction (SCR) is a relatively mature technology, widely used for NOx control in land-based industry and land-based transportation. SCR can reduce NOx emissions by 80-90% to below 2g/kWh. SCR systems are currently fitted to four-stroke medium-speed engines on a number of ships in service, which are able to gain commercial advantage from reduced NOx emissions.

The SCR system converts nitrogen oxides into nitrogen and water, by means of a reducing agent injected into the engine exhaust stream before a catalyst. Urea is the reductant typically used for marine applications. It decomposes to form ammonia in a mixing duct before adsorption onto the catalyst that facilitates the reduction process. Details of the chemical reactions can be found in Appendix D2.1.

An SCR system comprises the following main components:

- a pumping unit for transfer of urea solution from storage
- a urea dosing unit
- a mixing duct with urea injection point
- a reactor housing containing replaceable catalyst blocks
- a control system
- a soot/ash cleaning system

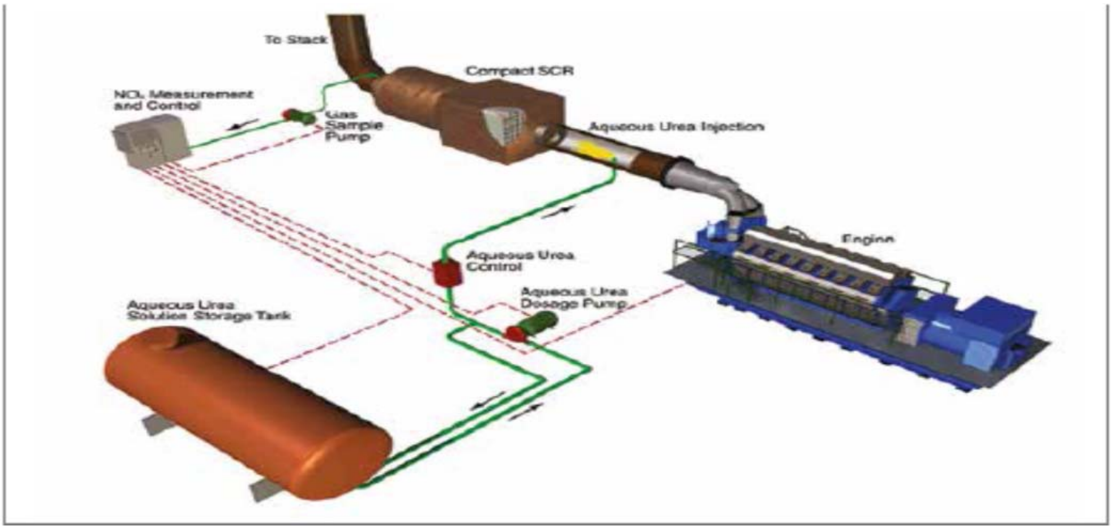


Figure 16: a vapour plume produced by an operating wet scrubber

SCR systems also offer ship-operators a potential fuel saving benefit when operating outside an ECA-NOx, as it is possible to use the SCR to meet Tier II NOx limits. This would allow the engine settings to be adjusted for optimum efficiency (Tier II engines are typically 4 – 4.5% less efficient than Tier I engines), resulting in reduced fuel consumption and lower CO2 emissions. For this the SCR control system would require control set points for operation inside and outside of ECA-NOx. It may be possible to apply this CO2 saving when calculating a ship's EEDI.

1.22.2. SCR systems fitted to four-stroke medium speed engines

The exhaust temperature dictates the position of the reactor containing the catalyst. To date, virtually all marine SCR systems have been installed on four-stroke engines, as there is a sufficiently high exhaust temperature to allow efficient catalyst operation after the turbocharger. In this arrangement the reactor is fitted before any waste heat recovery system. When the SCR is not required, reactors may be run dry without the need for a bypass.

Effective catalytic reduction typically requires an exhaust temperature of over 300oC, but below 500oC to prevent thermal damage to the catalyst. It is possible to run at lower temperatures but the Sulphur content of the fuel needs to be reduced to prevent deposits, which can plug the catalyst. The warming up period after engine start is typically 30 – 90 minutes (unless pre-warming equipment is fitted). This assumes that the engine loading is high enough to heat the SCR to its operating temperature. Extended operation at low loads will result in longer start up times and may result in the SCR not reaching its operating temperature. It is not yet clear how authorities will view ships that are non-compliant during the warming up period. The reactor and mixing duct are installed as integral parts of the engine exhaust system; it is crucial that urea mixes completely with the exhaust gas before entering the SCR reactor.

The catalyst has a finite life and part of the maintenance regime for the SCR should be periodic analysis of catalyst activity. Empirical evidence from oil fired power plant SCR indicate that the two principal elements causing accelerated catalyst deactivation are potassium and sodium. The mechanism for deposit formation involves an undesirable parallel reaction (to the NOx conversion) at the catalyst whereby Sulphur dioxide in the exhaust is oxidized to Sulphur trioxide (SO3), which can then react with ammonia to form ammonium sulphate and bisulphate. Deposits reduce the effective area and shorten the lifespan of the catalyst, with fuel-related hydrocarbon and particulate matter adding to the fouling. As conditions deteriorate, NOx reduction is impaired and more unreacted ammonia will slip past the catalyst. Figure 16 shows clean, partially fouled, and heavily fouled catalyst elements.

Figure 17: SCR arrangement two-stroke low speed engine (Source courtesy of MAN Diesel & Turbo)

Urea and catalyst

Typically, a 40% urea solution is injected as a fine spray into the mixing duct before the catalyst by means of compressed air. Effective dispersion of the urea in the exhaust stream is critical to efficient SCR performance; this may be achieved by suitable injection nozzles, atomizing air, high-pressure injection (typically 25 Bar), duct design, or a combination of all four. The urea converts to ammonia before entering the reactor. Regular cleaning of filters in the urea handling system and the injection nozzles is an important part of the system maintenance requirements. Urea is classed as non-hazardous and can be stored in existing tanks if epoxy-coated. It is used because of the difficulty with the storage and direct handling of ammonia, which is both toxic and corrosive. Using poor quality urea does degrade the performance of the SCR. A standard for Maritime Grade Urea Solution based on work by the European Chemical Industry Council (CEFIC) is available from the International Association for Catalytic Control of Ship Emissions to Air (www.IACCSEA.com).

The rate of urea injection must be sufficient to reduce NOx emissions to the required level but not so great that un-reacted ammonia exits the ship. 15 litres/MWh is typical for a 40% solution. Control is based on the load and speed of the engine with active feedback provided on some systems by NOx and ammonia emissions monitoring. At engine start-up urea injection is initiated once the catalyst reaches operating temperature, which is key for effective NOx reduction performance, deposit prevention and to avoid ammonia slip.

Catalysts have considerable heat capacity so the time taken to reach the injection trigger temperature is dependent on a number of factors including the minimum catalyst operating temperature recommended for the fuel type, the period of cool down since the engine was last operated, the size of the catalyst and the engine load pattern at start-up. Injection can begin up to 30 minutes after a fully cold start, whereas it may begin within 10–15 minutes if the catalyst is still warm from running in the previous 6–10 hours.

There will be similar considerations when entering an ECA-NOx if the reactor has been bypassed, as the catalyst will need to be brought online and reach the required temperature before injection can commence. While these figures are indicative for both pre and post turbocharger catalysts, those fitted before turbochargers on two-stroke engines are relatively more compact and therefore should heat up more quickly.

In marine SCR systems the catalyst is typically made up of porous titanium dioxide (TiO_2) ceramic material in layers of replaceable honeycomb blocks. The high surface area construction acts as a carrier for the catalyst's active compounds such as vanadium pentoxide (V_2O_5) and tungsten trioxide (WO_3). The reactor and blocks can be orientated so the exhaust gas passes either vertically or horizontally, with the former favoured for higher particulate/dust applications. Regular cleaning by compressed air soot blowers or sonic horn is used to reduce fouling of the gas passages and catalyst surfaces. It should be noted that urea injection and soot blowing will likely require the installation of additional air compressor capacity sized for all SCR systems on board. SCR catalyst material is susceptible to fouling, plugging and poisoning:

Fouling is a general deposition of material and is obvious when carrying out a visual inspection. The fouling masks the catalyst, preventing contact between the catalyst surface and the reactants. Fouling can be addressed by soot blowing and should not affect the life of the catalyst.

Plugging does not refer to plugging of the catalyst honeycomb (see figure 17) but rather the plugging of the catalyst pores.

The catalyst is a very porous material, and to work effectively these pores must be open as they give the catalyst a very large contact area with the reactants. Plugging may not be seen during a visual inspection, as it can occur without there being a heavy deposition on the catalyst.

Poisoning refers to chemical attack of the active element of the catalyst. The activity of the catalyst will decay with age but it can be deactivated by attack from phosphorous or alkaline/heavy metals.

Catalyst lifespan depends on a number of factors that result in physical plugging of the catalyst pores, including combustion conditions, engine operating (load) regime, exhaust temperature and fuel sulphur level. In addition 'poisoning' can occur when fuel- and lubricating oil-related compounds in the exhaust are adsorbed onto the catalyst resulting in progressive chemical deactivation. These compounds are formed from alkali metals (sodium, potassium), alkaline earth metals (calcium, magnesium), phosphorus or zinc. Manufacturers may have strict limits on concentrations in the exhaust gas and as such it is important to follow recommendations regarding fuel and lubricating oils. Excessive lubricating oil consumption should be avoided, and certain biofuels, for example, could have a high level of alkali metals/alkaline earth metals.

Typical lifespan figures for catalyst blocks are between two and five years with replacement undertaken by the SCR vendors or authorized contractors. In California spent catalyst elements require specialist disposal because of the vanadium content. Generally, however, the material is not considered to be hazardous; metals are recycled and waste is removed to landfill.

The ongoing monitoring of catalyst condition is important, not only to ensure NOx reduction is maintained but also to make sure that the injected urea is fully utilized to avoid ammonia slip. Emissions monitoring can also be utilized; increased urea feed to obtain the required NOx reduction indicates a loss of catalyst efficiency, as does an increase in un-reacted ammonia at the catalyst outlet.

1.23. Secondary compliance techniques for NOx and SOx – Common challenges

1.23.1. Flexibility

One of the benefits of exhaust gas treatment systems (EGTS) is that they offer operational flexibility. A SOx scrubber allows an operator to choose between meeting emission limits by using low-sulphur fuels or by using the SOx scrubber to clean the SOx from the exhaust gas. NOx treatment systems will offer ships constructed after 1

January, 2016, the flexibility to operate inside ECA-NOx (see section 2.3). They allow the engine to run at peak thermal efficiency because the resulting high NOx emissions are reduced after combustion.

1.23.2. The risk of non-compliance

If you are using an EGTS to comply with emissions regulations, you should consider the likelihood and consequences of it failing. The likelihood of failure will depend on the reliability of the system components and the redundancy included in the system's design. Building in redundancy reduces the likelihood that the system as a whole will fail. For example, designing a wet SOx scrubber with three pumps each capable of meeting 50% of the wash water pump demand or with two pumps each capable of meeting 100% of the wash water pump demand would allow the scrubber to continue to operate in the event of a single pump failure. Other areas where redundancy can be built in include the exhaust gas and wash water monitoring systems. It is worth noting that the integration of multiple exhaust streams into a single scrubber does exacerbate the consequences of the system failing.

The consequences of an EGTS failure will depend on whether your ship can use an alternative means to comply with the requirements. For example, in the event of a main engine SOx scrubber failing, you may be able to bypass the scrubber and use compliant fuel. You will need to make sure that enough compliant fuel is stored on board. If no compliant fuel is available, the ship will no longer be able to comply.

How flag and port states will respond in the event that a ship cannot comply is not yet apparent, but one possible outcome would be to require the ship to sail to the nearest port until either the EGTS has been fixed or an alternative method of compliance is available. The commercial consequences of the resulting delay will depend on the ship's trading pattern. Understanding the likelihood and consequences of a failure of an EGTS will allow you to make informed decisions about the amount of redundancy to be designed into the system.

1.23.3. Backpressure

Engine manufacturers include a permitted range of exhaust backpressures within the technical specifications of their engines – operating outside this range may lead to accelerated wear, greatly reduced maintenance intervals, reduced power and increased fuel consumption. In addition, an engine's NOx Technical File may also specify a range of permissible backpressures – operating outside this range will invalidate the engine's NOx approval.

EGTS intrinsically increase backpressure and system designers need to understand the impact of this on the engine. If the EGTS will increase backpressure to a level outside allowable operating limits, it may be reduced by adding an induced draft fan (ID fan) into the exhaust duct (see Figure 18). Although fitting an ID fan to control backpressure is technically straightforward this clearly increases the electrical load of the EGTS and increases the footprint of the EGTS in the uptake space. For some ships these two factors will make use of an ID fan unattractive.

The main concern with excessive backpressure is that it will result in reduced engine power output. If this happens, it will be obvious and can be rectified during the EGTS installation and commissioning period. Perhaps a more serious problem is a slight increase in backpressure above the allowable limits, as there is unlikely to be an obvious change in engine performance and the problem may remain hidden.

Buildup of deposits within the EGTS components (for example soot clogging of demisters or deposits on SCR catalysts) will increase backpressure while the ship is in operation. Monitoring the pressure differential across the EGTS will indicate if cleaning is required. Some of these deposits can present a significant health and safety risk to people entering the EGTS to carry out maintenance and cleaning activities.

Figure 18: ID fans in exhaust ducts (Source courtesy of Hamworthy-Krystallon)

1.23.4. EGTS bypass

A bypass provides an alternative path for the exhaust gas so that it avoids the EGTS. When the bypass is 'closed' exhaust gas will pass through the EGTS and when it is 'open' the exhaust gas will exit the ship without passing through the EGTS. Some wet SOx scrubbers are designed to 'run dry' whereas others may be damaged if hot exhaust gas is passed through them while they are not operating. For systems not designed to run dry, the bypass damper can be interlocked with the EGTS controls to provide a failsafe protection.

Opening the bypass when the EGTS is not operating will prevent a build-up of soot and unburned hydrocarbons within the system. When the bypass is open it might also be possible to undertake maintenance of the EGTS while the associated engine (or engines) is running (although care should be taken as the bypass damper is not a secure way of isolating the EGTS chamber).

The risk of using a bypass is that leakage past the bypass valve may cause the ship's emissions to exceed the limits. Because of the corrosive properties of SOx-laden exhaust gas, and the particular conditions associated with bypass arrangements, it is critical to ensure that materials are reliable and durable. There is also a risk in service that unless bypass valves are exercised regularly they will stick and not operate when needed.

Class does not require EGTS bypass valves to be fitted unless the EGTS is not suitable for operating in a hot and dry condition.

1.23.5. Exhaust gas velocity

The introduction of EGTS may slow the exhaust gas and any cooling will slow it down further. Consequently, to ensure the exhaust gas clears the ship, the exhaust duct outlet may have to be redesigned to increase the velocity of the gas as it exits the funnel. While relevant to all ships, this is particularly important for cruise ships and ferries. Care must be taken to ensure that the resulting increase in backpressure is acceptable.

1.23.6. Integration of multiple combustion devices

It is possible to combine the exhausts from a number of different combustion devices into a single EGTS. This may be necessary due to space restrictions, or simply to reduce the cost of the installation. Combining exhausts is uncommon within the

marine industry where typically each engine has its own independent intake and exhaust. Concerns arising from
combining exhausts include: backflow of exhaust gas into the exhaust duct of combustion devices that are not operating increased backpressure when two or more combustion devices are combined that have different exhaust gas flow characteristics; and designing the EGTS to operate effectively over a wide range of exhaust gas flow rates.

Dampers might be required for each exhaust to preclude the back flow of exhaust gas into the exhaust of combustion devices that are not operating. Monitoring is required to confirm that the backpressure on each device remains within allowable limits.

If you plan to integrate diesel engine exhaust arrangements with boiler exhaust arrangements, controlling backpressure is especially critical. This is due to the very different sensitivities of engines and boilers to exhaust backpressure.

1.23.7. Maintenance, crew training and workload

It is important to understand the impact of EGTS maintenance on system availability. For instance, annual inspection and cleaning of an SCR chamber will result in the SCR system not being available for a period of time, which may impact the availability of the ship to operate in an ECA-NOx. You will either need to schedule cleaning while the ship is operating in locations where the SCR system is not required, or you might need to take the ship out of service.

Hazardous chemicals are used in a number of EGTS and adequate controls should be put in place to protect ships' staff.

There is also a possibility of further hazardous chemicals and compounds (such as ammonium bi-sulphate in SCR systems) being generated. These will require robust procedures and crew training, as well as adequate signage and personal protective equipment (PPE).

Crew training should cover the normal operation of the EGTS, including bunkering of any chemicals (consumables), calibration of sensors and routine maintenance, as well as the procedures to be followed in case of system failure and deviation from normal operation. You should be aware that not all crew members will be familiar with basic chemical handling requirements and that all crew members should be provided with training specific to the chemicals, substances and effluents associated with the EGTS to be installed on board.

The additional workload associated with system operation and maintenance should be assessed. If it is significant, measures may need to be implemented to prevent crew fatigue.

1.23.8. EGTS Class approval requirements

As with most shipboard equipment installed to meet a regulatory requirement, EGTS require both statutory certification (issued by, or on behalf of, a flag administration) to show that the equipment meets the required performance criteria, and classification society approval (class approval) to show that the equipment does not present an unacceptable risk to the ship and the essential equipment required for the ship's continued operation. There are a number of different statutory and class approvals associated with exhaust gas treatment systems and their ship-specific installation. In addition to these formal approvals, equipment manufacturers and operators may also wish to undertake independent verification of the performance of either a given equipment design (Type Approval) or the performance of a ship-specific installation (verification of performance).

1.23.9. Statutory approval requirement.

Table 3 below shows the statutory approval requirements for EGTS. These are described in more detail in Appendices B1and B2.
Scheme A statutory approval of SOx scrubbers is sometimes referred to as 'type approval Note: this is different to Lloyd s Register Type Approval, described in section 7.9.1, which involves independent verification of performance against standards specified by the equipment manufacturer.
For statutory approval, the equipment manufacturer should provide equipment with all of the approved documentation required to demonstrate compliance.

Statutory – flag state ship specific approval	
SOx scrubber Continuous	IMO MEPC 184(59) – 2009 Guidelines for Exhaust Gas Cleaning Systems
	Scheme A: Technical and Operating Manuals including SECP Initial shop or onboard test of scrubber Daily monitoring of SO2/CO2 Continuous monitoring of key operating parameters Content monitoring of washwater
	Scheme B: Technical & Operating Manuals including SECP No shop or onboard test of scrubber Continuous onboard monitoring of SO2/CO2 Daily monitoring of key operating parameters Continuous monitoring of washwater
	Deliverable: Approved documentation (including Scheme A Certificate if applicable) and post-installation Initial Survey.
NOx-reducing device	Engine specific – certified entity is ‘engine + device
	Reviewed against NOx Technical Code 2008
	Technical File (including Onboard NOx Verification Procedure) Engine group / family certification Pre-certification Survey
	Deliverable: ‘engine + device’ certificate supported by approved documentation and post-installation Initial Survey

Table 3: Statutory approval requirements for EGTS

1.23.10. LR Class approval requirements

EGTS to be installed on board LR classed ships must comply with the applicable LR Rules. Specific Rules for EGTS are included within Part 5, Chapter 24 of the LR Rules for Ships and Volume 2, Part 12 of the LR Rules for Naval Ships. These rules are intended to ensure that EGTS are comprehensively and consistently approved, and provide stakeholders with information on Lloyd s Register's requirements.

The approval includes the EGTS design, installation on board and any chemical handling arrangements. The approval is a combination of a document review and onboard survey. It focuses on the system's impact on ship safety and covers ship specific piping installations, electrical and control installations, and structural modifications.

LR Class approval is intended to protect the reliability of essential systems and to ensure that the EGTS is safe to operate. LR Class approval does not consider environmental performance or operational aspects. In particular, system redundancy and EGTS durability are outside of class approval; you will need to consider your own requirements for redundancy, durability and longevity. We provide consulting services to help define EGTS system requirements and provide additional assurance beyond class rules compliance. Independent verification

1.23.11. Lloyd's Register Type Approval

LR's Type Approval service provides equipment manufacturers with independent confirmation of the performance of their products. It applies to series production of equipment whose critical components remain unchanged; typically, products are surveyed on a sample basis (as opposed to surveying every unit). The scope of the approval is specified by the equipment manufacturer and agreed by LR. For EGTS the scope of the Type Approval might include one or more of the following:

Compliance with statutory requirements (performance standard)

Class approval (to confirm that the unit complies with applicable LR class rules)

Compliance with specified maintainability and durability standards.

To apply for Type Approval the equipment manufacturer submits documents and plans and, depending on the scope of the approval, performance tests may also be required. As Type Approval does not follow a defined scope it is important to note what the equipment-specific Type Approval documents state; Type Approval is not a panacea. Note: aspects such as EGTS functionality, reliability and durability are not included within any of the statutory approvals or class approval of EGTS.

1.23.12. Verification of performance survey

LR can also provide independent verification of EGTS in-service performance. This service is delivered by exhaust emissions specialists experienced in exhaust gas measurement, analysis and legislative interpretation, who are familiar with working on board ships.

Chapter 2.

EU & US EPA transport funding programs and financial support to green maritime-based projects

2.0. EU & US EPA TRANSPORT FUNDING PROGRAMS AND FINANCIAL SUPPORT TO GREEN MARITIME-BASED PROJECTS.

New environmental rules on marine fuels, entering into force, will substantially reduce air pollution and its impacts on human health. Air pollutants from maritime shipping are transported over long distances and as a result contribute increasingly to the air quality problems in many European cities.

Without any action, Sulphur emissions from shipping in EU sea areas would exceed those from all land-based sources by 2020. The revised legislation will put an end to this trend reducing not only Sulphur emissions but more importantly particulate matter, marking a clear step forward in protection of people's health and the environment.

The Directive entering into force is guided by standards developed at the International Maritime Organization (IMO). It progressively reduces the maximum Sulphur content of marine fuels from the current 3.5% to 0.5% by January 2020. In some very fragile ecosystems such as the Baltic Sea and the North Sea including the English Channel, the maximum Sulphur content will be reduced to 0.1%, already in 2015.

As an alternative to low Sulphur fuels, ships can opt for equivalent compliance methods such as exhaust gas cleaning systems or LNG-powered ships. Current EU transport funding instruments, such as TEN-T and Marco Polo Programmed, as well as the European Investment Bank (EIB) give financial support to green maritime-based projects.

Furthermore, the

Commission has launched activities that encourage the use of marine LNG as ship fuel. It will also continue to implement medium- and long-term measures to promote green ship technology, alternative fuels and the development of green transport infrastructure in the context of the Sustainable Waterborne Transport Toolbox, jointly with industry and Member States.

This Directive is the latest element of the EU policy framework on air pollution which has been developed over the last 30 years. The European Commission is currently carrying out a comprehensive review of the policy framework with a view to updating it in 2013.

2.1. TEN-T EU program

The TEN-T Program was established by the European Commission to support the construction and upgrade of transport infrastructure across the European Union.

The TEN-T Program dedicated financial support towards the realization of important transport infrastructure projects - in line with the overreaching goal of European competitiveness, job creation and cohesion.

The TEN-T Executive Agency, created by the European Commission in 2006, managed the Programme on behalf of the European Commission for all projects established under the 2000-2006 and 2007-2013 funding schemes. The projects represent all transport modes – air, rail, road, and maritime/inland waterway – plus logistics and intelligent transport systems, and involve all EU Member States.

On 1 January 2014 the TEN-T EA became the Innovation and Networks Executive Agency (INEA), but management of all open TEN-T projects continues unaffected.

TEN-T (Trans-European Transport network,). Projects

The TEN-T Programme consists of hundreds of projects – defined as studies or works – whose ultimate purpose is to ensure the cohesion, interconnection and interoperability of the trans-European transport network, as well as access to it. TEN-T projects, which are located in every EU Member State, include all modes of transport:

- road
- rail
- maritime
- inland waterways
- air
- logistics
- co-modality
- innovation

30 Priority Projects (or Axes) and other horizontal priorities have also been established to concentrate on pan-European integration and development.

As a whole, TEN-T projects aim to:

- Establish and develop the key links and interconnections needed to eliminate existing bottlenecks to mobility

- Fill in missing sections and complete the main routes - especially their cross-border sections
- Cross natural barriers
- Improve interoperability on major routes

Some of the TEN – T Funding project running at present:

2.1.1. Pilot deployment of emissions reduction technologies on general cargo vessels on North Sea and Baltic MoS corridors.

This pilot project will install and test the latest scrubber technology that uses sea water instead of fresh water in an open loop to reduce the sulphur emissions on maritime transport in compliance with new EU Regulations. The new cleaning system is expected to bring a number of economic and environmental benefits: ships will no longer need to carry supplies of fresh water or transport/use chemicals for water treatment. In addition, more space will be available for cargo.

The latest scrubber technology will be tried out on three different types of cargo ships, which all together represent the most common general cargo vessels in the water trade routes of the North and Baltic Seas. The project results will be shared with key transport stakeholders and decision makers, and could facilitate introduction of the technology at EU level, enhancing the competitiveness of short sea transport compared to other modes.

2.1.2. Biomethane and LNG in the North for growth and competitiveness in EU (BioGaC)

The study covers the pilot deployment of two new CNG (compressed natural gas) filling stations in Härnösand and Umeå, as well as improves existing stations at Sundsvall and Skellefteå in northern Sweden. The aim is to increase the number and density of the CNG filling stations, encourage the use of CNG and create a market opportunity for CNG/LNG (liquefied natural gas) investors.

The project's results will be used to develop best practice for new actors in the CNG market and support decision-making for other possible CNG filling stations. The project will also provide solutions on how to accelerate market development of both CNG and LNG infrastructure along the roads in specific regions where the distance between urban centers and gas distribution grids is too long, or where such a grid does not exist

2.1.3. Monalisa 2.0

Project objectives

MONALISA 2.0 takes its point of departure in the results and experiences from the ongoing MONALISA project (2010-EU-21109-S), co-financed by TEN-T under the Motorways of the Sea Programme. MONALISA 2.0 will re-use the results and experiences from the development within the aviation sector and its SESAR (Air Traffic Management) Programme, which has been strongly supported by the European Union through the Framework Programmed and TEN-T during the past decade.

The overall objective of MONALISA 2.0 is to strengthen efficiency, safety and environmental performance of maritime transport, at the same time as the administrative burden of the maritime sector will be reduced.

Nine Member States are involved in the studies, which include:

- Testing concrete applications and services which would allow short-term commercial deployment for the navigational part of Sea Traffic Management
- Taking joint private-public action to elaborate better standards for maritime route exchange through a common interface and data format
- Demonstrating concrete services using new technology to enhance maritime safety, making search and rescue and mass evacuations more efficient than today and by addressing port safety
- Transferring the results of previous EU investments in air traffic management and other sectors into the maritime sector
- MONALISA 2.0 will be beneficial to maritime transport world-wide and the ongoing work within IALA, IMO and EU.

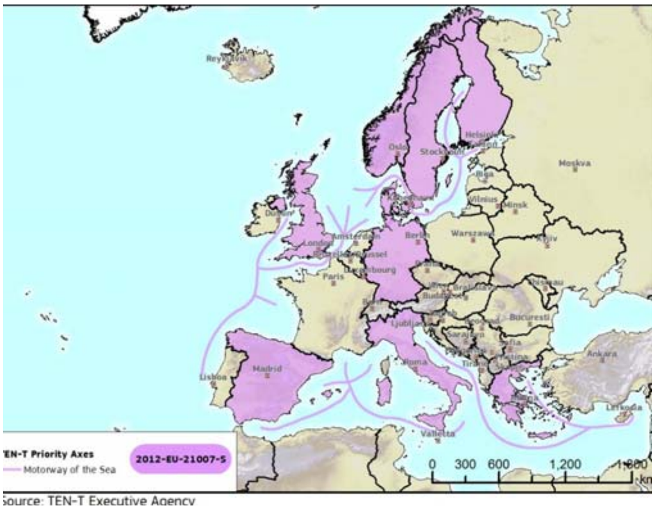


Figure 19: Countries affect Mona Lisa (Source TET T)

Member States involved:

- Sweden, German, Italy, Greece, Spain, United Kingdom, Denmark, Malta, Finland, Italy

Implementation schedule Start date: January 2012 End date: December 2015

Budget:

- Action promoter: €12,158,000
- Total project cost covered by this Decision: €24,316,000 EU contribution: €12,158,000 Percentage of EU support:
- Studies: 50%

2.1.4. Sustainable Maritime Transport with LNG between Greek mainland and islands in the Archipelagos (ARCHIPELAGO-LNG).

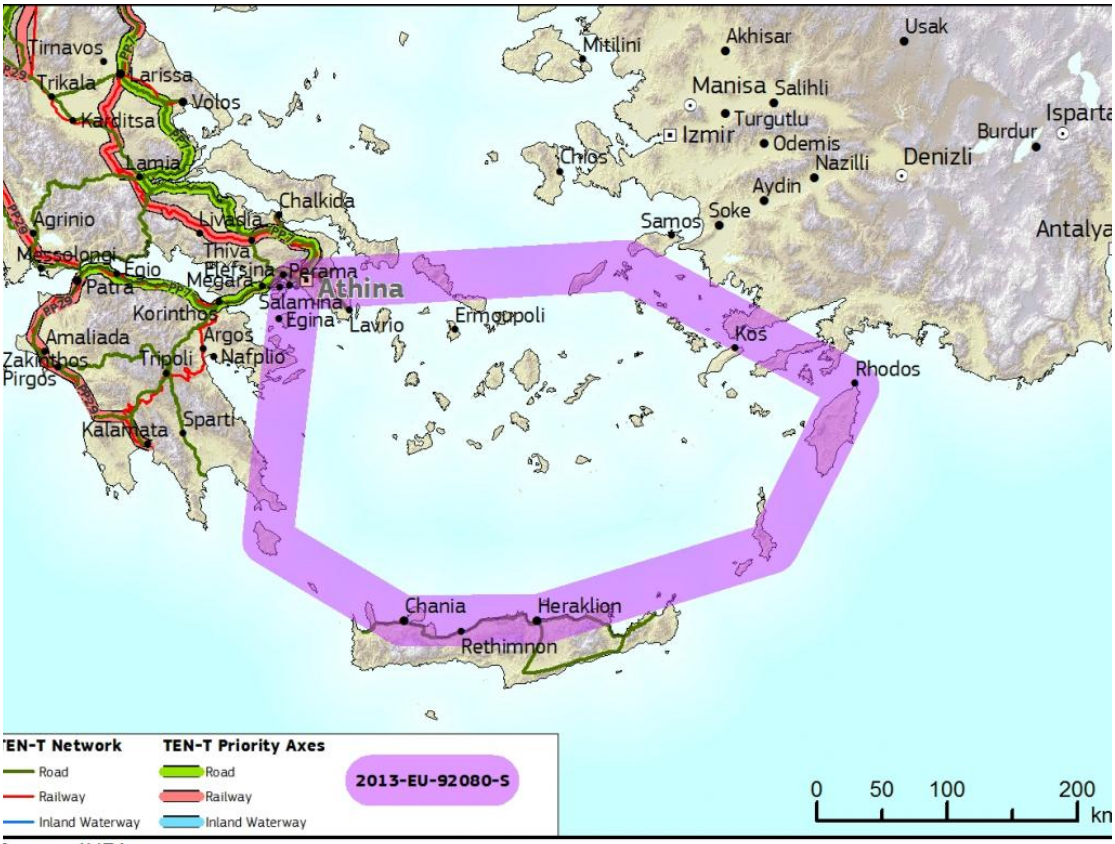
Project objectives

This project covers a study aiming to promote the use of LNG (liquefied natural gas) as a marine fuel in the passenger and shipping sectors of the Greek islands, in order to reduce supply costs and the environmental impact of oil derivative-based fuels. The main objective is to motivate and to provide the Greek authorities with the necessary tools in order to adopt a regulatory framework for the bunkering of gas-fueled (LNG) ships in the region by:

Identifying the key technical and economic framework of small-scale LNG as marine fuel value chain in South Aegean, e.g. main supply chain options, required retrofits and infrastructure in ports, ships and shipyards, business plans for each operator

Providing legislative recommendations to the Greek authorities with regards to the technical and financial aspects of the LNG supply chain in the island regions, using the South Aegean region as a reference

The project will bring together key Greek stakeholders representing a cross-section of the LNG as marine fuel supply chain - including national ministerial and regional authorities, LNG suppliers, ship owners/operators and shipyards, supported by academic/research institutes.



Source: INEA

Figure 20: Area oriented for the Archipelago project (Source INEA)

Member States involved:

- Greece

Implementation schedule

- Start date: October 2014
- End date: December 2015 Budget:

Project Promoters:

- €573,090 Total project cost covered by this Decision:
- €1,146,180 EU contribution:
- €573,090 Percentage of EU support:

Studies: 50%

2.1.5. Costa II East - Poseidon Med

This project, part of TEN-T Priority Project 21(Motorways of the Sea), is direct continuation of the COSTA project (2011-EU-21007-S) that aimed at developing a global strategy for the promotion of LNG (liquefied natural gas) as marine fuel. It also looked at how LNG could be an efficient and effective solution to the problem of emissions abatement in the Mediterranean, which enters into force on 1 January 2020.

COSTA II focuses on the eastern Mediterranean region/sea with five Member States (Greece, Cyprus, Italy, Croatia, Slovenia) in order to prepare a detailed infrastructure development plan promoting the adoption of LNG as marine fuel for shipping operations. It will design a LNG transport, distribution, and supply (including bunkering) network and infrastructure and define the framework for a well-functioning and sustainable relative market (vessels) for its demand. It has the following four objectives, namely to:

1. Study the establishment of a comprehensive LNG network (sources and destinations) in the East Mediterranean area (including the Adriatic)
2. Investigate all of the necessary activities to develop a sustainable market for LNG as marine fuel in the aforementioned Member States
3. Revive shipping in the area and increase fleet competitiveness, efficiency, and sustainability
4. Serve and satisfy EU/TEN-T objectives with respect to emission reduction, increased efficiency and competitiveness of EU shipping, in order to ensure and strengthen the accessibility to all areas of the Comprehensive Network, diversify EU energy supply sources, create new employment opportunities, and promote the mobility of people and goods in a safe and socially responsible way.

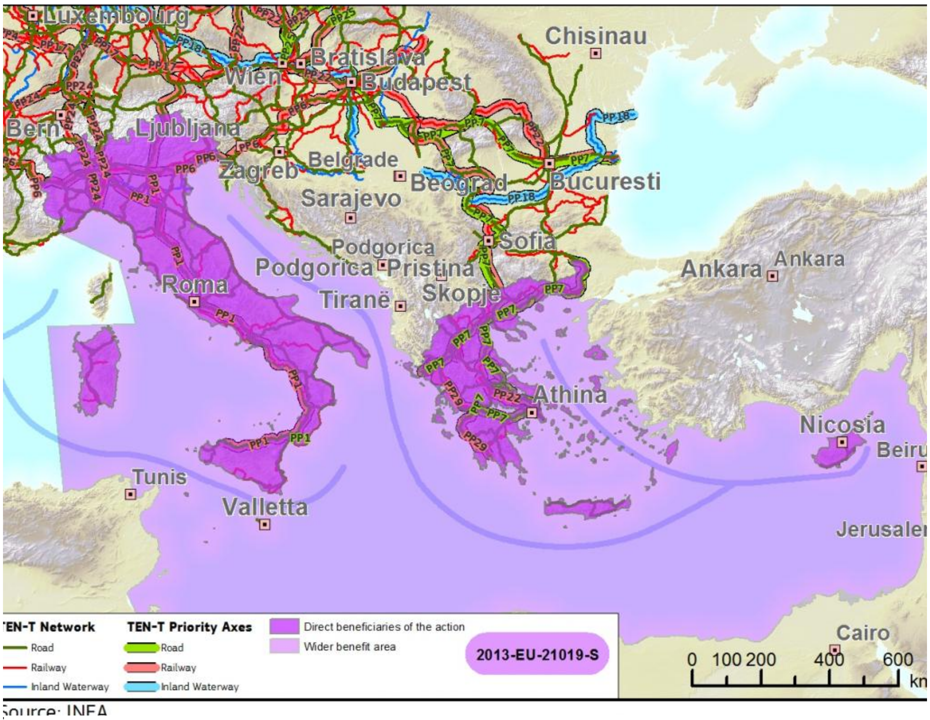


Figure 21: Countries and areas participating to Poseidon Med

Member States involved:

Croatia, Cyprus, Greece, Italy, Slovenia

Implementation schedule

Start date: December 2013

End date: December 2015

Budget: Project promoter: €2,563,125

Total project cost covered by this Decision: €5,126,250

EU contribution: €2,563,125

Percentage of EU support: Studies: 50%

2.1.6. Marco Polo Programme

The Marco Polo Programme aims to ease road congestion and the pollution it causes by promoting a switch to greener transport modes for European freight traffic. Companies with viable projects to shift freight from roads to greener modes can turn to Marco Polo for financial support.

Marco Polo co-funds direct modal-shift or traffic avoidance projects and projects providing supporting services which enable freight to switch from road to other modes efficiently and profitably. Funding is in the form of an outright grant. It is not a loan to be repaid later. Applicants must meet a series of conditions to obtain a grant. Grants cover a share of costs associated with the launch and operation of a new modal-shift project, but must be supported by results.

2.2. US Environmental Protection Agency Funding for Projects to Improve Air Quality at Ports

The Ports Program is an EPA initiative with goals to reduce air pollution and greenhouse gases, to achieve environmental sustainability for ports, and improve air quality for near-port communities. EPA is receiving recommendations and input from the MSTRS, CAAAC, and others to guide the future development of the program.

2.2.1. FASTLANE Program

The FASTLANE program provides dedicated, discretionary funding for projects that address critical freight issues facing our nation's highways and bridges. It is also in line with the Department's draft National Freight Strategic Plan released in October

2015, which looks at challenges and identifies strategies to address impediments to the efficient flow of goods throughout the nation.

2.2.2. Clean Diesel and DERA funding

The Clean Diesel Program offers DERA funding in the form of grants and rebates as well as other support for projects that protect human health and improve air quality by reducing harmful emissions from diesel engines.

Chapter 3

Introduction to LNG as a Marine Fuel and Existing vessel retrofitting

Scenario: Ropax vessel modification retrofitting of dual fuel engine (ME-GI) for using LNG as fuel.

3.0. Introduction to LNG as a Marine Fuel and Existing vessel retrofitting Scenario: Ropax vessel modification retrofitting of dual fuel engine (ME-GI) for using LNG as fuel.

The scope of this part of the thesis is to highlight the difficulties that have to be addressed in order to incorporate an LNG solution on board an existing vessel. This thesis will try to bring all the difficulties of this endeavor and will analyze the possible methods and technical solutions.

The Scenario will include all aspects of design, equipment selection, works on board Class approval in accordance with the latest Rules and Regulations.

We will bring all the problems that have to be huddled and we will provide some draft drawings from relevant vessels as an example of the each solution.

A real case is going to help us to understand the relevant topics. The cruise ferry of Greek ownership, flying the Greek flag and serving a domestic route is the subject vessel. Her Owner, is of keen interest to investigate the LNG solution as marine fuel and happily made their flagship available for this scope of work. The concept design of LNG retrofit for this vessel is under evolution since the beginning of the year within the frame of the EU co-founded program Costa II East Poseidon Med 2013–Eu–21020-S.

3.1. Natural gas as a marine fuel, the very basics.

3.1.1. What is LNG?

Liquefied natural gas, or LNG, is natural gas that has been cooled sufficiently to condense into a liquid. At atmospheric pressure, this happens at a temperature of -162°C (-260ºF). As the natural gas condenses, about 600 volumes of gas become one volume of liquid. This makes it commercially feasible to transport large volumes of gas in a ship. The LNG is generally regasified by heating at its destination before being fed into a pipeline grid.

LNG is a mixture of hydrocarbons, predominately methane (80 – 95%). Other significant components include other alkanes – ethane, propane and butane. Nitrogen may also be present at levels up to 1%. All the more complex hydrocarbons, along with carbon dioxide and Sulphur compounds, are removed to trace levels during production

Physical properties LNG, a colourless and odourless liquid, burn only when in its vapour state. It's very low temperature means that at ambient temperature the liquid is always boiling and creating vapour. The vapour is heavier than air until it warms to about -110°C. The vapour is colourless but can be seen as it mixes with air because water vapour in the air is condensed by the coldness of the warming natural gas. The result is a white cloud. How is LNG made and where does it come from? LNG is produced using a physical process: natural gas is compressed to 50 – 80 times atmospheric pressure and then cooled from ambient temperature until it liquefies.

LNG industry overview

Some 237 million tons of LNG were traded worldwide in 2013. Japan was by far the biggest importer (88 million tons) followed by South Korea (40 million tonnes) and China (19 million tons). Virtually all the LNG produced was used for electricity generation, industrial and commercial gas use, and by residential customers. Statistics show that about 5 million tonnes per year of LNG is transported by road tanker from bulk import terminals and small LNG producers around the world. Road transportation is most common in China, Spain, Turkey and the USA. Most of this LNG is consumed by large industrial users and power plants that do not have access to a gas pipeline network. The use of LNG as a fuel has expanded significantly in recent years but volumes are still relatively small.

Most transportation fuel is used by heavy-duty trucks or to fast-fill cars with compressed natural gas. The gas-fuelled shipping fleet is also expanding rapidly, particularly in Scandinavia. Using LNG to fuel railway locomotives is being trialled in the USA and Canada, while Australian miners and American shale gas/ oil producers are replacing diesel with LNG.

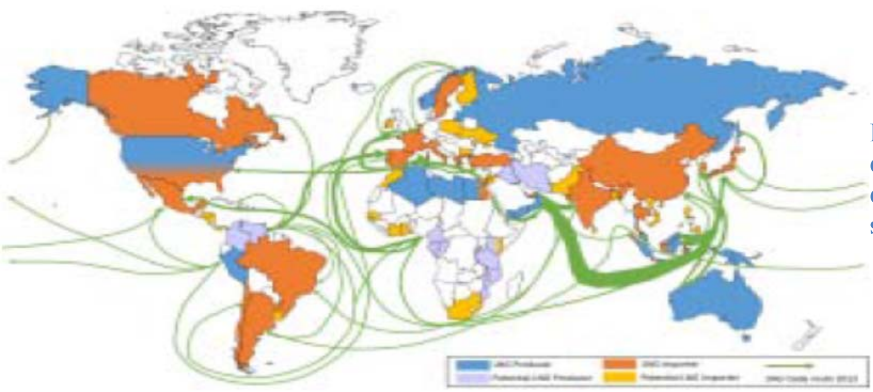


Figure 22: Bulk international LNG trade during 2013 with the arrows showing direction of flow and their size showing the scale of the trade.

MEPC 70(October 2016), IMO sets 2020 date for ships to comply with low sulphur fuel oil requirement.

In a landmark decision for both the environment and human health, 1 January 2020 has been set as the implementation date for a significant reduction in the sulphur content of the fuel oil used by ships.

The decision to implement a global sulphur cap of 0.50% m/m (mass/mass) in 2020 was taken by the International Maritime Organization (IMO), the regulatory authority for international shipping, during its Marine Environment Protection Committee (MEPC), meeting for its 70th session in London.

It represents a significant cut from the 3.5% m/m global limit currently in place and demonstrates a clear commitment by IMO to ensuring shipping meets its environmental obligations.

IMO Secretary-General Kitack Lim welcomed the decision which he said reflected the Organization's determination to ensure that international shipping remains the most environmentally sound mode of transport.

"The reductions in Sulphur oxide emissions resulting from the lower global Sulphur cap are expected to have a significant beneficial impact on the environment and on human health particularly that of people living in port cities and coastal communities, beyond the existing emission control areas" Mr. Lim said.

Further work to ensure effective implementation of the 2020 global sulphur cap will continue in the Sub-Committee on Pollution Prevention and Response (PPR).

Regulations governing Sulphur oxide emissions from ships are included in Annex VI to the International Convention for the prevention of Pollution from ships (MARPOL Convention). Annex VI sets progressive stricter regulations in order to control emissions from ships, including Sulphur oxides (SOx) and nitrous oxides (NOx) - which present major risks to both the environment and human health.

The date of 2020 was agreed in amendments adopted in 2008. When those amendments were adopted, it was also agreed that a review should be undertaken by 2018 in order to assess whether sufficient compliant fuel oil would be available to meet the 2020 date. If not, the date could be deferred to 2025. That review was completed in 2016 and submitted to MEPC 70. The review concluded that sufficient compliant fuel oil would be available to meet the fuel oil requirements.

Under the new global cap, ships will have to use fuel oil on board with a Sulphur content of no more than 0.50% m/m, against the current limit of 3.50%, which has been in effect since 1 January 2012. The interpretation of "fuel oil used on board" includes use in main and auxiliary engines and boilers. Exemptions are provided for situations involving the safety of the ship or saving life at sea, or if a ship or its equipment is damaged.

Ships can meet the requirement by using low-Sulphur compliant fuel oil. An increasing number of ships are also using gas as a fuel as when ignited it leads to negligible Sulphur oxide emissions. This has been recognized in the development by IMO of the International Code for Ships using Gases and other Low Flashpoint Fuels (the IGF Code), which was adopted in 2015. Another alternative fuel is methanol which is being used on some short sea services.

Ships may also meet the SOx emission requirements by using approved equivalent methods, such as exhaust gas cleaning systems or "scrubbers", which "clean" the emissions before they are released into the atmosphere. In this case, the equivalent arrangement must be approved by the ship's Administration (the flag State).

The new global cap will not change the limits in SOx Emission Control Areas (ECAS) established by IMO, which since 1 January 2015 has been 0.10% m/m. The ECAs established under MARPOL Annex VI for SOx are: the Baltic Sea area; the North Sea area; the North American area (covering designated coastal areas off the United States and Canada); and the United States Caribbean Sea area (around Puerto Rico and the United States Virgin Islands).

3.1.2. LNG bunkering facilities

LNG is available for marine fuel use in the European ports of Antwerp, Amsterdam, Rotterdam, Stockholm and Zeebrugge. LNG can also be bunkered at the Norwegian ports of Bergen, Florψ, Karmψy, Oslo and Risavika/Stavanger. In most cases this is by road tanker; however in Bergen there is a dedicated terminal and Stockholm has a bunker vessel called Seagas that provides LNG fuel. Ports in Finland, Italy and Spain have also loaded LNG as bunker. All these ports are able to offer LNG to prequalified vessels that are compatible with the LNG-loading infrastructure. EU policy is to have at least one LNG bunkering port in each member state. About 10% of European coastal and inland ports will be included, a total of 139 ports. Coastal port LNG infrastructure will be completed by 2020 and for inland ports by 2025. To date

Denmark, Estonia, Finland, France, Germany, Norway, Spain, Sweden and the UK are considering where to locate LNG bunkering facilities. There are several ports under development in North America, mostly in the Gulf of Mexico and around the Great Lakes, but also for ferry operations on the west coast South Korea is able to offer LNG bunkering in the port of Incheon and is looking at a second facility at Busan. Elsewhere in Asia, Singapore, Japan and China are looking at LNG bunkering facilities.

3.2. Type of LNG fuel Engines and what are the main parts in a LNG fuel systems:

3.2.1. Low Pressure Consumers:

3.2.1.1. 4-Stroke combustion engines Dual Fuel

Hybrid Otto-Diesel cycle

1. Gas mode - Otto cycle, pilot diesel ignition
2. Diesel mode - Diesel cycle, standard operation

•Automatic Changeover

•Start-up / stop on fuel oil

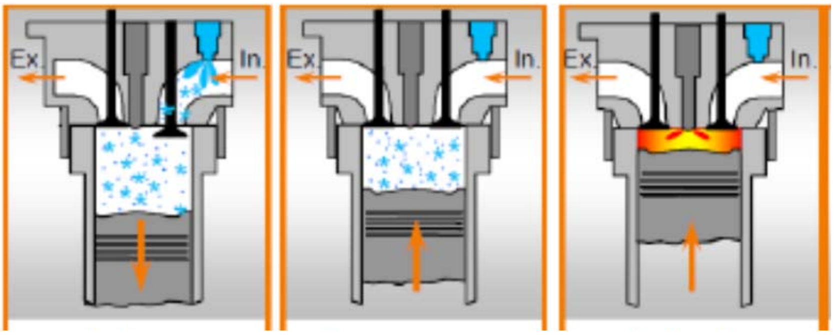


Figure 24: Gas mode (Source Wartsilla)

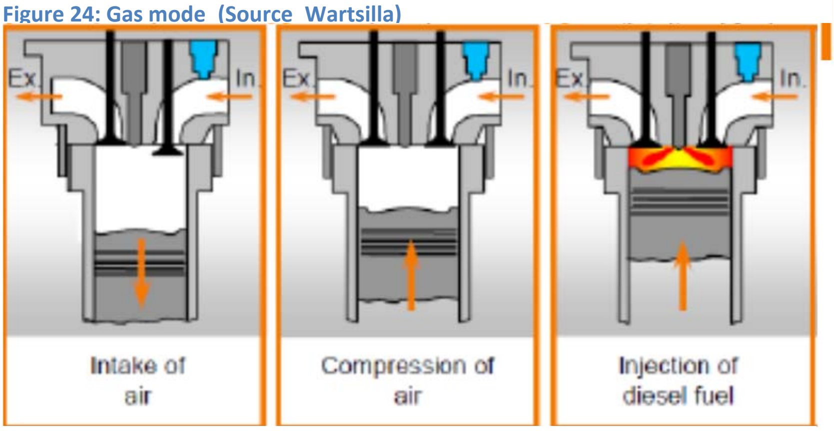


Figure 25: Diesel mode (Source wartsilla)

3.2.1.2. Wartsila duel-fuel (DF) engines

• Runs on gas with 1% diesel (gas mode) or 100% diesel (diesel mode)

Automatic changeover:

• Instant trip to diesel mode on alarm without loss of power and speed

• Trip to diesel mode after 3 minutes at loads below 15%

• Diesel mode on request at any load without loss of power and speed

Figure 26: Wartsila duel-fuel (DF) engines_(Source Wartsilla)

3.2.1.3. 4-Stroke Combustion Engines (pure gas)

- Pure Gas
- Otto Cycle
- Spark ignition
- Redundancy required in gas supply / storage Single fault should not lose propulsion. Single fault should not lose propulsion.

Quiz: What are the safety advantages/disadvantages of dual fuel vs single fuel?

➢ Single Can only operate in locations with existing gas / LNG supply

➢ Dual can Immediately change over to liquid fuel on command or for various fault conditions

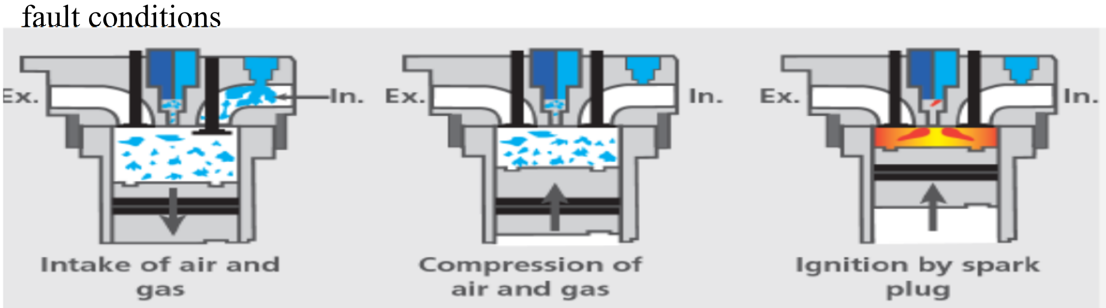


Figure 27: Ignition procedure (Source Wartsilla)

3.2.1.4. Rolls Royce Pure Gas Engine

- **Methane number 70 or higher without de-rating (DF ≥ 80)**
- **Lower pressure operation than DF**
- **Reduced knocking**

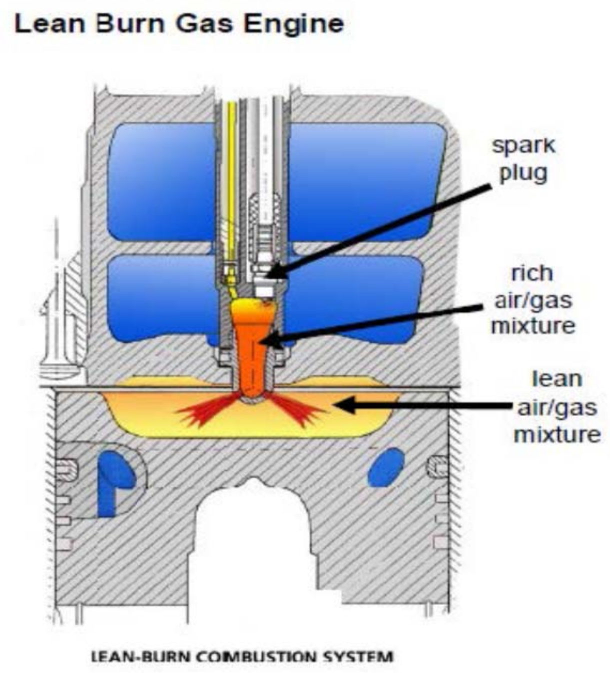


Figure 28: Rolls Royce Pure Gas Engine_(Source_ Rolls Royce)

3.2.2. Gas Turbines main Characteristics

GE Marine turbines

- Space efficient (higher energy density)
- 42% thermal efficiency
- Fewer moving parts
- Modular system
- Installation flexibility diesel-electric system

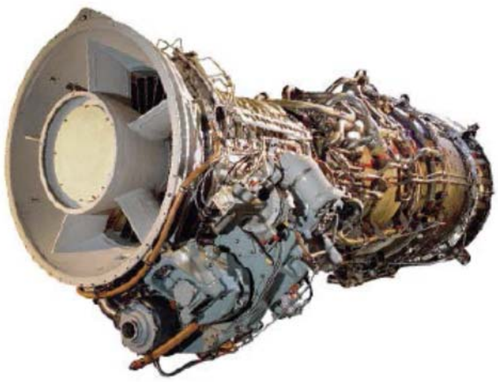


Figure 29: Gas turbine_(Source MAN)

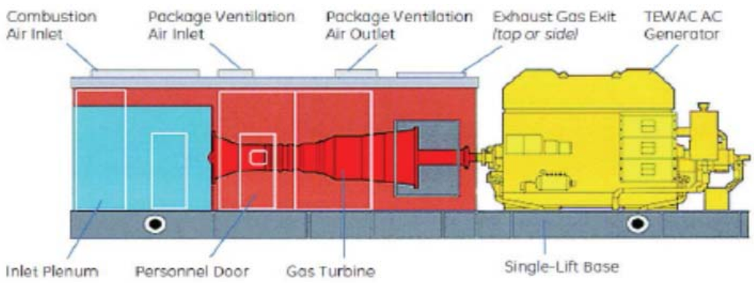


Figure 30: Diagram of main part

Quiz Tip: What is it about gas turbines that give them greater flexibility in terms of installation location? – Small size, low weight, low vibration.

3.2.3. Other consumers – Boilers & incinerators

3.2.3.1. SAACKE burners

Dual fuel or pure gas fuelled

Fired marine water boilers

Light fuel oil / gas SKVG

Heavy oil / gas SKVG

Gas SG

Safeguarded machinery

Figure 31: Part of the boiler

Figure 32: Image of the boiler

Quiz tip: Why may be it a good idea to include this type of consumer in a gas fuel system? – An alternative consumer if boil-off-gas builds up for whatever reason

3.2.3.2. SAACKE Gas Combustion Units (GCUs):

- BoG Management Currently used in LNGC
- Environmental impact Methane vs CO2
- Larger ships – atmospheric pressure fuel storage

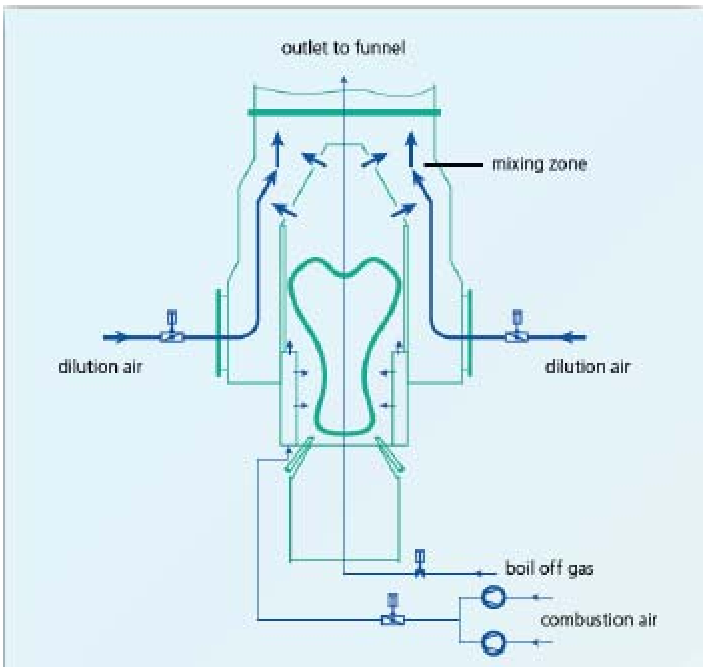


Figure 33: Basic functionality of SAACKE GCU

Quiz Technical Tip: On what ship types may it become necessary to install this sort of BoG management? – Larger ships with low pressure storage, BoG may exceed fuel requirements of boilers

High pressure engines main characteristics:

High Pressure Dual Fuel Engines

- 320bar-g design pressure
- Diesel Cycle
- Gas or liquid fuel
- Immediate change over
- Start-up / stop on fuel oil
- Large power range

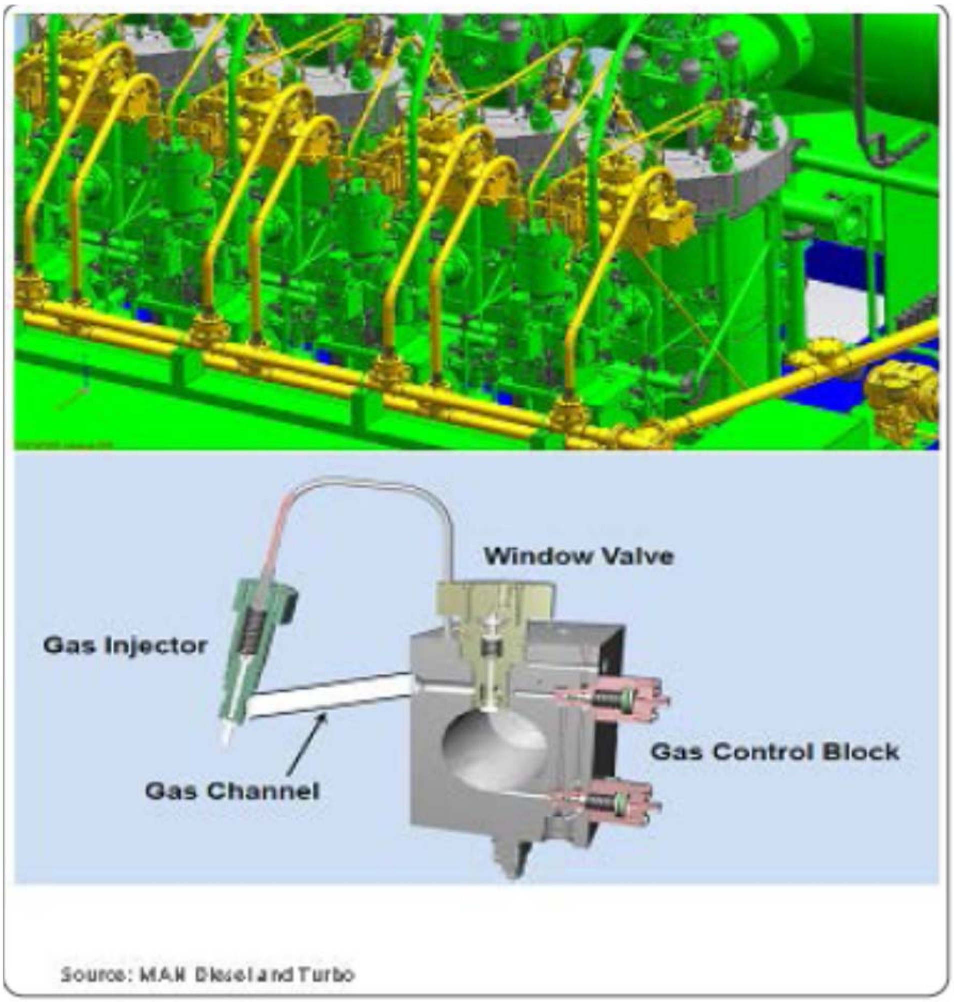


Figure 34 High Pressure Dual Fuel Engines (Source MAN)

What pressures do current high pressure consumers require? – 250-300 bar-g

Quiz Technical Tip: What propulsion system is this engine type suitable for? – Slow speed direct drive i.e. tanker/container ship

3.2.4. MAN B&W – Duel fuel ME-GI: Main operational Characteristics:

- Electronic gas injection valve system
- Pilot oil fuel required for gas operation
- 250-300 bar gas continuously on inlet valve spindle
- Gas injected directly into the compressed charge
- No premixing required

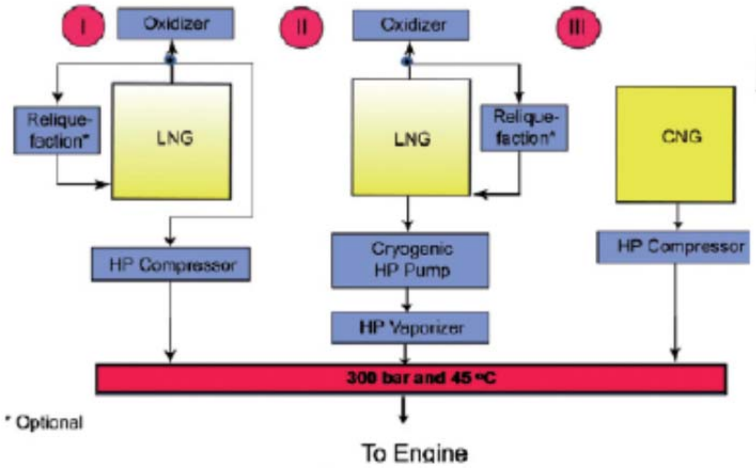


Figure 35: ME-GI characteristics

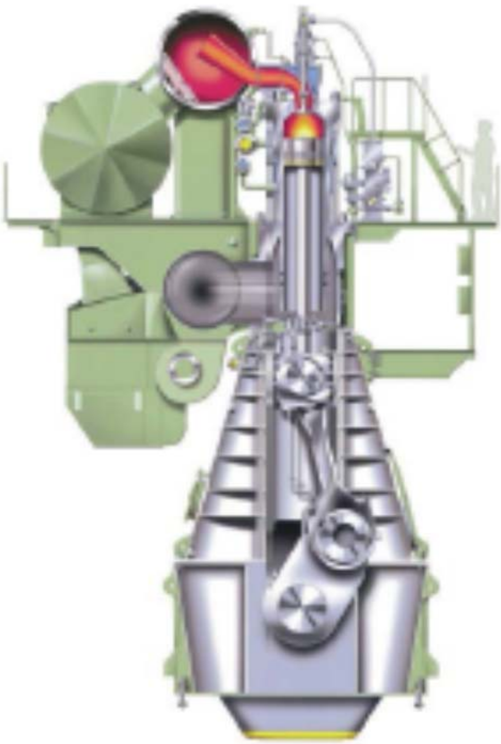


Figure 36: ME-GI image

3.3. LNG as fuel system Retrofitting Scenario

Introduction to the Principals requirement s, technical characteristic and possible route background in order the modification in question will be profitable in the long term and give all the info to the Ship Owners and managers/operators. The best case scenario is the retrofit to be for a vessel that has dedicated routes and can analyze the cost before the retrofitting and after so that can eventually this project considered beneficial for the owner.

Our hypothetical type of vessels scenario will be as follows?

Principal Characteristics

Type of Vessel: Ro-Ro/passenger Vessel

Loa = 214,00m MCR = 4 × 16800 = 67200 KW

Lpp = 191,22m RPM, Props = 500, 2 × CPP

Beam mld = 26,40m Passengers = 2200

Depth = 10,00m Cars = 660 (full), 135 (comb. with trucks)

Draft = 7,10m @full displ. Lane meters = 1560 (approx. 125 large trucks)

GT = 37.482 Service speed = 29,5 kn (as built), 21,5 kn service speed

NT = 15.989 Cont. speed = 31,2 kn @ 85% MCR

Main Engines = 4 × Wartsila 16V46C

The following information that has to be offered is the most important:

The Naval Architect/ designer needs to have the route operation profile of the vessel in order to adjust the appropriate/calculate consumptions. In addition, this input will be used for the LNG retrofit feasibility study and the techno economic analysis.

The following inputs were requested and should be provided

The vessel operates around xx days per year on the circular service with daily departures from either port.

She sails around 350 xx times with “slow” speed of 20 kn, that is daily night departures from each port in turn.

She sails 30 xx times with “fast” speed of 26 kn, that is 30 express day departures from each port in turn, in addition to “slow” night departures.

The Vessel is operating with running only 2 of her main engines on both cases.

Bunkering operations are taking place only in the port of Piraeus, typically once per week.

- Detailed technical information of the vessel and all the latest class examined drawings. In addition,
- How many engines will be retrofitted to use both LNG and fuel oil?
- In case there is no LNG retrofit kit for the main engine, does the Owner favors the installation of new “LNG ready” engines?
- Will the diesel generators will also be included in the retrofit?
- Vessel’s operation AFTER the LNG retrofit

It is important for the Designer to know how the Owner thinks about operating the vessel with LNG. The main question is:

What is Owner’s approach on LNG bunkering procedure? Does he want to follow the current fuel oil established bunkering pattern, or he is thinking of another model

Hypothetical feedback:

- How many engines will be retrofitted to use both LNG and fuel oil? 2 main engines only
- In case there is no LNG retrofit kit for the main engine, does the Owner favors the installation of new “LNG ready” engines? N/A, Wartsila can provide a solution for this model of main engine
- Will the diesel generators will also be included in the retrofit? No diesel generator(s) to be considered for LNG retrofit.

What is Owner’s approach on LNG bunkering procedure? Does he want to follow the current fuel oil established bunkering pattern, or he is thinking of another model? Owner would like to keep the existing bunkering pattern of the vessel, i.e. once per week in the port of Piraeus.

Summary of inputs that affect the LNG retrofit design:

- Full existing operational vessel's profile was provided.
- Access to the technical literature of the vessel was granted.
- Operational vessel's profile after LNG retrofit was formulated.

Based on the above, the starting was clearly defined and the very first critical question, i.e. what should be the capacity of the LNG tank(s) on board, was answered.

3.3.1. Onboard positioning of LNG tanks and Cold Box, the critical question: inside or outside?

The LNG retrofit equipment includes:

- ➢ The LNG storage tank(s)
- ➢ The regasification box, or "Cold Box", complete with valves, evaporators, relief vent etc.
- ➢ The master Gas Valve Unit or "GVU" that receives the NG from the Cold Box
- ➢ The LNG Bunkering Stations (port and starboard), together with the piping to the tanks
- ➢ The Gas distribution piping from the GVU to the main engine gas receiving point
- ➢ The dedicated ventilation system onboard, as well as the gas relief system
- ➢ The Emergency Shut-Down Device (ESD)
- ➢ The necessary control, electrical, firefighting and lifesaving system upgrade onboard.

Main LNG onboard System Components:

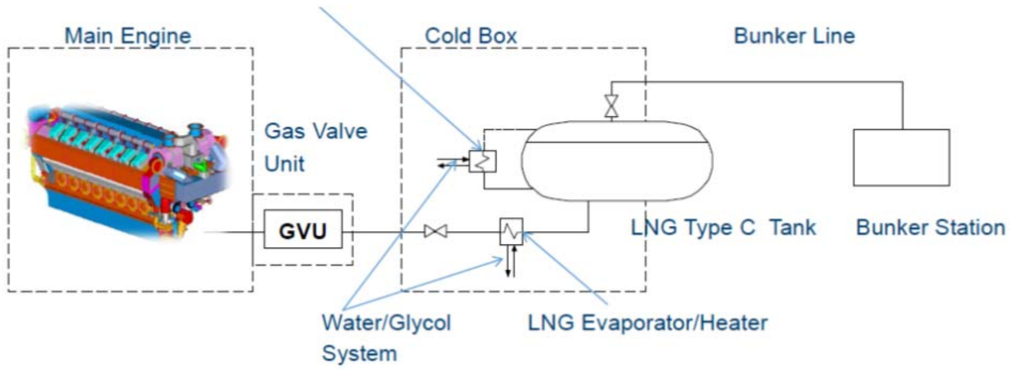


Figure 37: Pressure built-up Evaporator in Cold Box, (Source: Presentation "Initiation of an LNG retrofit design on a Cruise Ferry, lessons so far and challenges ahead)

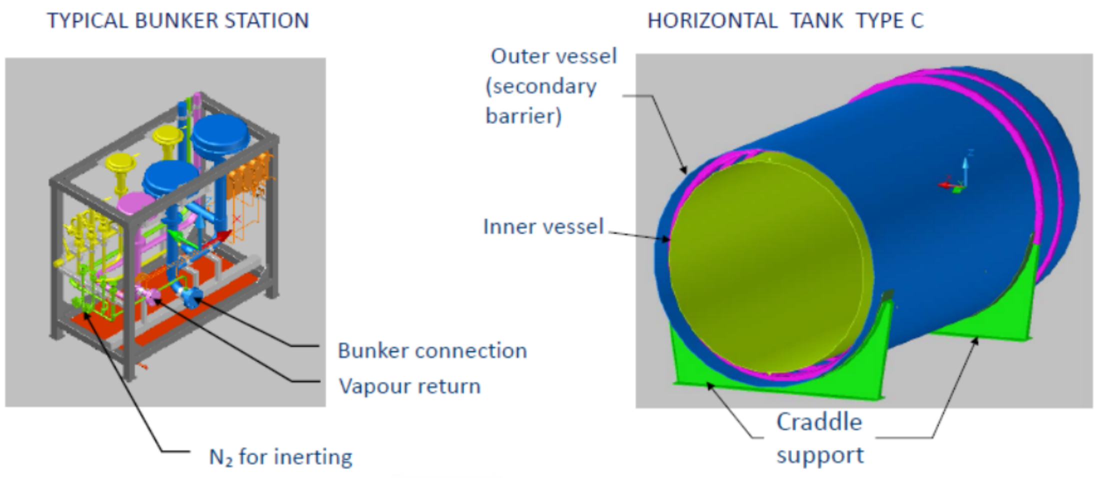


Figure 38: Onboard positioning of LNG tanks and Cold Box: inside or outside, (Source: Presentation "*Initiation of an LNG retrofit design on a Cruise Ferry, lessons so far and challenges ahead)*

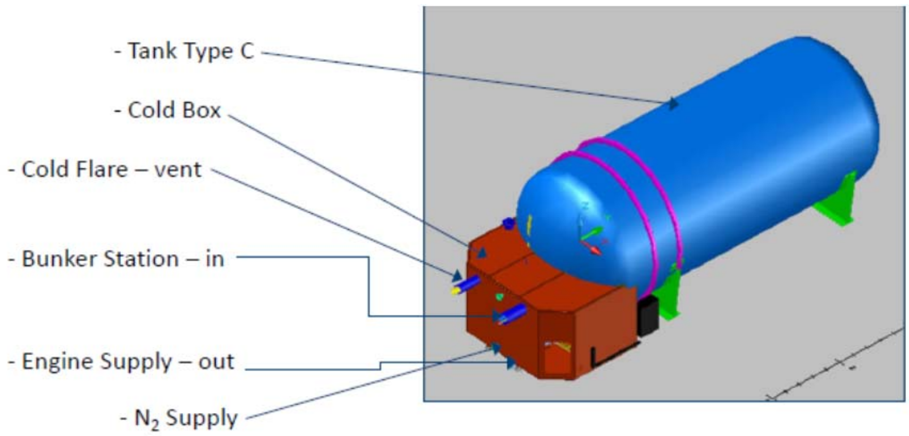


Figure 39: Tank & Cold Box Main Parts (Source: Presentation "*Initiation of an LNG retrofit design on a Cruise Ferry, lessons so far) and challenges ahead)*

3.3.2. Why is the TYPE C TANK? The Pros and Cons analysis:

C Type: Vacuum insulated cylindrical Pressure >2bar

Pros: High pressure capability, Superior insulation, Boil off control, Proven robust design, Voluntary 2nd barrier, Simple installation onboard, Production availability

Cons: Low volume utilization, Higher Cost, Volume < 1000 m^3

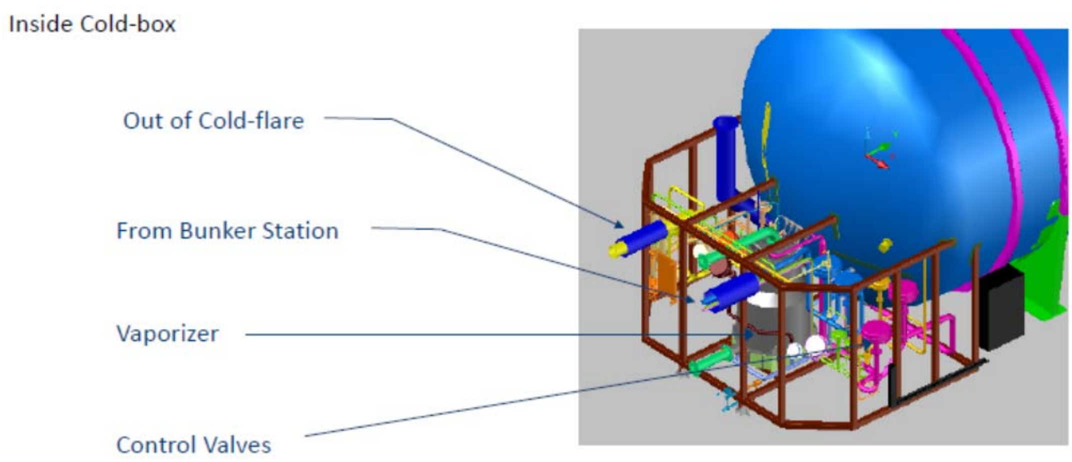
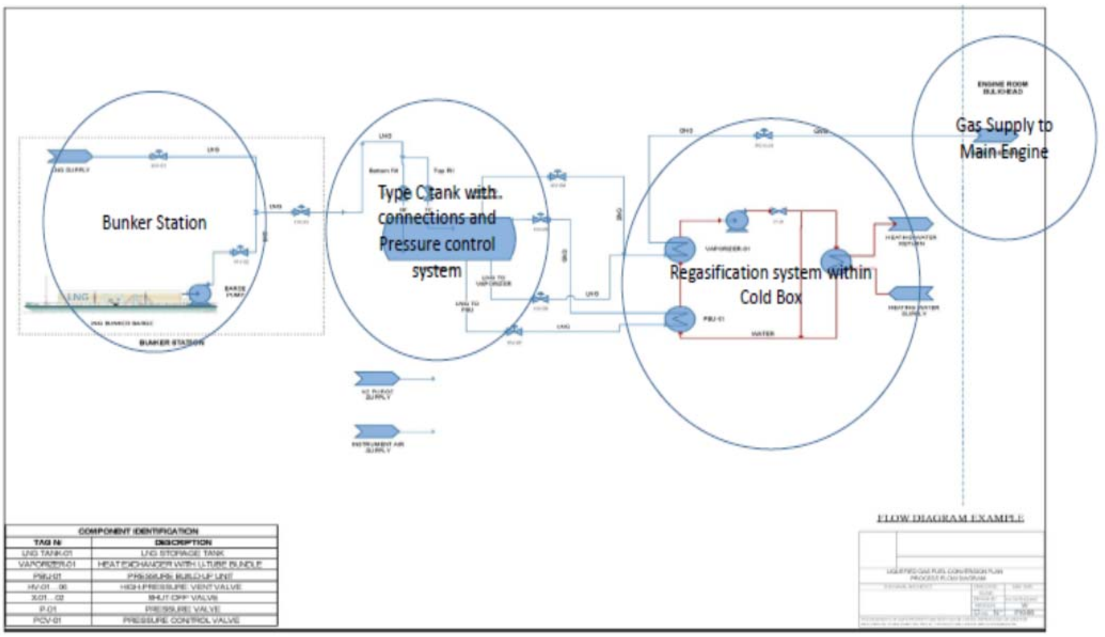


Figure 40: Diagram of the piping_ (Source: Presentation "*Initiation of an LNG retrofit design on a Cruise Ferry, lessons so far)*



igure 41: Typical flow diagram__ (Source: Presentation "*Initiation of an LNG retrofit design on a Cruise Ferry, lessons so far)*

The critical question: LNG Tank(s) to be located outside or inside?

• A straightforward answer occurs in case there is no space for one of the alternatives.

• In case that both of them are feasible, the answer should be given by taking into consideration the following aspects:

3.3.3. Class Assessment of Risk Based Designs (ARBD) - Designs and Arrangements for the Use of Low Flash Point Fuels.

This provides guidance for the Assessment of Risk Based Designs (ARBD). That is, approval of designs and arrangements (for the use of low flash point fuels) using risk based techniques. As such, it may be considered an annex to the document Internal Guidance for Lloyd's Register Staff Involved in the Plan Approval of Ship Design Using Risk Based Techniques (refer to Appendix 1).

3.3.3.1. Process Overview

Class and Statutory Rules and Regulations increasingly require 'risk studies' to be undertaken to identify hazards and to assess and control the corresponding risks, not least Lloyd's Register's (LR's) Requirements for Machinery and Engineering Systems of Unconventional Design (Part 7 Chapter 15) and SOLAS Alternative Designs and Arrangements (II-1 Reg. 55, II-2 Reg. 17 & III, Reg. 38). Typically, such studies are required for designs which deviate from existing Rules and Regulations or for novel or complex designs for which prescriptive Rules and Regulations do not currently exist.

To ensure that such studies are undertaken consistently, with an appropriate degree of rigour and in a manner consistent with applicable Classification and Statutory requirements then, unless stated otherwise in such requirements, risk studies associated with the use of low flash point fuels (e.g. Liquefied Natural Gas, LNG) should be undertaken according to the following four stage process.

Generic Process for the Assessment of Risk Based Designs (ARBD)

The process is scalable according to the degree of novelty/deviation, design complexity and safety considerations. Hence, the time and effort for each stage will vary. In short, the process comprises the following stages:

Stage 1 – Scoping Study

Stage 2 – Conceptual Design Hazard Identification Study (HAZID)

Stage 3 – Detailed Study(s)

Stage 4 – Detailed Design Hazard and Operability Study (HAZOP)

Responsibility for conducting the studies for each of the stages lies with the organisation requesting approval or approval-in-principle (AIP) from LR. Each stage is concluded by a report which should be approved by LR (and generally the National Administration) before commencing the next stage. It should be appreciated that the assessment process aims to ensure that all reasonably foreseeable hazards associated with a particular design are adequately controlled, irrespective of whether they may eventually fall within the scope of Classification approval or within the scope of Statutory approval,.

Where a design submitted for approval is based on a design previously approved by LR using a risk based approach then the risk studies to be undertaken may reference previous approval (and risk studies) and focus on the differences in the design and/or in the application of its use.

ARBD – Stage 1 Assessment, Scoping Study

Items to be considered

3.3.3.2. Propose Project Team

- Design team composition
- Team coordinator
- Ship owner/operator
- Ship yard
- Alternative fuel (e.g. LNG) system supplier
- Alternative fuel (e.g. LNG) bunker supplier
- Qualifications and experience
- Plan of engagement with Class and National Administration
- Contact persons
- Schedules

3.3.3.3. Relevant requirements

IMO MSC Circ.1002, 4.1-4.3

IMO MSC Circ.1212, 4.1-4.3

LR Rules and Regulations for the Classification of Ships, P 7, Ch 15, 1.7.3

3.3.3.4. Define novel or alternative design

- Functional requirements including underway, manoeuvring, berthing and alongside
- System design
- Requirements
- Description
- Block diagram
- Rules, Regulations, Codes and Standards applied
- Operational modes
- Start-up
- Shut-down
- Normal operation
- Emergency-shutdown
- Relevant requirements
- IMO MSC Circ.1002, 4.3 & 5.1.1
- IMO MSC Circ.1212, 4.3 & 5.1.1
- LR Rules and Regulations for the Classification of Ships, Pt 7, Ch 15, 1.4.3

3.3.3.5. Define scope of novel or alternative design

- Bunkering
- Fuel storage
- Fuel distribution
- Spaces, separation, containment, ventilation
- Consumers (e.g. Main engines, boilers)
- Control, alarm and safety systems (e.g. gas detection)
- Fire protection
- Fire detection
- Fire extinguishing
- Relevant requirements

3.3.3.6. Identify Classification and Statutory requirements not complied with

- Fire Safety
- Engineering
- Relevant requirements
- SOLAS Chapter II-2, Part B, Reg. 4,1 & 4.2.1

- SOLAS Chapter II-1, Part C, Reg. 26 & 27
- IMO MSC Circ.1002, 4.3.4 & 5.1.2
- IMO MSC Circ.1212, 4.3.4 & 5.1.2
- LR Rules and Regulations for the Classification of Ships, Pt 5, Ch 1, 3
- LR Rules and Regulations for the Classification of Ships, Pt 6, Ch 2, 14

3.3.3.7. Determine safety objectives of Classification and Statutory requirements

- Fire Safety
- Engineering
- Relevant requirements
- SOLAS Chapter II-2, Part A, Reg. 2
- SOLAS Chapter II-1, Part C, Reg. 26.1 & 26.2
- SOLAS Chapter II-1, Part D, Reg. 45
- IMO MSC Circ.1002, 4.3.4 & 5.1.2
- IMO MSC Circ.1212, 4.3.4 & 5.1.2
- LR Rules and Regulations for the Classification of Ships, Pt 1, Classification Note
- LR Rules and Regulations for the Classification of Ships, P 7, Ch 15, 1.7.1

3.3.3.8. Determine functional requirements to satisfy safety objectives

- Fire Safety
- Engineering
- Relevant requirements
- IMO MSC Circ.1002, 4.4 & 5.1
- IMO MSC Circ.1212, 5.1
- IMO MSC Circ.1002, 4.4
- SOLAS Chapter II-2, Part A, Reg. 2

3.3.3.9. Describe overall extent of deviation from Classification and Statutory requirements

- Extent of deviation from functional requirements
- Extent of deviation from prescriptive requirements

3.3.3.10. Prepare Stage 1 assessment report

- Above information to be included
- Further Risk Assessment Stages anticipated with justification

- Relevant requirements
- IMO MSC Circ. 1002, Annex, 7.1.1-7.1.3.3
- IMO MSC Circ. 1212, Annex, 7.1.1-7.1.3.3

3.3.3.11. ARBD – Stage 2 Assessment, Conceptual Design HAZID

Items to be considered and involvement with Stakeholder is required:

- Stakeholder representation
- Ship operator
- Ship designer
- Alternative fuel system designer
- Classification observer
- National Administration observer
- Port Authority
- Technical expertise (both general and alternative fuel specific expertise)
- Fire Safety
- Engineering (Mechanical, Piping, Electro-tech, etc.)
- Risk Assessment
- Conflict of interest between design and approval
- LR providing an observer (no conflict of interest)
- LR providing SMEs in HAZIDs (SMEs cannot be involved in approval)
- Relevant requirements
- Appendix 3 – Tender Requirements for Stages 2 and 4

3.3.3.12. Propose assessment method

- Hazard identification and risk ranking according to ISO 31010 or similar
- Alternative and appropriate recognised technique(s) for hazard identification/risk ranking
- Relevant requirements
- IMO MSC Circ.1002, 5.2.1.1
- IMO MSC Circ.1212, 5.2.1.1
- ISO 31010 Risk Assessment Techniques

3.3.3.13. Propose acceptance criteria

Acceptance criteria based on either

- equivalence with current arrangements

- risk being As Low As Reasonably Practicable (ALARP)
- ➢ Acceptance criteria to account for likelihood and consequence
- ➢ Acceptance criteria to take account of Stage 1 Assessment Report
- ➢ Acceptance criteria to distinguish risk by a minimum of three groupings:
- ➢ unacceptable or intolerable
- ➢ tolerable if ALARP; and
- ➢ acceptable, tolerable or negligible
- ➢ Acceptance criteria to ensure appropriate safety margin
- ➢ Relevant requirements
- ➢ IMO MSC Circ.1002, 5.4.2 & 6.3
- ➢ IMO MSC Circ.1212, 5.3.1.4 & 6.3

3.3.3.14. Identify hazards

- ➢ Fire
- ➢ Explosion
- ➢ Asphyxiation
- ➢ Cryogenic burns
- ➢ Rapid Phase Transition
- ➢ Roll-over
- ➢ Low temperature embrittlement
- ➢ Pressure release
- ➢ Electric shock
- ➢ Structural failure
- ➢ Flooding
- ➢ Loss of essential functionality e.g. propulsion, auxiliary power
- ➢ Relevant requirements
- ➢ Appendix 3 – Tender Requirements for Stages 2 and 4
- ➢ LR Rules and Regulations for the Classification of Natural Gas Fuelled Ships,
- ➢ IMO MSC Res. 285(86), 2.1
- ➢ IMO MSC Circ.1002, 5.2.1.1
- ➢ IMO MSC Circ.1212, 5.3.2

3.3.3.15. Identify how hazards can occur

- ➢ Normal ship conditions
- ➢ Ship motions (e.g. inclination, shock, vibration)

- Equipment degradation
- Equipment failure
- Control system failure/error
- Operational error
- Maintenance error
- Fuel characteristics
- Abnormal ship conditions
- Fire outside of the space
- Flooding of the space
- Ship collision
- Grounding
- Operational modes
- Start-up
- Shut-down
- Normal operation
- Emergency-shutdown
- Relevant requirements
- LR Rules and Regulations for the Classification of Natural Gas Fuelled Ships, 3.2.2 & 3.2.4
- IMO MSC Circ.1002, 5.2.1.1
- IMO MSC Circ.1212, 5.3.2

3.3.3.16. Determine consequences (accident/casualty scenarios)

- Safety of Ship
- Ship's occupants
- Ship's machinery and equipment
- Environment
- Severity category

3.3.3.17. Estimate likelihood (accident/casualty scenarios)

- Incident/Accident history
- Owner
- Ship type
- Ship routes (e.g. Europe, Asia, North America)
- Other factors

- Complexity of equipment and layout
- Competency of crew
- Relevant requirements
- Appendix 3 – Tender Requirements for Stages 2 and 4
- IMO MSC Circ.1002, 5.2.1.3
- IMO MSC Circ.1212, 5.3.4

3.3.3.18. Categorise risk (accident/casualty scenarios)

- The sensitivity of risk categorization to small changes in consequence and likelihood judgements (see 2.6 & 2.7)
- Relevant requirements
- LR Rules and Regulations for the Classification of Natural Gas Fueled Ships, 3.2.1
- IMO MSC Circ.1002, 5.2.1.3
- IMO MSC Circ.1212, 5.3.5

3.3.3.19. Determine if acceptance criteria are satisfied

- Acceptance criteria
- Sensitivity of risk categorization to small changes in consequence and likelihood (e.g. does a 'small' change in consequence or likelihood change the risk grouping from tolerable if ALARP to 'unacceptable'?)

3.3.3.20. Identify additional measures to satisfy acceptance criteria

- Risk control hierarchy
- Inherently safer design
- Prevention measures
- Mitigation measures

3.3.3.21. Justify appropriate safety or need for further assessment

- Safety objectives and functional requirements (see 1.5 & 1.6)
- Risks equivalent or ALARP
- Risk unknown or uncertain

3.3.3.22. Prepare Stage 2 assessment report

- Above information to be included
- HAZID Study report
- Required approvals
- Class

- National Administration
- Relevant requirements
- Appendix 3 – Tender Requirements for Stages 2 and 4
- IMO MSC Circ. 1002, 5.4 & Annex, 7.1.1-7.1.3
- IMO MSC Circ. 1212, 5.5 & Annex, 7.1.1-7.1.3
- Recommendations/considerations/actions are considered and a convincing/appropriate justification is given for those not implemented

3.3.3.23. ARBD – Stage 3 Assessment, Detailed Study

Items to be Considered
Define objective and scope of assessment

- Study(s) as determined necessary by Stage 2, such as
- Failure Modes & Effects Analysis (FMEA) of the control system. It is unlikely that such a study would **not** be required for the operational and safety controls associated with, for example, an LNG fuelling system. Extensive justification is required where an FMEA is not undertaken.
- Gas dispersion
- Ship collisions and groundings
- Fire spread (e.g. from one space to another and to adjacent equipment)
- Explosion
- Equipment reliability

3.3.3.24. Identify acceptance criteria

Acceptance criteria as determined by Stage 2 and sufficient to facilitate justification of appropriate safety

Propose assessment team(s), method(s) and techniques(s)

Refer to Stage 2, 2.1, and relevant international standards for proposed methods and techniques

Undertake assessment

Reference to international standards and use of recognized methods/techniques

Justify appropriate safety

- Safety objectives and functional requirements (Refer to Stage 1, 1.5 & 1.6)
- Risks equivalent or ALARP
- Risk unknown or uncertain

3.3.3.25. Prepare Stage 3 Assessment Report

- Above information to be included
- Required approvals
- Class
- National Administration
- Relevant requirements
- IMO MSC Circ. 1002, 5.4 & Annex, 7.1.1-7.1.3.
- IMO MSC Circ. 1212, 5.5 & Annex, 7.1.1-7.1.3

Revise Stage 2 Assessment Report or provide Addendum/Supplement

Above information to be included

Refer to Stage 2, 2.12

3.3.3.26. ARBD – Stage 4 Assessment, Final Design HAZOP

Items to be considered

- Define objective and scope of assessment
- Appendix 3 – Tender Requirements for Stages 2 and
- Define objective and scope of assessment
- Propose assessment team(s), method(s) and techniques(s)
- Undertake assessment

Reference to an international HAZOP standard

Prepare Stage 4 Assessment Report

Recommendations/considerations/actions are considered and a convincing/appropriate justification is given for those not implemented.

3.4. Outside area installation

The deck area is in safe distance of accommodation block, funnel area, radar masts, life boats and other lifesaving appliances? What about in case of collision?

- Is there any cargo movement next to the proposed area?
- The tanks will be located in a safe distance from ramps, stern, bow and vessel's side?
- Is there going to be a long piping from bunker station to tanks and then from thanks to engines?

- Is the proposed area capable to successfully pass the relevant Class Risk Assessment?

Further below we will provide the principal requirements of what a Class Risk Assessment regarding the Risk Based Designed should be reviewed.

1. Will the pre-cooling - the preparation of the piping to receive the cryogenic LNG - phase to be done within an accepted time period for the vessel?
2. Any extreme environmental conditions that will eventually affect the tanks, like high temperatures, extreme sunshine etc?
3. Will the stability of the vessel be affected in a negative way?
4. Is the proposed area structurally capable to withstand the additional weight?
5. How the selected position affects the capacity of the vessel? What will be the % of d.w. deduction?
6. For inside installation
7. The deck area is within B/5 limits?
8. Safe distances from bow (0,08L) and base line (at least 2m) can be ensured?
9. An A-60 boundary for ventilation trunks can be created?
10. Safe egress from the space can be ensured?
11. Is the proposed area structurally capable to withstand the additional weight?
12. Is the proposed area capable to successfully pass the relevant Class Risk Assessment?
13. Will the stability of the vessel be affected in a negative way?
14. How the tank(s) will be brought inside the vessel?
15. Is there enough space for the creation of air-locks in order to access the tank(s)?
16. How the selected position affects the capacity of the vessel? What will be the % of d.w. deduction?
17. How the ventilation routing and pressure relief system will affect other vessel's installation and the accommodation?

The study of the of IGF Code is essential before start designing the retrofit! Methodology starting point: tank capacity, consult with the LNG Storage System Supplier tank(s) overall dimensions, check about access and draw the initial general arrangement

1. Consult with LNG Storage System Supplier about the dimensions and layout of the Cold Box and Bunker Station.
2. Create a draft version of Equipment General Arrangement Plan, as well as of the Bunker Station. check accessibility and egress in case of emergency, check fire resistant boundaries.
3. Check possible ventilation trunks routing, together with the gas relief piping.
4. Check the piping route from the bunker station: preferably it should be as sort as possible to avoid difficulties with the pre-cooling.
5. If SIMPOS (simultaneously operations) is to be consider, exclusion zone limits should be identify and analyzed.
6. A walk-through inspection of the vessel is a must! If possible, discuss with the crew onboard about the candidate areas, same with the Technical Manager of the company. Their input is valuable, because there is not only the installation, but the future operation as well, which will be done by those people.
7. Perform a quick stability analysis, refer to chapter 6 hereafter!
8. Consultation with the Owner regarding the space loss.
9. The preliminary selection of LNG tanks onboard positioning , should be addressed to Class for getting their comments and inputs.

The final selected position is to be forth for a detailed engineering analysis.

3.4.1. Selected position, pros & cons, and interaction with the LNG new Bunker Station

Both alternative positions are feasible. Both can fulfill the design aspects analyzed previously, thus both were put into further study.

From stability point of view, both positions are ok, the internal position gave a little better stability results.

The proposed positions of the LNG tanks are the following

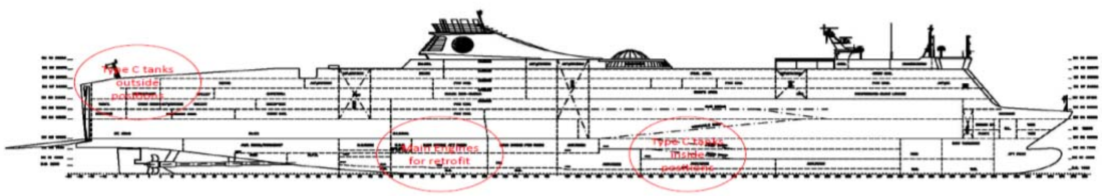


Figure 42: Diagram showing the possible positions of the LNG tanks

The cons of each position.	
Outside:	Inside:
➢ Impact on aesthetic	➢ Difficult installation
➢ Exposed to environment	➢ Loss of car space
➢ Need for deck extension	➢ Deck penetration
➢ Longer piping runs (P drop)	➢ Equipment relocation
➢ Difficult pre-cooling	➢ Difficult vent route
➢ Complicated fire fighting	➢ Difficult relief routes
	➢ Difficult installation

3.4.2. Decision regarding position onboard.

The above mentioned design approach together with the Pros & Cons list, were presented and further discussed with the Owner.

•The Owner agreed to proceed with the internal positioning of the LNG tanks and Cold Boxes.

Reasons:

1. Easier operations (bunkering & SIMOPS)
2. No impact on aesthetics (this was a strong point on decision making!)
3. The loss of passenger car capacity can be compensated with the fuel economy due to LNG

Following capacity calculations, three (3) large LNG tanks are foreseen for internal installation.

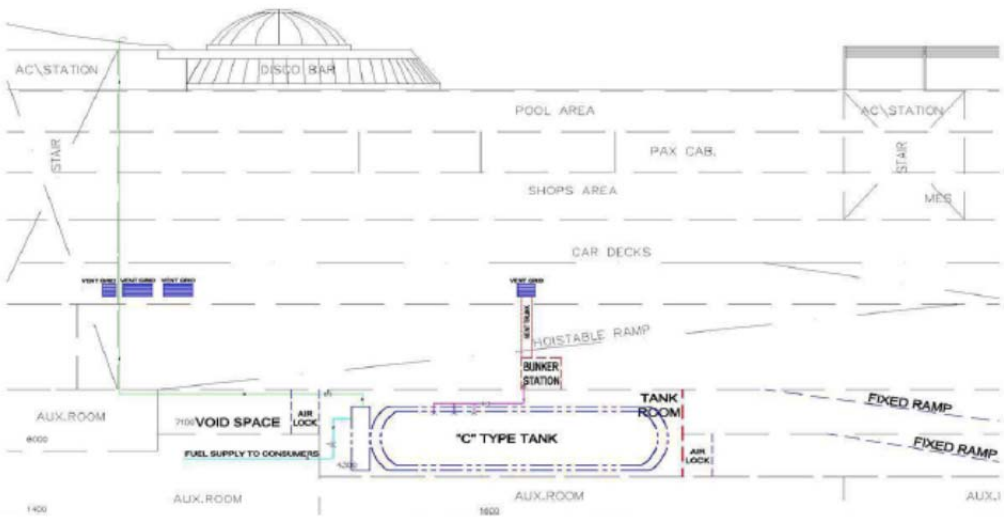


Figure 43: Diagram of the position of the Tank as decided

3.4.3. Details of the internal positioning

- The actual space: the lowest car deck (Garage No 1).
- Height restriction : it is needed to penetrate the upper car deck (Garage No 2)
- Equipment relocation : fixed ramps need to be relocated
- Connection with B.S. : very easy, bunker stations will be located directly above, on the main deck (Deck No 3)
- Escape routes: through air-locks, directly to emergency escape garage routing.
- Fire-fighting : easy to upgrade, A-60 encasement of the tanks is foreseen

- Ventilation routing : relatively easy through the main casing and then through side shell grilles, no impact to accommodation areas
- Pressure Relief routing: difficult solution due to accommodation, funnel and radar mast.

Stability Analysis of the vessel after the retrofit, intact and damage stability, conformity with International Rules and Regulations will follow.

3.5. Stability Analysis of the vessel after the retrofit, intact and damage stability, conformity with International Rules and Regulations.

It is most important to ensure that the vessel shall comply **AFTER** the LNG retrofit, with **ALL** Rules and Regulations that currently comply with, regarding Stability - Intact and Damaged.
The Stability Analysis was executed by using HCAD a special Naval Architecture program and ANKO a special marine load planner program. The analysis is based on the requirements of Rules and Regulations the vessel currently comply with, like SOLAS (latest editions in force), Stockholm Agreement, SOLAS 90 and Greek Flag requirements.
Here below will be provided the LR Rules & Regulations and other Statutory requirements that have taken in to consideration about Stability Compliance after retrofitting.

3.5.1. LNG Retrofit Concept Design Stability Assessment Ro-Ro Passenger Ship

A short reference to the relevant existing statutory regulations and the corresponding LR interpretations can be also found in the next paragraph

Existing regulatory framework
The ninety-fifth session of the IMO Maritime Safety Committee adopted on June 2015 the International Code of Safety for Ships Using Gases or Other Low-flashpoint Fuels (IGF Code), Resolution MSC.391 (95).

The IGF Code is mandatory under the provisions of SOLAS Convention (Chapters II-1, II-2) and will take effect on the 1st of January 2017 upon entry into force of the amendments to Chapters II-1, II-2 and the appendix to the annex of the Convention. With respect to stability, the only reference in the IGF Code is found in Chapter 6.5 (Regulations for portable liquefied gas fuel tanks) where is stated that:
"Consideration shall be given to the strength and the effect of the portable fuel tanks on the ship's stability." As a result, there are no specific stability requirements imposed by the new IGF Code. However, ships should comply with the requirements of other IMO instruments which are applicable, considering the effect of the LNG fueling arrangements to the intact and damage stability. Special attention should be paid on the existing ships where modification may affect the lightship particulars and/or the watertight integrity of the ship. Lloyd's Register does not have any specific stability requirements for the classification of ships using LNG as fuel. However, it is the Lloyd's Register point of view that, the investigation of the potential risks which are associated with the probabilities of collision/grounding and the survivability of the ship should form part of the Risk Assessment as defined in Chapter 4.2 of the new IGF Code.

Arrangement of LNG bunkering and effect on stability

The vessel has been fitted with three C-Type LNG tanks located between Deck 1 (4.3m from BL) and Deck 3 (10.0m above BL) and between frames 143 and 175. It is understood that the new bulkhead fitted on frame 175 constitutes a watertight boundary. As can be seen in Figure 1, the location of the tanks and other modifications in the internal subdivision are outside of the assumed transverse damage extents (B/5) so the existing SOLAS damage stability calculations can be considered valid. It is noted that the vessel has been designed in order to comply with both SOLAS 90 and Stockholm Agreement (Water on Deck - WoD) damage stability standards. With respect to Stockholm Agreement it is expected that, due to the watertight bulkhead at frame 175 and the reduced size of the lower holds on Deck 1 and Deck 2, the existing damage stability GM limiting curves listed in the approved stability booklet are on the safe side. The above conclusions are only valid provided that there are no significant alternations to the watertight integrity of the ship and no progressive flooding can be occurred as a result of new fitted pipes or trunks.

With respect the above, it is noted that the new LNG bunker station door fitted about 10.5m above BL on the side shell at frame 185 should be able to close by watertight means. In addition, the location of the new ventilation opening on the side shell at frame 132.5 can be considered close enough to existing unprotected openings so it does not affect the approved intact and damage stability calculations. All other modifications as shown in the submitted information (i.e. relocation of vents, vehicles ramp, etc.) are not expected to alter the existing intact and damage stability characteristics of the ship.

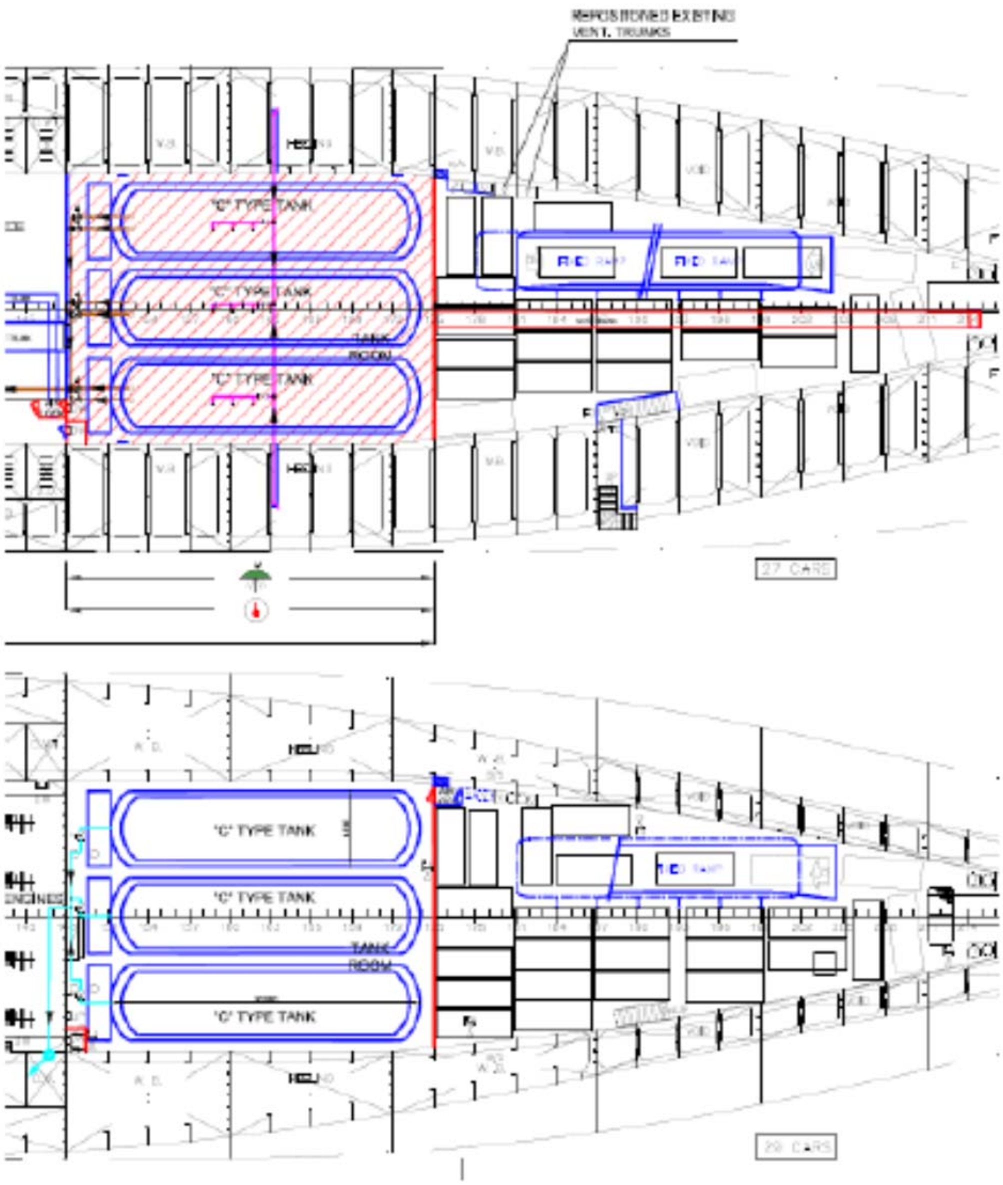


Figure 44: Location and type of the LNG bunkering tanks (deck view)

Regarding the weights estimations it is noted that no detailed calculations was provided at this stage.

Based on the submitted information, the new lightship after the modifications has been estimated to be about WLS=15494t having a longitudinal centre of gravity at LCG= 83.02m from AP and a vertical centre of gravity VCG=12.58m from BL. The resulted differences comparing with the existing lightship particulars are then dWLS=2%, dLCG=0.4%LBP and dVCG=-10cm. It is noted that according with the MSC/Circular.1158 (Unified Interpretation of SOLAS Chapter II-1) in order to avoid an inclining test, the deviation of lightship displacement should not exceed 2% of the original approved lightweight. In addition, the deviation of LCG from the original should not exceed 1% of the LBP of the ship. Where the deviation exceeds either of these limits, an inclining test should be carried out. Where a ship is within these limits the calculated values of lightweight, lightship LCG and lightship VCG should be used in all subsequent stability information supplied to the master. The above deviations can be considered as marginally acceptable.

Comments on the submitted stability assessment:

One pair of full loading conditions has been submitted corresponding to a draught of 7.0m using water ballast. It is noted that the design draught of the ship is 7.10m while the scantling draught is of 7.30m. As no information is found regarding the existing freeboard assignments, it is understood that the above loading condition corresponds to the summer load line. If this is not the case then it is suggested that additional conditions to be investigated.

The loading conditions have been assessed using the stability loading software ‘ANKO Marine Load Planner’.

However, no evidences regarding the approval status of the loading computer software are provided. Based on the supplied calculations, the vessel complies with the applicable intact and damage stability requirements considering the lightship particulars after the modification as described in the previous paragraph of this document. According with the approved stability information booklet, the vessel has a GM margin regarding the intact stability requirements about GM excess (IS)=0.98m. With respect to SOLAS and damage stability, the ship demonstrates compliance having satisfactory stability margins GM excess (SOLAS)=0.83m and GM excess(WoD)=0.99m, respectively. It is noted that no free surface moments due to the

LNG fuel have been considered in the calculations. However, the above stability margins indicate that the vessel complies with the intact and damage stability requirements even if the maximum transverse moment of inertia is taken into account for the correction of the GM and GZ curve values.

Damage probability and survivability

The possibility of the LNG tanks space to be involved in a damage scenario can be calculated using the SOLAS 2009 probability distributions of collision and grounding. When the ship is damaged, the resulted overall probability of flooding for the space between the frames 143 and 175 inwards of the longitudinal bulkhead, assuming that damages can be extended up to two zones, is about 5.4%. The probability of having only the above space flooded or together with the aft adjacent compartment is about 1.6% while the possibility of involvement of both the LNG bunkering space and the forward adjacent space is about 2.3%.

The survival capability of the ship considering the damages where the LNG bunkering space is involved cannot be calculated due to the lack of sufficient information and the need of developing a full stability ship model.

3.6. Technical Solutions for LNG piping routing.

- To identify the best possible routing of LNG & NG piping to and from the LNG tanks.
- To minimize the impact on existing vessel’s piping and cable routings
- To create an effective ventilation system of the enclosed areas with LNG equipment
- To establish an accepted (by Rules) emergency gas relief piping.

Available Tools to support this endeavor

- Detailed Piping Drawings of the vessel, schematics are of – almost – no value in this case!
- Onboard inspection of the areas affected by the new piping.
- Consult the Crew, especially the Chief Engineer! He knows the vessel better than anyone else!
- If it is possible, proceed with an actual 3-D scanning, it will free your design by visualizing all possible solutions

Additional LR Rules and IGF Codes requirements will follow.

Solution coordination with Class, risk assessment, how to obtain the "Approval in Principal". Submission of relevant drawings (firefighting, lifesaving, electrical & control systems upgrade.

In order to proceed to Detailed LNG Retrofit Design, the Designer should consult the vessel's Class and obtain the so called "Approval in Principle" or AIP.
AIP is the first, but very essential, step for obtaining later on, the "LNG ready" notation for the vessel.
AIP includes three distinguish steps:
1. Record of Design Screening
2. Review of the required drawings (GA, Life Saving & Escape, Fire Fighting, Ventilation, Stability, Control & ESD, Weight Control & Analysis)
3. Risk Assessment report on the proposed LNG retrofit solution.
The required drawings are almost ready for submission and evaluation.
Add plan etc. LR:

Feasibility study on the proposed LNG retrofit.

Based on the results of the subject study, the Owner will be able to decide on a "go" or "not go" basis.
The feasibility study should be based on an international accepted method of calculation.

Cost inputs for the feasibility study

- Main Engine Retrofit "Kit"
- LNG Storage Tank(s) type C, complete with cold box, safety devices
- Bunker Station(s)
- Automated System Control Systems
- Nitrogen System, LNG Piping works
- Steel Works (stiffening, adding/removal of steel)
- Fire Fighting & Evacuation Systems upgrades
- Emergency Shut Down Systems (ESD)
- Engineering, including Risk Assessment, Class, Testing & Comm.
- Ship's Electrical & Electronics Systems upgrading, new ventilation
- Training
- After Sales & Warranties

Optimizing the solution

The expansion of the spiral approach towards the detailed design should be undertaken on the basis of the "existing" ship, i.e. there are some parts of the design that simply cannot change, like the hull form!

Designer should always bear in mind that the retrofit should be within certain limits, like:

1. The retrofit disruption on the vessel - for installation purposes – should be as minimum as possible.
2. Running of piping should avoid accommodation areas as practical as possible.
3. The retrofit design should be ergonomic and "operational friendly", i.e. the actual ship operation after the retrofit should always be a significant concern for the Designer.
4. The whole retrofit should be in line with IGF Code and all relevant Rules and Regulations.
5. The Designer should always have a clear picture on production and availability of LNG retrofit equipment; otherwise he may face delays during the installation.
6. The economic impact of the retrofit should be within the limits the Owner addressed and he is going to accept. These limits however, must have been formulated in advance with the input of the Designer through the Feasibility Study, so as the Owner to be prepared about the initial investment.

3.7. Findings from a technical point of view and comments regarding the Approval in Principal:

This paragraph contains The 'Design Screening – Gas Readiness (A) Notation. Approval in Principle

And all the above Rules, Regulations, Codes and Guidance should the vessels to comply in order to enable her to obtain the relevant notation.

- LR's Rules and Regulations for the Classification of: (a) Ships (b) Inland Waterways Ships; (c) Natural Gas Fuelled Ships; and (d) Construction and Classification of Ships for the Carriage of Liquefied Gases in Bulk.

- International Code of Safety for Ships using Gases or other Low-flashpoint Fuels (IGF Code Jan-15).
- LR's ShipRight Guide: Assessment of Risk Based Designs(ARBD)

3.7.1. Class notation and descriptive notes, the meaning: And findings in order for the vessel will be eligible to obtain the relevant Notation.

1. Ships complying with the requirements of these Rules will be eligible for assignment of the **GF** machinery notation.
2. Ships complying with aspects of these Rules may be eligible for the Gas-Fuelled Readiness **(GR)** descriptive note. This descriptive note will be added to column 6 of the Register Book. This descriptive note is not an LR class notation and is provided solely for information.

GF_ Assigned to ships other than LNG carriers, where the main propelling and/or auxiliary machinery is designed to operate on natural gas as fuel, or a combination of natural gas and fuel oil. The notation also indicates that the gas fuelled machinery has been installed and tested in accordance with LR's Rules and Regulations.

GR_Assigned to ships other than LNG carriers, with the extension of one or more of the following associated characters shown in brackets, detailing the aspects of design and construction that are in accordance with LR's Rules and Regulations in force on the date of 'contract for construction'. If a ship has been assigned the GF notation then it will not be eligible for the GR descriptive note. Further appraisal against the Statutory and LR requirements at the time of commissioning followed by testing and commissioning under survey will be required if assignment of the GF notation is requested.

A_The complete gas fuel system design has been approved in principle. A design screening exercise is to be completed in accordance with the requirements of ShipRight procedure Assessment of Risk Based Designs (ARBD). The following drawings and documents are also to be submitted:

(i) Arrangement drawings of LNG fuel tanks, bunkering station, fuel gas supply system, GVU room, ventilation system, passive and active fire protection associated with the gas fuel system

(ii) Hull key plans (Construction profile and deck plan, Key section of E/R structure) for future installation of LNG

Fuel tanks and spaces associated with the proposed gas fuel system

(iii) Strength calculations of LNG fuel tank supports and hull structure

(iv) Piping, electric and control diagrams for LNG fuel system.

S_Enhanced structural reinforcement and appropriate material grades have been applied to support the proposed fuel tank. Details of the proposed tank type, size and location are to be provided to support the calculations for enhanced scantlings and structural reinforcement.

T_Gas storage tank, tank master isolation valve, fuel venting arrangements and, where applicable, the fuel storage hold space, structural fire protection and ventilation arrangements for under deck tank locations are built under survey and installed in accordance with an approved design and certified suitable for gas fuel operations.

P_All piping equipment associated with the gas-fuelled system, e.g. pipes, pumps, valves, etc. including all bunkering arrangements and associated access arrangements including structural fire protection as applicable, have been installed in accordance with an approved design and certified fit for gas fuel operations.

E_Engineering systems have been installed in accordance with the approved design and certified suitable for using gas as a fuel. Applicable control and electrical systems are installed in accordance with the requirements of these Rules. Additional letters will be assigned in brackets to identify which items meet the requirements for 'gas-fueled readiness

M_main engine(s);

A_auxiliary engines;

B_boiler;

I_incinerator.

Note: For additional characters **S**, **T**, **P** and **E** the full design, applicable to the character as described above, is to be submitted and approved against the applicable Sections of these Rules including risk-based studies where required.

For example the descriptive note **GR (A, S, E(M,I))** indicates that the full design of the gas fuel system has been appraised and approved in principle, the vessel structure is reinforced to support the proposed gas storage tank but the gas fuel tank and associated arrangements are not yet installed and the main engine and incinerator are approved, certified and installed ready for gas fuel operation, in accordance with the

LR Rules and Regulations for the Classification of Natural Gas Fueled Ships in force on date of contract for construction for the vessel in question.

Where parts of the gas fuel installation are installed on board in order to maintain the **GR** notation with the applicable associated characters described in 1.2.2, these are to be surveyed as required by the applicable requirements of the survey regulations referenced in 1.1.7.

Some critical requirements that are satisfactorily addressed are:

As far as the Fuel Tank – Protective distance

1. At the summer load line, is the fuel tank(s) located at a distance greater than B/5 or 11.5 m (whichever is less) from the side of the ship?

Distance is greater than B/5. B=26 m

GF 5.3.6 / IGF 5.3.3

The distance is measured from the ship's side shell plating to the primary barrier of the fuel tank (i.e. the barrier normally in contact with the fuel). For measurement purposes only, the primary barrier of the tank includes connected pipework that cannot be isolated, and the isolating valve along such pipework. Hence, if the distance measured to the pipework or valve is less than that measured to the fuel tank then this distance is used in answer to this question. The letter 'B' is the greatest moulded breadth of the ship at or below the deepest draught (summer load line draught).

2. Other than at the summer load line, from the side of the ship, is the fuel tank(s) located at a distance greater than B/10 for a passenger ship or at a distance greater than 0.8 m* for a cargo ship? Distance is greater than B/10. B=26 m

GF 5.3.6 / IGF 5.3.3

**For a cargo ship, if the volume of a fuel tank(s) (Vc) is greater than 1,000 m3 then the following distance shall replace 0.8 m in the above question:*

- 0.75 + Vc x 0.2/4,000 m, where 1,000 m3 < Vc > 5,000 m3;

- 0.8 + Vc/25,000 m, where 5,000 m3 ≤ Vc < 30,000 m3; and

- 2 m, where Vc ≥ 30,000 m3.

Vc corresponds to 100% of the gross design volume of an individual fuel tank at 20°C, including domes and appendages. Letter 'B' is defined in Question 1.

3. Is the fuel tank(s) located at a distance greater than B/15 or 2 m (whichever is less) from the bottom of the ship? Distance is greater than 2 m. B=26 m.

IGF 5.3.3
The distance is measured from the primary barrier of the fuel tank to the moulded line of the ship's bottom shell plating at the centreline. Letter 'B' is defined in Question 1. For guidance on measuring the distance
see Question 1.

4. Is the fuel tank(s) located at a distance greater than 0.08L from the forward perpendicular for a passenger ship or located abaft (behind) the collision bulkhead for a cargo ship? Distance is greater than 50 m.

IGF 5.3.3
The distance L is as per SOLAS regulation II-1/2.5. This refers to the International Convention on Load Lines: Article 2 - "(8). "Length" means 96% of the total length on a waterline at 85% of the least moulded depth measured from the top of the keel, or the length from the fore-side of the stem to the axis of the rudder stock on that waterline, if that be greater. Where the stem contour is concave above the waterline at 85% of the least moulded depth, both the forward terminal of the total length and the foreside of the stem respectively shall be taken at the vertical projection to that waterline of the aftermost point of the stem contour (above that waterline). In ships designed with a rake of keel the waterline on which this length is measured shall be parallel to the designed waterline."

As far as the Fuel Tank – below deck – Fuel tank within a fuel Storage Hold Space (FSHS)

5. Is the class division between the FSHS and adjoining space(s) A-60? YES

GF 10.2.3 / IGF 11.3.3.
The FSHS has A-60 boundaries. HFO tanks are in a room/space below the LNG fuel tanks. There is a cofferdam between the decks of varying depth, but is typically 0.5 m.

6. Is the FSHS designated as non-hazardous (i.e. 'gas safe')? Yes

GF 5.6 / IGF 5.11
The FSHS may be 'non-hazardous' if: (a) the fuel tank is Type C or it has a full secondary barrier (to contain all leakages); (b) all pipe connections are provided with a full secondary

barrier (to contain all leakages); (c) ventilation inlets and outlets are from/to the open deck; and (d) no other gas containing equipment is within the FSHS

7. Has the fuel tank(s) been sized taking full account of accepted filling and loading limits? Yes

GF 6.3.8/ IGF 6.8
Filling and loading limits influence the physical dimensions of the tank(s). These limits should be considered to ensure there is sufficient available space for the tank.

8. In the event of a credible maximum leakage, will the leaked fuel and generated vapour be contained within the TCS and the vapour vented to a safe location? YES. To be designed appropriately and supporting calculations are to be provided if the design is progressed to GF.

GF 5.3.3, 5.4.2, 6.4.3 / IGF 6.3.7, 6.3.8, 6.7.1.1
The TCS is to be designed to withstand (without leakage) the maximum pressure within the space in the event of a credible maximum leakage. This can be achieved through structural design and (as necessary) venting of gas and generated vapour. A 'credible maximum leakage' is, for example, a full-bore failure downstream of the Tank Master Isolation Valve (TMIV) where either: (a) the leak is 'fed' by tank pressure and the leak ceases once the pressure has reduced or the fuel inventory has been exhausted; or (b) the leak is 'fed' by a pump (owing to insufficient tank pressure) and the leak ceases once the pump is 'closed' or the inventory of fuel has been exhausted.

As far as the Tank Connection Space (TCS) – Below Deck

9. Is the TCS within a Fuel Storage Hold Space (FSHS) or a Fuel Preparation Room (FPR)? The TCS is within FHM

Tank connections (i.e. valves and instruments) are required to be located as close as possible to the fuel tank. If the TCS is located outside the FSHS then this requirement may not be met and special consideration by LR will be required.

10. Does the TCS contain tank connections and fuel preparation equipment? Yes. All connections and gas fuel preparation equipment are located within the TCS.

This is because: (a) the TCS is within the FSHS; (b) the TCS contains only
tank valves and/or instruments; and are not applicable to the TCS (they are applicable to the FSHS covered by Section B).

As far as Pressure Relief Valves (PRVs)

11. Can fuel tank pressure be maintained below the set pressure of tank PRVs for a minimum period of 15 days? Yes

IGF 6.9.1.1
The minimum period of 15 days assumes a full tank at normal service pressure and the ship in idle condition (i.e. only power for domestic load is generated). This requirement can be achieved through tank/PRV design (i.e. pressure accumulation) and/or liquefaction of vapours, thermal oxidation of vapours, liquefied gas fuel cooling, and the use of fuel consumers.

As far as the Bunkering Stations (BS)

12. Is the BS(s) located on open deck in a naturally 'well ventilated' location or in a space that is provided with forced ventilation? BS is an enclosed space with air-lock and forced ventilation.

GF 5.2.1 / IGF 8.3.1.1, 13.7
Forced ventilation (at least 30 air changes/hour) is required if the space is enclosed on three or more sides.

13. Is the bunkering manifold designed to withstand the external loads expected during bunkering? To be designed

GF 6.2.10 / IGF 8.4.1
Completion of this task is required to gain approval for Gas Fuelled Readiness (GR) Notation (A – approval in principle) and/or for the screening element (if used) for Assessment of Risk Based Designs, Stage 1. GR(A) is subject to approval of the drawings and information to be submitted as part of GR(A). Approval in Principle (AIP) and GR(A) relates to the 'gas' equipment installed on the vessel. It does not take into account the LNG bunkering operation and the safety zone that that will be in operation during bunkering.

It should be noted that 'GR (A)' Approval in Principle does not guarantee design approval for classification. There may well be technical or regulatory challenges which appear when details of the design are considered and are subjected to full application of the normal rigors of classification approval (including LR's assessment of 'Risk Based Designs', RBD). Design approval will require revision and re-submission of the plans and documents together with submission of all plans and documents as required by LR's rules. This full submission will require formal approval both from classification aspects and statutory aspects (subject to Flag Administration authorizations). Subject review refers to the gas readiness level of the proposed gas fuel system. For the assignment of the relevant gas fuelled notation, detailed design appraisal in compliance with the relevant LR Rules and statutory requirements as applicable will be required.

3.7.2. Stability Conclusions

After the modification, the changes in the lightship weight and longitudinal centre of gravity have been marginally found to be within the acceptable tolerances as defined by MSC/Circular.1158. The changes in the watertight subdivision of the ship, as identified in the corresponding plans, show that the existing stability information can be considered as valid. Based on the submitted loading conditions, the vessel has demonstrated compliance with the applicable intact and damage stability requirements at the fully loaded conditions which correspond to a draught of 7.0m in departure. Finally, the possibility of flooding of the
LNG bunkering compartment, assuming that the ship is damaged, has been estimated using the SOLAS 2009 probability distributions and found to be about 5.4%.

3.7.3. Electro technical and machinery aspects. Comments in accordance with relevant Lloyd's Register Rules & Regulations:

LNG Retrofit Concept Design Flow Diagram:

- The system design, including the gas bunkering stations , gas storage tanks, gas process equipment and gas-fuelled machinery , shall be subject to risk based studies and acceptable to LR while the system design is also to satisfy the requirements of section 6 of LR Gas Fuelled Ships Rules. Relevant plans and information are to be submitted as required by section 2 and 3 of the Rules for class and statutory approval against the relevant requirements of the IGF code.

- Bunkering operations are to be capable of being controlled from a safe location where gas storage tank pressures and level indicators are provided. Overfill alarm and automatic shutdown is to be indicated at this location. As per Paragraph 6.2.1 of Natural Gas Fueled Ship Rules refers. *(LR Rules and Regulations for the Classification of Natural Gas Fueled Ships July_6.2.1 Bunkering operations are to be capable of being controlled from a safe location where gas storage tank pressures and level indictors are provided. Overfill alarm and automatic shut-down is to also be indicated at this location.)*
- Gas storage tanks, including their design, materials, and construction and testing are to be in accordance with the requirements for liquefied gas cargo tanks in Chapters 2, 3, 4 and 6 of the Rules for Ships for Liquefied Gases, and Class 1 fusion welded pressure vessels in Pt 5, Ch.11 of the Rules for Ships. Par. 6.3.1 of Natural Gas Fuelled Ship Rules. *(Gas storage tanks, including their design, materials, and construction and testing, are to be in accordance with the requirements for liquefied gas cargo tanks in chapters 2, 3, 4 and 6 of the IGC Code, and Class 1 fusion welded pressure vessels in Pt 5, Ch 11 of the Rules for Ships.)*
- The filling limit of an LNG tank is to ensure that the gas in the inlet of the pressure relief valve(s) will remain in the vapour phase under normal and emergency conditions. Paragraph 6.3.8 of the Gas Fuelled Ship Rules *(6.3.8 Storage tanks are to have a tank master isolating valve located as near to the tank as is practicable. This valve is to be capable of local manual operation and provide full closure.)*
- The Maximum Allowable Working Pressure (MAWP) of gas storage tanks is not to exceed 90 per cent of the Maximum Allowable Relief Valve Setting (MARVS) as per paragraph 6.3.18 of the Gas Fuelled Ship Rules refers. It is also noted that from LR experience, a proposed 92% loading limit is the upper ‘acceptable’ limit for a horizontal tank of the size proposed and operating at approximately 6 bar with a tank design pressure of 10 bar. (DSQ-LR comment 13/H refers).

- Any increased boil-off due to failure of gas storage tank insulation is not to result in an uncontrolled release of gas to atmosphere. Paragraph 6.3.3 of Natural Gas Fuelled Ship Rules refers.
- It is to be confirmed that piping connected below the liquid level of the gas storage tanks are protected by a secondary barrier (i.e. double wall pipe) up to the first valve. Paragraph 6.3.5 of Natural Gas Fuelled Ship Rules refers.
- **Confirmation** is required that tank master isolation valve is located as near to the tank outer shell as is practicable and within the tank connection space. This valve is to be capable of remote and local manual operation and provide full closure. Paragraph 6.3.6 of the Gas Fuelled Ship Rules refers.*(6.3.6 Pressure relief valves as required in IGC Code chapter 8 are to be fitted. The outlet from the pressure relief valves are normally located at least B/3 or 6 m, whichever is greater, above the weather deck and 6 m above the working area and gangways, where B is the greatest moulded breadth of the ship in meters. The outlet from pressure relief valves is to be led to the open at least 10 m from the nearest air intake or opening to accommodation spaces, service spaces and control stations, or open decks which are accessible to personnel, or other non-hazardous spaces. It is also to be located at least 10 m from the nearest exhaust outlet from machinery installations. As an alternative to the distance requirements given above, a safe release of gas vented from the pressure relief valves may be permitted by the Administration.)*
- **Tank connections** including all piping and equipment therein are to satisfy the requirements of 6.4 of Gas Fuelled Ships. In particular it is highlighted that the tank master isolation valve is to be subjected to a Failure Modes and Effects Analysis (FMEA). Paragraph 6.4.10 of the Gas Fuelled Ship Rules refers. *(6.4.10 _Provision is to be made for gas-freeing and inerting gas piping.)*
- The gas supply system is to comply with the requirements of 6.5 of Gas Fuelled Ships and also with Part 5 of Ship Rules as applicable.
- Propulsion Engine_Main Engines and associated systems /components are to be certified for gas fuel. In this respect It is noted that main Engine is of type Wärtsilä 16V46C It is understood/ expected that while subject engine as constructed, delivered and installed is not suitable for dual fuel operation, this may be retrofitted to operate also with Natural Gas in full compliance with the relevant requirements of section 6.6 of Gas Fuelled Ships and 10.3 IGF code. Engine manufacturer confirmation, supplemented by any available general or type approval and relevant unit retrofit approval and certification procedure are to be presented.

- Main Engines and associated systems /components are to be certified for gas fuel. In this respect It is noted that main Engine is of type Wärtsilä 16V46C It is understood/ expected that while subject engine as constructed, delivered and installed is not suitable for dual fuel operation, this may be retrofitted to operate also with Natural Gas in full compliance with the relevant requirements of section 6.6 of Gas Fuelled Ships and 10.3 IGF code. Engine manufacturer confirmation, supplemented by any available general or type approval and relevant unit retrofit approval and certification procedure are to be presented.
- Piping_ Design and construction of piping is to be as required by section 7. Of LR Natural Gas Fuelled Ship Rules / section 7 of IGF.
- Noting that Gas fuel supply piping is to fulfil one of the requirements in paragraph 7.2.19 of the Gas Fuelled Ship Rules and relevant selection will affect the further design, the applicable protection method each and every part of the piping system in each location should be made clear at an early stage of the design. *(7.2.19_Low temperature liquefied gas piping is to have suitable insulation supplied in two layers, with joints staggered and covered with an efficient vapour barrier.)*

Electrical, Control, alert and safety systems requirements:

- Electrical, Control alarm and safety system systems are to comply with the requirement of sections 8 and 9 of the Gas Fuelled Ship Rules.

Fuel Storage Hold Space (FSHS)

The existing cofferdam of 0.5 m between the HFO tanks and LNG fuel tanks is accepted provided that the insulation of Deck 1 is A-60 class as per Section 10.2.3 of the Natural Gas Fuelled Ship Rules, 11.3.3 of IGF.

Fire Control Plan LNG Retrofit Concept Design

- A fire detection and alarm system, satisfying the requirements of Pt.6, Ch.1, 2.8.2 to 2.8.14 of the Rules for Ships, is to be fitted in all spaces containing potential sources of gas leakage and ignition.
- Gas detectors should be fitted in spaces in which gas fuel is utilised, particularly in the zones where air circulation is reduced. The gas detection system should comply with the requirements of Section 8.4 of the Gas Fuelled Ship Rules.

- A permanently installed dry chemical powder fire-extinguishing system is to be installed in the bunkering station area to cover all possible leak points. Paragraph 10.5.1 of the Gas Fuelled Ship Rules.

Ventilation System for LNG Retrofit Concept Design

- All enclosed hazardous areas are to be provided with fixed mechanical ventilation of negative pressure that has a capacity of at least 30 air changes per hour under all foreseeable operating conditions, including a single failure in equipment or control system. Paragraph 5.8.1 of the Gas Fuelled Ship Rules. Noting that tank connection space is provided only with exhaust ventilation, this will need to be further evaluated through a Risk Assessment (phase II*). (5.8.1 All enclosed hazardous areas are to be provided with fixed mechanical ventilation of negative pressure that has a capacity of at least 30 air changes per hour under all foreseeable operating conditions, including a single failure in equipment or control system. The arrangements are to be such that there will be no regions of stagnant air within the ventilated space.*

3.7.4. Cost approach for an LNG as fuel system retrofitting project:

List of the cost effect items for provisions of the ME-GI retrofit.
The items provided below are from an identical case scenario having the cost effect for provisions of ME-GI retrofit and comparison of Specifications between Builder's Outline and the ME-GI retrofit to be done by the Owner in the future. Since for the stage that we are with 'our' Scenario and there is no much information of the items, It is tried to conform our perspective retrofitting with the cost of some relevant modifications on board from another vessel and with the prices of a big Korean Shipyard DSEM.
LNG storage tanks. The hull structure shall be reinforced, by the Builder, to install two (2) LNG storage tanks (2 x 1,000 m3, 2 x 300 MT)" on main deck. Cost: 180.000$, - 200.000$.
Fuel gas room.
The hull structure for fuel gas supply room [8m x 11m x 4.5m (h)] to be pro Firefighting system for FGS and LNG tank.
The following systems to be provided:

FGS room
- High pressure CO2 system combined with ER CO2 system

- SW from fire main
- Portable fire extinguisher

LNG tank
- Dry powder system
- Water spray system
- SW from fire main

LNG bunkering area
- Dry powder system
- Water curtain system (hull side only)

However, one (1) dedicated water spray pump with starter including cabling, capacity of approx. 360m3/h, and water spray main line in ER to be provided. Extra 78,800 vided on main deck by the Builder. Extra 100,000$ for all the equipment.-

Piping for FG system -
FG piping for ME-GI in the ER to be provided with cost adjustment.
- From the connection on ER outside (about 500 mm from the upper or accommodation) to Engine connection (not to include Flexible helix pipe)
- Inner FG pipe: Duplex steel
- Outer FG pipe: Duplex steel
- Any other provisions other than FG piping itself not to be provided by the Builder.
FG piping for GE and aux. boiler not to be provided by the Builder. Cost: 251,500$
Feeder breaker in switchboard for additional equipment of ME-GI: Not provided by the Owner. Feeder breakers for additional equipment of ME-GI system to be provided in switchboard by the Builder.
Local starter for additional equipment of ME-GI system to be provided by the Owner. Cost 5,500&-
Engineering fee: Approximately 15,000.

3.7.5. Conclusions: Technical and economic aspects related to the possible retrofitting of LNG fuel systems on board existing vessels.

It was presented a fully worked example of the retrofitting scenario of the RO-PAX Vessel. The ships two Wartsila main engines will be retrofitted to use both LNG and fuel oil. The 3 x Type-C vacuum-insulated tanks LNG tanks and Cold Boxes will be located inside deck. It was considered as an attractive payback for operation in ECA regions.

Since that at the time of writing of the thesis still a lot of number of factors was not provided and it needs to be admitted that no decision can be made at this point with an acceptable level of certainty.

At the time of the study a higher CAPEX requirement would be required to convert to LNG, that the MGO-HFO spread is the main sensitivity but the absolute LNG price is also important, application of LNG as a fuel to a new build will make the option more attractive.

In addition, the LNG-fuelled engines are a viable option in the long term in case of retrofitting, particularly for ships on liner trades in order to make the initial investment beneficial to the Owner.

3.8. Table with summarising conclusions of the Class comments regarding the LNG as fuel retrofit GR (A) Approval in Principal compliance in accordance with relevant LR Rules & Regulations and IGF Code.

1. Design Screening - AIP & GR(A) Notation – LNG as Fuel
✓ LR comments of the Design Screening questionnaire which could not be identified in specific submission:
✓ Note that thermal isolation needs to consider LNG leakage into: (a) the annular space of the LNG fuel tanks; and (b) the TCS.
✓ Loading of cars during LNG bunkering is not envisaged. However, maintenance, inspection and deliveries can be expected. Therefore, these activities need to be considered with respects to protection of the BS location, deck access and activities, and ventilation requirements of the BS and decks, etc.
Following matters (as presented in paragraphs 2-7 below) are indicated as prioritising targets for detailed level of design (Phase II).
2. LNG Retrofit Concept Design Flow Diagram
✓ The system design , including the gas bunkering stations , gas storage tanks, gas process equipment and gas-fuelled machinery , shall be subject to risk based studies and acceptable to LR while the system design is also to satisfy the requirements of section 6 of LR Gas Fuelled Ships Rules. Relevant plans and information are to be submitted as required by section 2 and 3 of the Rules for class and approval against the relevant requirements of the IGF code.
Gas bunkering system
The gas bunkering system is to comply in particular with the requirements of 6.2 LR Gas Fuelled Ships Rules.
Arrangements are to be provided to the Gas bunkering system to: ✓ (a) drain any liquefied gas from bunkering lines/pipes; ✓ (b) purge (i.e. make gas-free) bunkering lines/pipes with inert gas; ✓ (c) confirm that bunkering lines/pipes are free of liquefied gas and vapour (gas) upon completion of bunkering. ✓ Paragraph 6.2.7 of Natural Gas Fuelled Ship Rules refers.

✓ Bunkering operations are to be capable of being controlled from a safe location where gas storage tank pressures and level indicators are provided. Overfill alarm and automatic shutdown is to be indicated at this location. Paragraph 6.2.1 of Natural Gas Fuelled Ship Rules refers.
Gas Storage Tanks
✓ Gas storage tanks, including their design, materials, and construction and testing are to be in accordance with the requirements for liquefied gas cargo tanks in Chapters 2, 3, 4 and 6 of the Rules for Ships for Liquefied Gases, and Class 1 fusion welded pressure vessels in Pt 5, Ch.11 of the Rules for Ships. Par. 6.3.1 of Natural Gas Fuelled Ship Rules
✓ The filling limit of an LNG tank is to ensure that the gas in the inlet of the pressure relief valve(s) will remain in the vapour phase under normal and emergency conditions. Paragraph 6.3.8 of the Gas Fuelled Ship Rules refers.
✓ The Maximum Allowable Working Pressure (MAWP) of gas storage tanks is not to exceed 90 per cent of the Maximum Allowable Relief Valve Setting (MARVS) as per paragraph 6.3.18 of the Gas Fuelled Ship Rules refers. It is also noted that from LR experience, a proposed 92% loading limit is the upper ‘acceptable’ limit for a horizontal tank of the size proposed and operating at approximately 6 bar with a tank design pressure of 10 bar
✓ Any increased boil-off due to failure of gas storage tank insulation is not to result in an uncontrolled release of gas to atmosphere. Paragraph 6.3.23 of Natural Gas Fuelled Ship Rules refers.
✓ It is to be confirmed that piping connected below the liquid level of the gas storage tanks are protected by a secondary barrier (i.e. double wall pipe) up to the first valve. Paragraph 6.3.5 of Natural Gas Fuelled Ship Rules refers.
✓ Confirmation is required that tank master isolation valve is located as near to the tank outer shell as is practicable and within the tank connection space. This valve is to be capable of remote and local manual operation and provide full closure. Paragraph 6.3.6 of the Gas Fuelled Ship Rules refers.
Tank Connection space
✓ Tank connections including all piping and equipment therein are to satisfy the requirements of 6.4 of Gas Fuelled Ships. In particular it is highlighted that the tank master isolation valve is to be subjected to a Failure Modes and Effects Analysis (FMEA). Paragraph 6.4.10 of the Gas Fuelled Ship Rules refers.
Gas supply system

✓ The gas supply system is to comply with the requirements of 6.5 of Gas Fuelled Ships and also with Part 5 of Ship Rules as applicable
Propulsion Engine
✓ Main Engines and associated systems /components are to be certified for gas fuel. In this respect It is noted that main Engine is of type Wärtsilä 16V46C It is understood/ expected that while subject engine as constructed, delivered and installed is not suitable for dual fuel operation, this may be retrofitted to operate also with Natural Gas in full compliance.
✓ Engine Manufacturer gas system installation instructions/ specification need to be presented for correlation with subject plan revised and completed as necessary.
Piping
✓ Design and construction of piping is to be as required by section 7. Of LR Natural Gas Fuelled Ship Rules / section 7 of IGF.
✓ Noting that Gas fuel supply piping is to fulfil one of the requirements in paragraph 7.2.19 of the Gas Fuelled Ship Rules and relevant selection will affect the further design, the applicable protection method each and every part of the piping system in each location should be made clear at an early stage of the design.
Electrical, Control , alert and safety systems
✓ Electrical, Control alarm and safety system systems are to comply with the requirement of sections 8 and 9 of the Gas Fuelled Ship Rules.
LNG Arrangement System Details
✓ Fuel Storage Hold Space (FSHS)
✓ The existing cofferdam of 0.5 m between the HFO tanks and LNG fuel tanks is accepted provided that the insulation of Deck 1 is A-60 class as per Section 10.2.3 of the Natural Gas Fuelled Ship Rules, 11.3.3 of IGF.
✓ The bulkhead separating the FSHS from the car deck is to be designed sufficient to withstand vehicle impact at 30 km/h (and watertight taking into account stability considerations). Additional collision bollards or similar are recommended. The double walled bunker pipe and the penetration of this pipe through the FSHS bulkhead will be designed to maintain integrity in the event of vehicle impact as per Section 10.2.3 of the Natural Gas Fuelled Ship Rules, 11.3.3 of IGF.

✓ Dedicated bilge is not required because the FSHS is to be designed as a non-hazardous space. However, to ensure bilge from other areas cannot enter the FSHS bilge; confirmation is requested on installation of section valves (e.g. non-return valves) to separate FSHS bilge from the bilge of other areas such as the garage space. Section 6.3.9 of the Natural Gas Fuelled Ship Rules, 5.9 of IGF refers.
Tank Connection Space (TCS)
✓ All tank connections, fittings, flanges and tank valves are to be enclosed in a tank connection space. Paragraph 6.3.3 of the Gas Fuelled Ship Rules refers.
✓ The TCS is to be designed to withstand (without leakage) the maximum pressure within the space in the event of a credible maximum leakage. This can be achieved through structural design and (as necessary) venting of gas and generated vapour. Paragraph 5.3.3/6.4.1 of Natural Gas Fuelled Ship Rules, 6.3.8 of IGF refers.
✓ Guidance should be taken from the TCS manufacturer/supplier on the venting duct size required to vent the gas/vapour in the event of a credible maximum leakage. Section 6.4 of the Natural Gas Fuelled Ship Rules, 13.3.8 of IGF refers.
✓ Connections between the tank connection space and gas storage tank are to be subjected to stress and fatigue analysis to demonstrate their suitability for their intended
Bunker Station (BS)
✓ The unused shell door/ramp (frames 169 to 175) is located close to the portside BS and needs to be made gastight. Paragraph 5.3.1 of the Gas Fuelled Ship Rules, 5.7.2 of IGF refers.
✓ Bunker Station is to be located in an appropriate area ensuring the MES vertical launch area is not compromised. Paragraph 5.3.1 of the Gas Fuelled Ship Rules, 5.7.2 of IGF refers. In this respect, Ship's FSA consensus may also be required.
Fire Control Plan LNG Retrofit Concept Design
✓ A fire detection and alarm system, satisfying the requirements of Pt.6, Ch.1, 2.8.2 to 2.8.14 of the Rules for Ships, is to be fitted in all spaces containing potential sources of gas leakage and ignition.
✓ Gas detectors should be fitted in spaces in which gas fuel is utilised, particularly in the zones where air circulation is reduced. The gas detection system should comply with the requirements of Section 8.4 of the Gas Fuelled Ship Rules.
✓ A permanently installed dry chemical powder fire-extinguishing system is to be installed in the bunkering station area to cover all possible leak points. Paragraph 10.5.1 of the Gas Fuelled Ship Rules refers.

Inerting arrangements are to be provided for:

- ✓ purging of all gas piping during normal operation and ESD;
- ✓ purging of gas-fuelled machinery;
- ✓ atmospheric control, e.g. double-walled piping annulus, inter-barrier spaces;
- ✓ fire protection systems

Paragraph 6.8 of the Gas Fuelled Ship Rules refers.

Escape Plan (LNG Retrofit)

- ✓ It has been indicated that escape routes/exits from the FSHS need to be confirmed. Typically, two independent escape routes are required: each to a different safe space with an airlock separating a hazardous (e.g. car deck) and non-hazardous space. Exits to be considered include: access to car deck adjacent to FSHS; and access to car deck above FSHS. (DSQ-LR comment 8/4 refers)
- ✓ Access from the FSHS is from: (1) airlock to car deck; and (2) portside and starboard side airlocks to spaces with vertical access to the deck above. (DSQ-LR comment 8/E refers)

6. Hazardous Areas LNG Retrofit Concept Design

- ✓ All air locks, as required for safe separation of non-hazardous areas from hazardous areas to satisfy 5.6 of the Gas Fuelled Ship Rules, 5.12 of IGF.

- ✓ Any electrical installation (system / equipment) installed or serving hazardous area as well as that serving the Fuel Storage Hold Space should be certified and installed as per relevant requirements of section 9 of Natural Gas Fuelled Ship Rules and section 14 of the IGF. Special attention is drawn to 12.5.2.8 of IGF according to which for any space protected by an airlock, any equipment required to operate following loss of deferential pressure between the protected space and the hazardous area , should be certified for zone 1.

- ✓ The differential pressure of the ventilation systems serving adjacent spaces of deferent hazardous area categories is to be in accordance with Natural Gas Fuelled Ship Rules section 5.7.

- ✓ The inlet of TCS ventilation openings shall be arranged at least 3 m vertically clear of any structure and at least 6 m from the nearest air intakes or openings to accommodation and enclosed working spaces and from possible sources of ignition. Section 6.4.3(g) of the Natural Gas Fuelled Ship Rules, 6.3.7/6.3.8/6.7.1.1 of IGF refers.

✓ All enclosed hazardous areas are to be provided with fixed mechanical ventilation of negative pressure that has a capacity of at least 30 air changes per hour under all foreseeable operating conditions, including a single failure in equipment or control system. Paragraph 5.8.1 of the Gas Fuelled Ship Rules. Noting that tank connection space is provided only with exhaust ventilation, this will need to be further evaluated through a Risk Assessment (phase II).
✓ The ventilation system for the fuel storage hold spaces should comply with Paragraph 5.8 of the Gas Fuelled Ship Rules, 13.3 of IGF. SOLAS (and other statutory) requirements remain applicable to FSHS ventilation.
✓ Air inlets for hazardous enclosed spaces shall be taken from areas that would be non-hazardous. Air inlets for non-hazardous enclosed spaces shall be taken from non-hazardous areas at least 1.5 m away from the boundaries of any hazardous area.
✓ The differential pressure of the ventilation systems serving adjacent spaces of deferent hazardous area categories is to be in accordance with Natural Gas Fuelled Ship Rules section 5.7.

Table 3: Table with summarise comments for class and IGF Compliance

Chapter 4

Scenarios analysis of the three alternatives Methods from economical and technical point view

4.0. Scenarios analysis of the three alternatives Methods from economical and technical point view.

The objective is to bring the attention of critical points of the project and to set up practical solutions as well as uncovering the financial aspects regarding installation, operation and maintenance of the three most realistic alternatives:

- Low-Sulphur fuel/distillate
- LNG as fuel
- Scrubber technology

In the study, the use of low-Sulphur fuel/distillate will function as reference case as to the feasibility of the other two investigated solutions. The alternative solutions will be evaluated by means of various scenarios considering operational profiles and fuel prices, and the evaluation will take into account that the vessel will be sailing in both ECA and non-ECA waters. This comparison Scenarios extracted from the Stuby of the Green Ship of the Future, having my comments from Operational and Technical point of view.

4.1. Real Case scenario: Technical and Economical evaluation of retrofitting to existing vessel the three alternative Solutions (MGO, Scrubber Technology, LNG as fuel), in order to comply with the IMO Air Emission regulations.

Our vessel is a 38,500 dwt product tanker. The service speed at design draft including 15% sea margin is 14.0 knots. Details are provided in the tables below.

Main Particulars	
Length (LOA):	182.86 m
Length PP (LPP):	174.50 m
Breadth (Bmld):	27.40 m
Depth (Dmld):	16.80 m

Draft (Design) :	9.55 m
Draft (Scantling):	11.60 m
Deadweight (Design):	29,000 dwt
Deadweight (Scantling)	38,500 dwt

Table 4:: Ship Main Particulars

Installed Main Engine

Supplier	MAN B&W
Model	6S50MC-C7.1TI
Specified Maximum Continuous rating (SMCR)	9,480 kW@ 127.0 RPM
Normal Continuous rating (NCR)	8,058 kW @ 120.3 RPM

Table 5: Main Engine data

Installed Auxiliary Engines

Supplier	MAN B&W
Model	3 X 6L23/30H
Normal Continuous rating (NCR)	960kW @ 900 RPM
	910 KWe, 450V@ 60 Hz
SFOC (mechanical)	197 g/kWh +/- 5%
SFOC (electrical)	240 g/kWeh

Table 6: Auxiliary Engine data

4.1.1. Change from fuel (HFO) to low-Sulphur fuel (MGO).

The tanker in as-built condition in case of operation in ECA will shift to low-sulphur fuel in order to comply with the emission requirements. Low-sulphur fuel comprises fuel with not more than 0.1% sulphur in the case of ECA operation as of 2015. In addition, it comprises fuel that will satisfy the global sulphur cap of 0.5% as of 2020 as agreed in IMO on November of October of this year setting the Low sulphur contents fuel oil used by ships not to exceed the 0.50% m/m as of January 2020. For simplicity reasons, all of these low-sulphur fuels are referred to as 'MGO' (marine grade oil, i.e. distillates). The expectation is that the price difference between 0.1% and 0.5% sulphur fuel will be limited.

No major modifications are required in order to run on low-sulphur fuel, but for extended operation on MGO, it will be necessary to install a fuel cooler to increase viscosity to a sufficient extent. The fuel cooler should have a capacity of between 25 kW and 50 kW and can be placed in parallel to the fuel pre-heater of the main engine. The cost of such a cooler lies in the range of 30,000 - 50,000 USD. Attention must be paid to lubrication oil: depending on the duration of continued operation on MGO, it will be necessary to apply an appropriate type of system or cylinder oil for the main engine and auxiliary engines.

The total adaptation cost is considered negligible compared with the cost of purchasing MGO and is not taken into account in the financial analyses of the different scenarios when comparing with the option to fit a scrubber or to use LNG as a fuel.

The Table 6 below shows information on the number of operational days per year at sea and in port. In addition, for a certain percentage of time in ECA, the corresponding number of days in ECA is also shown.

Ship operation profile based upon 50% ECA			
	Non ECA	ECA	Total
Days at sea	110	110	220
Day at harbour idling	57.5	57.5	115
Days at harbour unloading	15	15	30
Total	182.5	182.5	365

Table 7: Operation data profile

Data from the referred vessel (based upon data from the ship owner) indicates an average operation of 13% in ECA (with a maximum of 17%). The average daily fuel consumption of the main engine and auxiliary engines (based upon operational data provided by the ship owner) is provided below in Table when running on HFO or MGO. The average fuel consumption is in the range of 60-70% MCR.

ME consumption at sea	
HFO	28.7 1 t/day
MG	27.0 t/day
AE consumption at sea	
HFO	3.7 1 t/day
MGO	3.5 1 t/day
AE consumption, harbour idling	
HFO	4.31 t/day
MGO	4.11 t/day
AE consumption, harbour unloading	
HFO	12.71 t/day
MGO	11.91 t/day

Table 8: Fuel consumption average

4.1.2. Operation in ECA, fuel options and global sulphur cap

All scenarios are for a period of 10 years spanning from 2015 to 2025. In view of the tentative date for the entry into force of the global sulphur cap of 2020 is considered for a number of cases so as to determine the sensitivity of investment decisions to this date. The global sulphur cap enters into force in 2020, the case scenario (shift to MGO in ECA) is shown in Table 6 below.

Scenario: MGO				
	2015- 2019		**2020-2024**	
	Non ECA	ECA	Non ECA	ECA
Consumption at sea (ME)	HFO	MGO	MGO	MGO
Consumption at sea (AE)	HFO	MGO	MGO	MGO
Consumption at port loading (AE's)	HFO	MGO	MGO	MGO
Consumption at port, unloading (AE's)	HFO	MGO	MGO	MGO

Table 9: MGO in ECA and after 2020.

The scenario for alternative- Solution 1, installing a scrubber system, would entail have HFO at all time for both the main engine and auxiliary engines as shown in Table.

Solution 1: Installing Scrubber operation				
	2015- 2019		2020-2024	
	Non ECA	ECA	Non ECA	ECA
Consumption at sea (ME)	HFO	HFO	HFO	HFO
Consumption at sea (AE)	HFO	HFO	HFO	HFO
Consumption at port loading (AE's)	HFO	HFO	HFO	HFO
Consumption at port unloading (AE's)	HFO	HFO	HFO	HFO

Table: 10: Scrubber operation

The scenario of alternative- Solution 2, enabling the use of LNG as fuel for the main engine, depends on whether or not LNG is used only in ECA or also outside ECA. Due to limited tank capacity of the LNG tanks (total volume is 700 m3 externally placed on the main deck, see section 5 of this report), the range of the vessel when running on LNG is limited to around 4,500 nautical miles. The selection of 4,500 nautical miles is based upon an operation from Suez to the Baltic Sea.

If the vessel is on a route where the distance between ports is less than this range, it is assumed that the vessel will run on LNG all the time, and that LNG can be bunkered in the various ports of call. For comparison purposes, analyses are also done for conditions where LNG would be used only inside ECA.

The LNG scenario for LNG used in both ECA and non-ECA is portrayed in Table below assuming the global sulphur cap as of 2020. In case of LNG used only inside ECA, MGO would be used for the main engine as of 2020 outside ECA.

Solution 2: LNG as fuel system operation				
	2015.2019		2020 - 2024	
	Non ECA	ECA	Non ECA	ECA
Consumption at sea {ME)	LNG/HFO *	LNG	LNG	LNG
Consumption at sea {AE)	HFO	MGO	MGO	MGO
Consumption at harbour, loading (AE)	HFO	MGO	MGO	MGO
Consumption at harbour, unloading (AE)	HFO	MGO	MGO	MGO

Table: 11: LNG operation

A main factor determining the use of LNG is the fuel cost: if the LNG purchasing cost is less than HFO, then the main engine will run on LNG outside ECA in the period 2015 - 2019, and if the cost of LNG is higher than HFO,then the vessel would run on the bunkered HFO under the same conditions (the retrofit solution has left the HFO tanks intact).

4.1.3. Fuel cost bunker analysis

Each cost scenarios are considered for HFO, MGO and LNG.

HFO: 280 USD per tonne

MGO - HFO: 300-350 USD per tonne additional cost for MGO compared with HFO

LNG: 550 USD, 650 USD and 750 USD per tonne depending on many reason as analysing below. The prices have been extracted from https://www.bunkerspot.com/.

In the financial analyses, it is assumed that whatever the selected price levels for the different fuels, they remain constant throughout the period 2015 - 2024. As mentioned in section 5 of the report, the cost difference between 0.1% and 0.5% sulphur is assumed to be negligible. The cost of LNG plays role such as on where it would be purchased as there is no global LNG market/pricing yet and also whether it is fixed relative to oil or gas price, hence in view of the significant market uncertainties above values should be considered only as indicative.

4.2. Solution 1st - Scrubber installation_ Pure SOx Scrubber

It is advised that the financial analyses carried out for a range of conditions from 0 to 100% operation in ECA.

The exhaust gas scrubber system removes sulphur oxides and particulates from exhaust gas. The scrubber system is a hybrid system being capable of operation both on fresh water as well as sea water. The shift between these operation modes can be made as flying change-over while the scrubber is in operation controlled by a GPS signal informing about the position of the vessel.

The scrubber consists of two sections - the jet scrubber and the packed tower. The jet scrubber is the inlet to the scrubber, and in this section of the scrubber the initial cooling and cleaning of the exhaust gas takes place before the exhaust gas enters the packed tower.

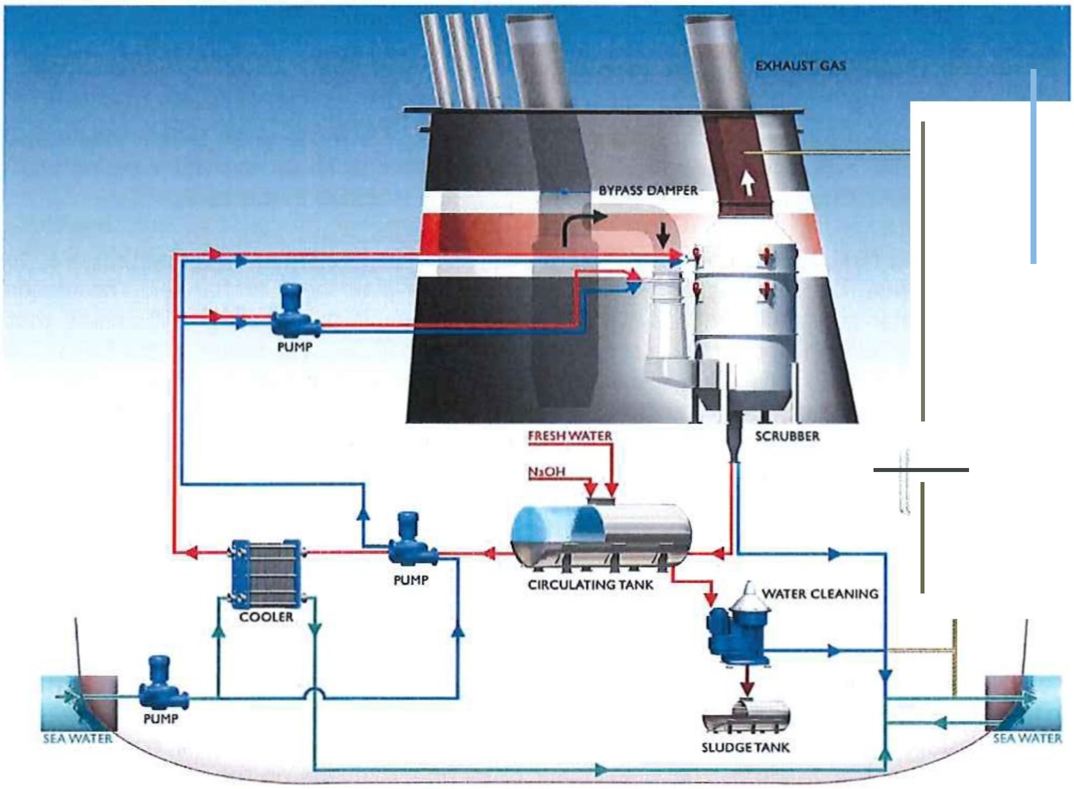


Figure 47: Installation of Scrubber (Source Green Ship)

The cooled exhaust gas will be cleaned in a packed tower filled with high-efficient/low-resistance packing material. This packing material has an open structure which prevents flooding under all loading conditions. On the other hand, the open structure has a large, wet surface ensuring a high efficiency in S02 and particulate removal.

The water used for scrubbing is supplied via spray pipes to guarantee a perfect distribution under all conditions including the ship's motions.

The exhaust gas leaves the scrubber with 100% R.H. Before leaving the scrubber, water droplets in the exhaust gas are separated by a demister. The demister efficiency is important to ensure a minimum of water loss, especially during fresh water operation, and to limit the content of water in the plume after the funnel.

The demister will be cleaned regularly to avoid soot build-up and excessive pressure drop. Inspection openings are installed for reasons of maintenance and inspection.

Dimensions/weights of the scrubber		
Length	6.8	m
Width	5.3	m
Height	8.7	m
Weight operational	15	ton

Table 12: Dimensions and weight of the Scrubber

The system includes a circulation tank for freshwater mode. This tank is needed for degassing the water and acts as a buffer tank for fresh water to fill up the water piping with fresh water after operation on sea water. Furthermore, NaOH is added in this tank.

While in fresh water mode, the cleaning water will be circulated in the system in a closed loop. In this mode, the cleaning water will be cooled in a plate heat exchanger. The reason for cooling the water is to limit the loss of water as cold water in the scrubber will ensure that water from the combustion of the oil will condensate in the scrubber. The water in the fresh water operation mode will be cleaned in a separator, and sludge and clean water are generated. The separated sludge from the water cleaning unit can go to the ship's sludge tank for delivery to shore. A part of the cleaned water will be fed back to the circulation tank, and the other part will be discharged directly overboard as its quality is within the MEPC guidelines.

As more engines are connected to the scrubber, precautions are made to avoid exhaust gas in standby engines. If an engine is not in operation, the exhaust gas supply to the jet scrubber is blocked by a double valve with a compressed air sealing system. Then the standby engine is effectively protected from exhaust gasses from the engines in operation.

The control panel contains all the equipment for controlling and adjusting the exhaust gas scrubber unit. All failure messages/communication etc. are integrated in a touch screen PLC installed on the front door of the control panel. In case of a failure, the direct cause of the failure will be made visible by changing colour or by an alarm sign on the screen. In case of failure or if an emergency bottom is activated, the exhaust gas scrubber will shut down automatically, and the by-pass damper will open without stopping the engine. After elimination of the failure, the exhaust gas scrubber can be restarted while the relevant failure extinguishes of the screen.

The exhaust gas scrubber monitoring and data logging system complies with the MEPC regulations. As the rules require, the system logs S02, C02, pH, PAH and turbidity data as well as stamping the GPS position. All this data will be logged every 30 sec/1min. The logged data is recorded on a PC and a sent by email once a day to various recipients

Operational information		
Max amount exhaust gas	92,000	kg/h
Exhaust gas pressure drop	100	mm/Wc
SOx Removal efficiency	Equivalent to 0.1% Sin fuel oil	

Table 13: Operational information

4.2.1. Modification requirements and main parts

The retrofitting of a scrubber system includes the following work on board the ship: Removal of the following equipment and structures:

- Funnel structure from D-deck and upwards
- B-deck platform aft of funnel (4.7m symmetrical about CL),incl. ladders
- C-deck platform aft of funnel (4.7m symmetrical about CL),incl. ladders
- D-deck platform aft of funnel (4.7m symmetrical about CL),incl. ladders
- Exhaust gas pipes from D-deck and upwards (excluded the pipe for oil fired boiler)
- Exhaust gas pipes for A/E from C-deck to D-deck
- Free fall life boat
- Installation of the following equipment and structures:
- B-deck extension, pillars, ladder and platforms
- Sludge tank (internal structure tank)
- FW circulation tank

- NaOH compartment and tank
- C-deck extension, pillars, ladder and platforms
- Scrubber
- D-deck extension, ladder and platforms
- Free fall life boat
- Exhaust gas pipes, scrubber water pipes etc
- Funnel top structure
- Scrubber auxiliary machinery and pipe connections
- 440 V, 220 V, 24 V Electrical and automation installation

Figure 48: Aft Ship as built photo

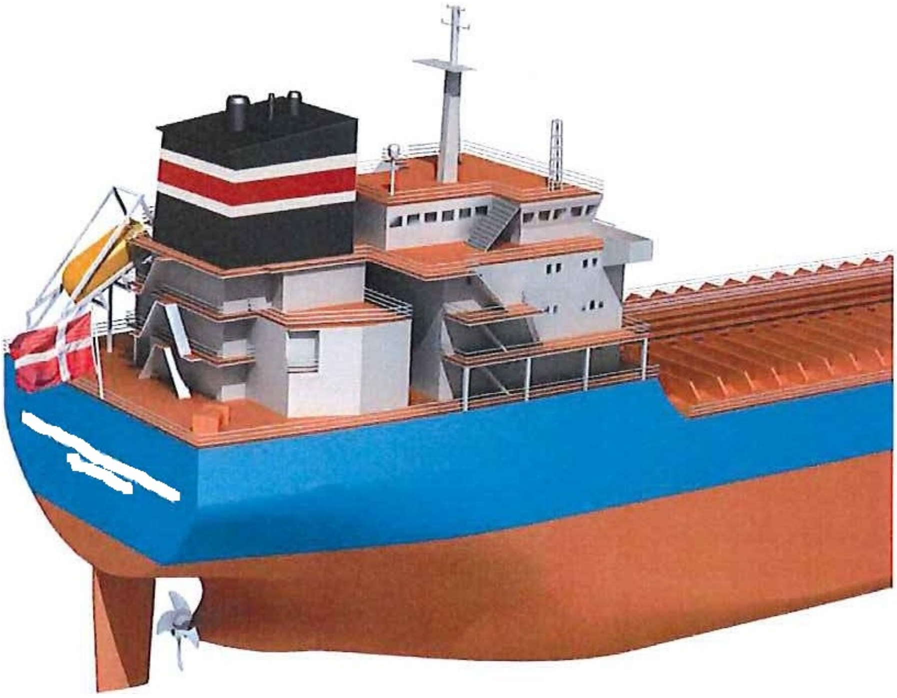


Figure 49: Aft Ship after modification

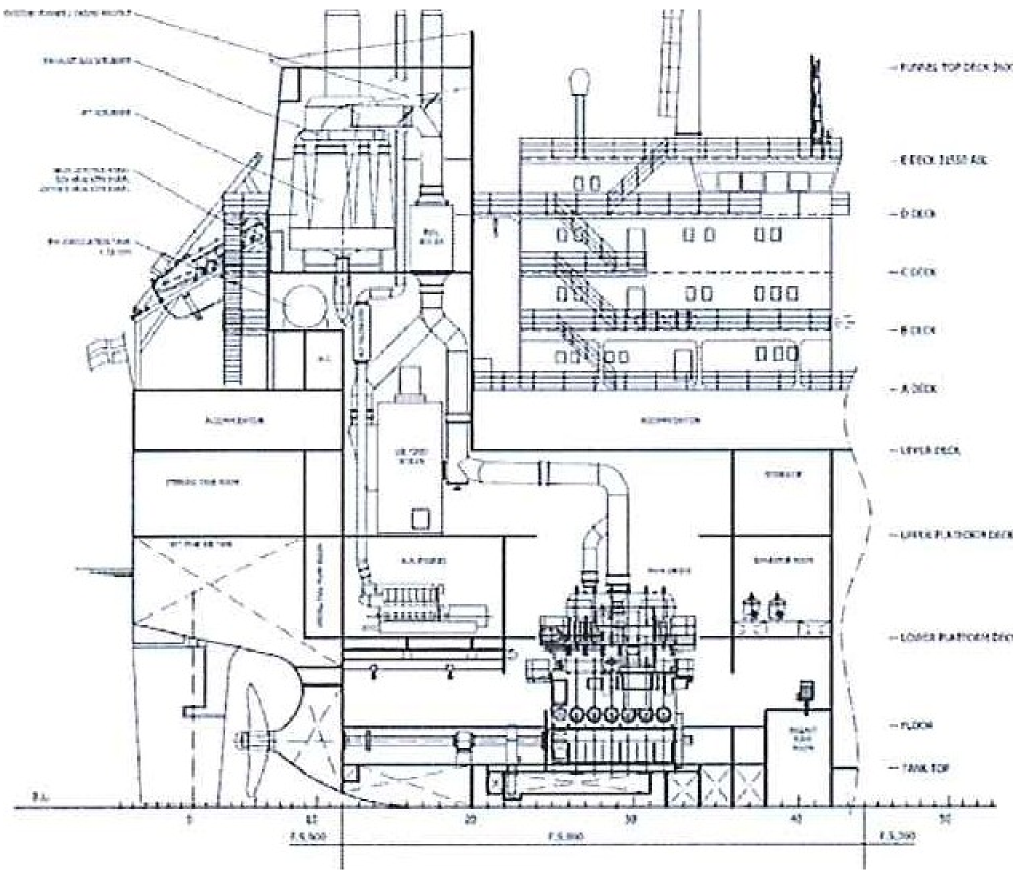


Figure 50: Inside modified parts and diagrams

4.2.2. Operational issues

The additional fuel consumption of the auxiliary engines for operation of the scrubber including pumps, respectively, is shown in Table 12. In case of ECA operation, the auxiliaries will run on MGO.

HFO at sea	0.8	t/day
HFO harbor loading	0.2	t/day
HFO harbor unloading	0.4	t/day

Table 14: Additional consumption, Scrubber equipment

The scrubber for the vessel in question is designed for fully automatic operation and requires only minimal attention from the crew. In the event of a breakdown of the scrubber, the exhaust gas is sent through by-pass chimney until the scrubber is ready for operation again.

Normal operation of the scrubber system is done using a control panel placed in the engine control room. The scrubber can be operated in automatic mode or semi-automatic mode. When operating in auto mode, the 'engines running' signals starts the scrubber, and the signals from the ship's Global Positioning System (GPS) determines whether the scrubber operates in seawater mode or freshwater mode in a predefined manner. Normally the engines' fuel flow index determines the amount of sea water used in the scrubber and/or the NaOH dosing to the system if in fresh water mode. The performance of the scrubber is measured continuously, and the adjustment of the different operational parameters is controlled accordingly.

According to the MEPC guidelines, the scrubber system will be supplied with manuals approved by the authorities, containing instruction in the proper use of the exhaust gas cleaning system and how to report the performance of the system to the authorities, if demanded. The manuals in question are the SECA compliance plan,SCP-B, Onboard Monitoring Manual, OMM, and the EGC - SOx technical manual - scheme B,ETM-B.

These manuals provide the technical information to ensure proper operation and reporting of the Exhaust Gas Cleaning unit installed on board in order to comply with MARPOL Annex VI regulation 14.4. These manuals must be stored on board the ship for surveys.

Caustic Soda:

The caustic Soda or sodium hydroxide solution is a highly alkaline liquid, thus making it very important to follow the health and safety guidelines. Alkalis have a decomposing effect on proteins which may gradually penetrate the deep tissues unless the adhered alkali is completely removed. In particular, if the eyes are exposed to an alkali, since eye tissue is rapidly affected, causing a lowering or loss of vision, great care should be taken.

Operators that handle sodium hydroxide should be required to observe the operating standard for safe operations. For this, it is necessary to provide education and training concerning:

- The characteristics, level of hazard, and methods of handling of sodium hydroxide.
- The location of protectors, showers, eye washers, water taps, cleaning hoses, and first aid facilities
- Proper method for the use of protectors and first aid facilities
- First aid measures to be taken in case of an emergency
- Proper usage of the first aid facilities
- Measures to be taken in the case of a chemical injury.

The emissions from the scrubber system are carefully monitored and logged in order to comply with current regional legislation and demands of relevant classification society. The scrubber control system will alarm the operator of exceeding limits.

Sludge generated during water cleaning

During the operation of the scrubber in fresh water mode, the water cleaning system will generate sludge. This sludge can be treated as other normal sludge from ships' engine rooms; however, it is not allowed to incinerate it on board the vessel. If the "normal" sludge is not incinerated on board, the sludge from the scrubber water cleaning system can be mixed with this sludge and treated in the same manner meaning delivered to the port waste reception facilities. The amount of sludge from the scrubber water cleaning system will amount to 2.5 liters/MWh engine output which are around 10% of the "normal" sludge. The sludge from the scrubber water will be 20% solid and 80% water.

4.2.3. Technical feasibility of the Scrubber installation

The presented scrubber installation is based upon the experience gained by Alfa Laval - Aalborg on the scrubber installation on board the Ro-Ro vessel FICARIA SEAWAYS (formerly TOR FICARrA) (a project which also is a part of the Green Ship of the Future collaboration). FICARrA SEAWAYS has today logged more than 4,000 hours of operation with the scrubber installation and it is today working as designed and installed. The operation has mainly been on open loop operation with limited closed loop operation. There have been some modifications made based upon observations during the initial operation of the scrubber system.

Thus the presented scrubber installation is expected to be technically feasible and should not introduce any major problems in installation and operation on board the vessel. Naturally there will be a need for training of the crew with respect to operation and maintenance of the scrubber installation.

4.2.4. Class review and approval

Lloyd's Register has prepared a preliminary review of the proposed installation and has given the following feedback to the designers:

Based on the above, it is our opinion that the described scrubber retrofit would be feasible and technically sound. However, there are several points which require consideration for a final design:

- IMO Resolution MEPC.184 (59) Scheme B compliance shall be demonstrated by continuous monitoring of the exhaust gas by means of a monitoring system approved by the Administration. Where wash water from the EGC is discharged the condition of the discharged water shall be monitored for pH, polycyclic aromatic hydrocarbons (PAH) and turbidity, and remain within stated limits. The values shall be logged.
- Lloyd's Register has "Exhaust Gas Abatement Rules" with specific requirements for scrubbers also DNV & ABS have relevant rules.

- A common scrubber for several engines is a new design. This needs to be tested in order to demonstrate that the different back pressures can be correctly balanced in all power ratings and engine configurations.

- The proposed integral NaOH tank on the B-Deck needs to be carefully considered with respect to overflow protection, containment and handling of any chemical leakage.

- Material used for ship's piping systems to be specially considered

- It is assumed that the scrubber sea water intake has no negative effect on the ships cooling system performance and that it is accepted by the engine manufacturer.

- Power supply and power management necessary for operation of the scrubber to be separately considered.

- Final approval of the proposed scrubber is subject to a risk assessment of the complete system being approved and when all systems have been installed and tested to the satisfaction of the attending Surveyor.

- For the vessel in question the influence on the stability aspects (intact and damage) have not been evaluated in details. It is assumed that the impact of the conversion will not have a significant impact on the stability compliance thus operability of the vessel. On other ship types/sizes a conversion with a scrubber this may have some more impact on the stability aspects and would therefore have to be addressed in details on an early stage of the project.

4.3. Solution 2nd - LNG as fuel System modification.

Conversion of the existing engine to ME-GI dual fuel engine requires that the MC engine is first converted to a ME-B type engine with electronically controlled fuel injection. This requires installation of hydraulic equipment for the electronically controlled fuel injection system and replacement of the camshaft for the exhaust gas valve actuation. A further benefit of converting the MC-C engine to ME-B type engine includes improved specific fuel consumption during Tier II mode operation. During conversion of the MC-C to ME-B engine, the additional GI conversion can also take place simultaneously. This requires installation of new cylinder covers with gas valves and gas control blocks, with all ancillary piping, and the gas chain pipes to supply the engine with gas. Additional control systems and instrumentation is also required to fully convert the engine to ME-B-Gt type engine.

4.3.1. Conversion into LNG system fuel

The retrofitting of a LNG system is a major undertaking and includes the following work on board the ship:

Removal of the following equipment and structures:

• Deck pipes and electrical cable pipes in an area for LNG storage tank foundation and deck houses for LNG equipment

• Grating/platform in CL at A-deck in way of new LNG storage tank foundation

Installation of the following equipment and structures:

General

• Foundations for LNG storage tanks

• Deck houses for LNG equipment including foundation

• Rerouting/reinstallation of deck pipes, electrical cable pipes and pipe foundations

• New grating, platforms and ladders

• Foundations for new LNG pipe system MAN Diesel Turbo (based upon detailed report)

• Main engine conversion from MC-C to ME-GI

• Fuel gas supply system

• Block and bleed valve arrangement

• Gas piping system

• Ventilation system

• Inert gas system

• Sealing oil system

• LNG tank

• Fuel gas supply system

• LNG piping system and valves

• Auxiliary systems

• Safety equipment

• Instrumentation and control system

The design is based upon input from the ship owner, engine manufacturer, LNG equipment and various other vendors.

The design package contains a breakdown of steel, outfitting, components, pipes etc. necessary for the conversion.

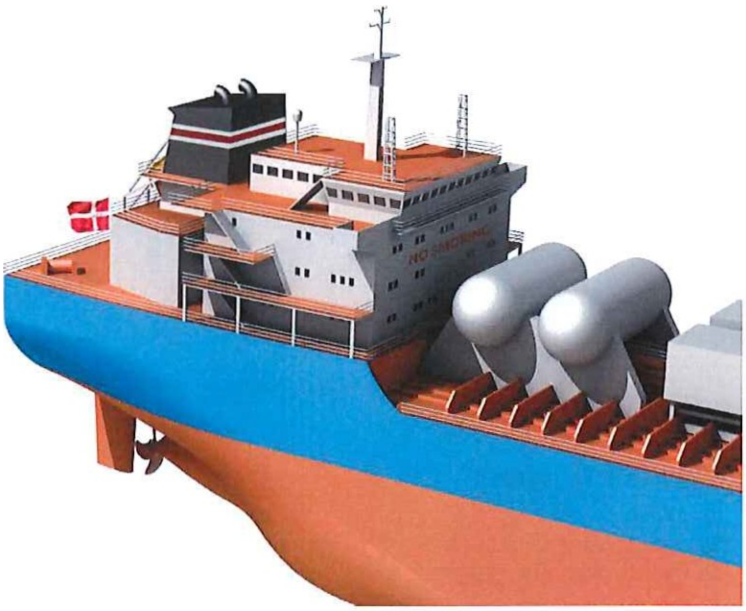


Figure 51: LNG tanks seen from the side stored in deck

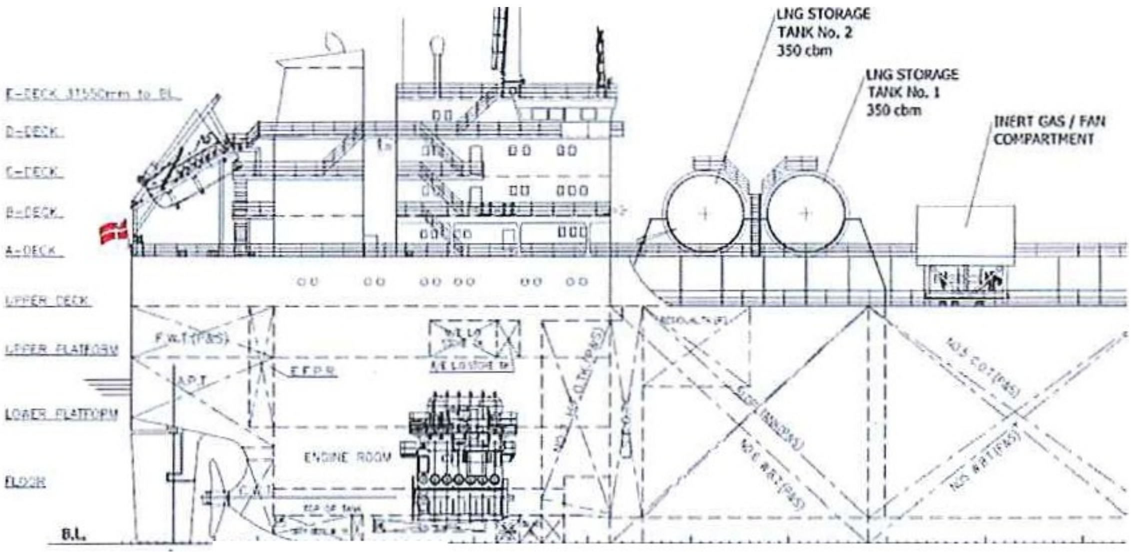


Figure 52: LNG tank arrangement and engine room

The fuel consumption in case of LNG application is provided in Table 13 and Table 14 below for the main and auxiliary engines, respectively.

ME consumption at sea	
LNG	21 t/day
MGO pilot fuel for LNG operation	1.4 t/day

Table 15: ME - Consumption

The most crucial aspect for the future success of LNG as a fuel is the implementation of, and adherence to, adequate safety standards. Both the technical and emotional aspects of safety must be fully addressed to ensure all persons involved in LNG handling are equipped with the correct information and can respond in the correct manner. For technical safety aspects, unified standards and specifications can go some way in ensuring safe LNG operation. Harmonisation of standards both for LNG bunkering (SO 28460) and for LNG as a fuel (IGF code) will ensure consistent safety standards for vessels operating with LNG.

On the emotional side, training of the crew in LNG handling and operation of LNG-specific equipment is required, for example ME-GI training courses will be available, and equipment vendors will offer the same. Onshore staff will also require similar training, and in the case of LNG bunkering, responsibilities of personnel must be clarified to ensure a safe process. A further issue is the public perception of

LNG which is harder to address directly but nonetheless important to maintain that LNG is a safe alternative fuel.

Availability of LNG is also an important issue to consider when investigating such a conversion, and many projects are underway to develop LNG bunkering terminals at ports in the European ECA's. However, should LNG not be available, the conversion of the main engine to ME-B-GI still allows for operation on conventional fuel oils. Full fuel flexibility provides operators with reduced risk with regard to fuel prices and availability without compromising engine performance.

4.3.2. Feasibility of the LNG solution

Operating LNG tankers on LNG is not new. There are many years of experience in operating LNG tankers on the "boil off gas" using steam turbines, and Dual Fuel Diesel Electric (DFDE) engines. In this case, the vessel will operate on LNG fluid directly from a fuel tank, a concept which has also been tested on smaller projects using the DFDE concept. The ME-B concept for the main engine is also proven technology, and the ME-GI concept, although developed, tested, and "In Principle" approved by class, is yet to be installed on a vessel. However the GI technology is not new, so application of the ME-B-GI engine will not introduce major technical challenges. Furthermore, installation of gas tanks and auxiliary equipment will be familiar to many shipyards and will smoothly facilitate vessel conversion.

4.3.3. Class review of LNG solution

The partner in the project Lloyd’s Register has prepared a preliminary review (3) of the proposed LNG installation based on the Rules and Regulations and has given the following feedback to the ship owner and designers:

In case that the Owner wishes to proceed with the design of the LNG retrofit installation, a number of subjects need to be addressed and a much more detailed design and documentation work including risk analysis is to be carried out.

However, based on the above conceptual design review, no major and unsolvable problems has been identified at this stage and therefore, it is concluded that the project is feasible from a regulative point of view. The technical aspects have already been analyzed with the Chapter 3 of this Thesis.

4.4. Cost analysis for the two retrofits, OPEX, CAPEX, NPV and Payback time for both of them.

Analysis will follow within the next sections, regarding the two retrofit alternatives from a financial point of view. The respective investment costs (CAPEX) and operating expenses (OPEX) of the retrofit options versus the operational cost with the shift to MGO as required by the regulations, the net present value (NPV) and payback period are determined for opting for the scrubber or LNG solution instead.

The payback results are provided in comparison with use of MGO and payback are positive for a chosen alternative, then that solution could be financially more attractive than the base case under the selected conditions.

To calculate the NPV and payback time, and the savings period is 10 years (2015 - 2024). Payback results are presented as a function of fuel cost spread between MGO and HFO and as a function of percentage of operating time inside ECA's.

4.4.1. Scrubber solution and retrofitting endeavour.

The total cost is providing as follows:

CAPEX SCRUBBER Installation		
Scrubber machinery and equipment	2,600,000	USD
Steel (150t) I pipe I electrical installations and modifications	2,400,000	USD
Design cost & Classification costs	500,000	USD
Off-Hire Cost = 20X17000 USD (Installation time)	340,000	USD
Total	5,840,000	USD

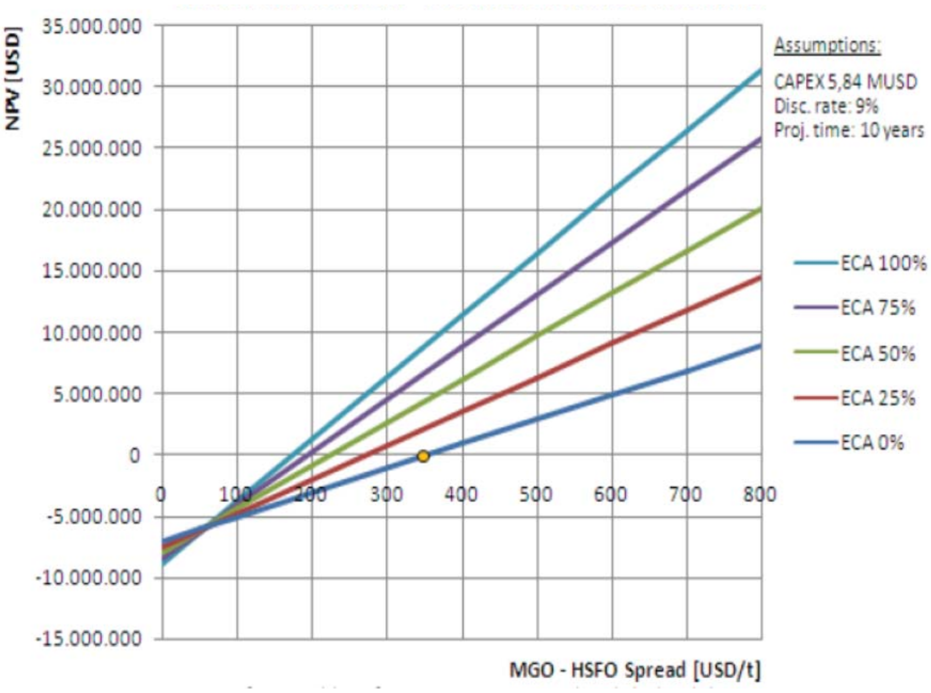
Table 16: Cost in total for the retrofitting of Scrubbers in our Vessel_(Source_Greenship.org)

Conversion prices were obtained from three shipyards (FAYARD (Denmark), MWB (Germany) and GSI(China)) and quite interestingly the spread in cost was minimal**.**

From a financial perspective, the scrubber alternative is potentially attractive when the vessel would operate a reasonable amount of time inside ECA. The NPV and payback time are quite sensitive to the spread in fuel cost between HFO and MGO. For a cost differential of around USD 350 per ton, the payback time is around 3 years for 100% ECA operation, a little over 4 years for 75% ECA, 6 years for 50% ECA and 8 years for 25% ECA operation. If a payback time of at most 5 years would be considered acceptable, then the time spent inside ECA would have to be at least 75% using this criterion in the case of SO% or less time spent inside ECA,it would be more attractive to shift to MGO.

The high sensitivity of financial benefit to spread in fuel cost is illustrated if the spread between HFO and MGO is USD 300 instead of USD 350 per tonne, the payback period increases from 3 to 4 years for the 100% ECA case and from 8 to 10 years for the SO% ECA case.

Net Present Value – Scrubber vs MGO Scenario



TabFigure 53: NPV for Scrubber for HFO at USD 650/t, global Sulphur cap in 2020

Payback period Scrubber vs MGO Global Sulphur cap in 2020

MGO – HFO spread: 350 USD/t

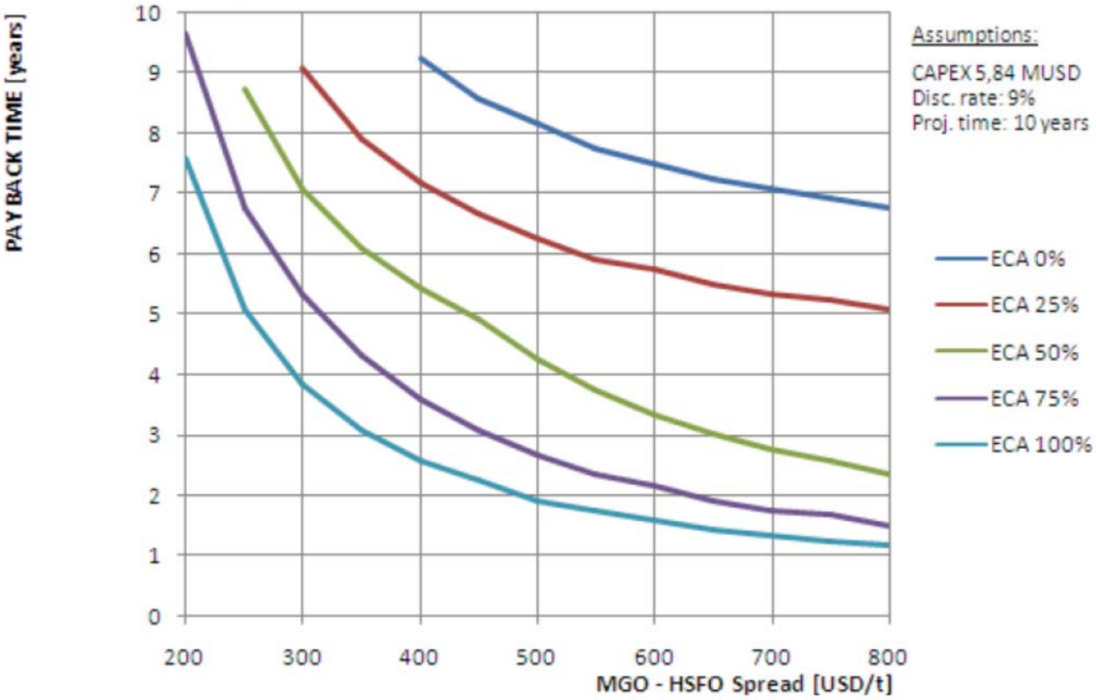


Figure 54: Payback time for Scrubber for HFO at USA 650/t, global sulphul cap in 2020

Payback period Scrubber vs MGO Global Sulphur cap in 2020

MGO – HFO spread: 350 USD/t

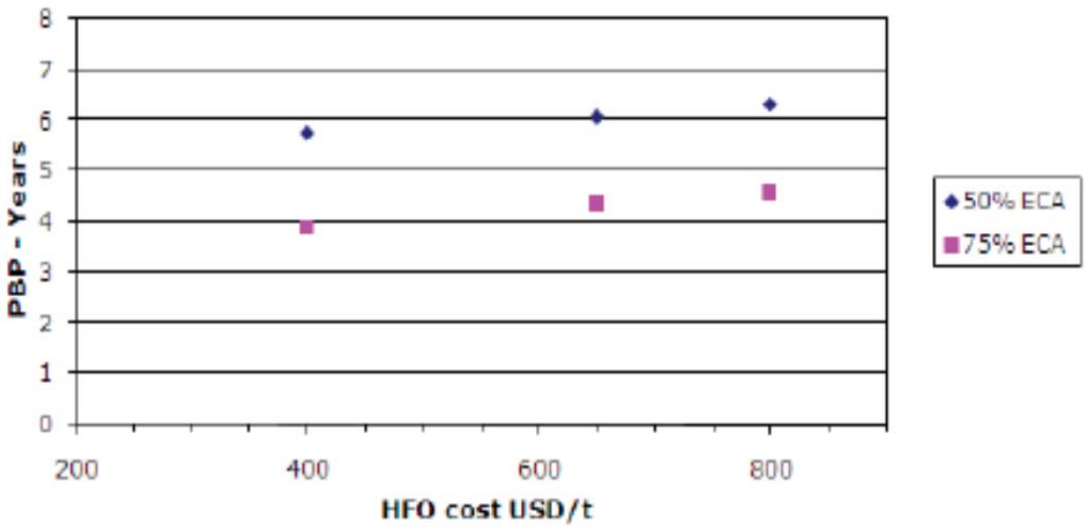


Figure 55: Payback time as a function of HFO cost, global Sulphur cap in 2020

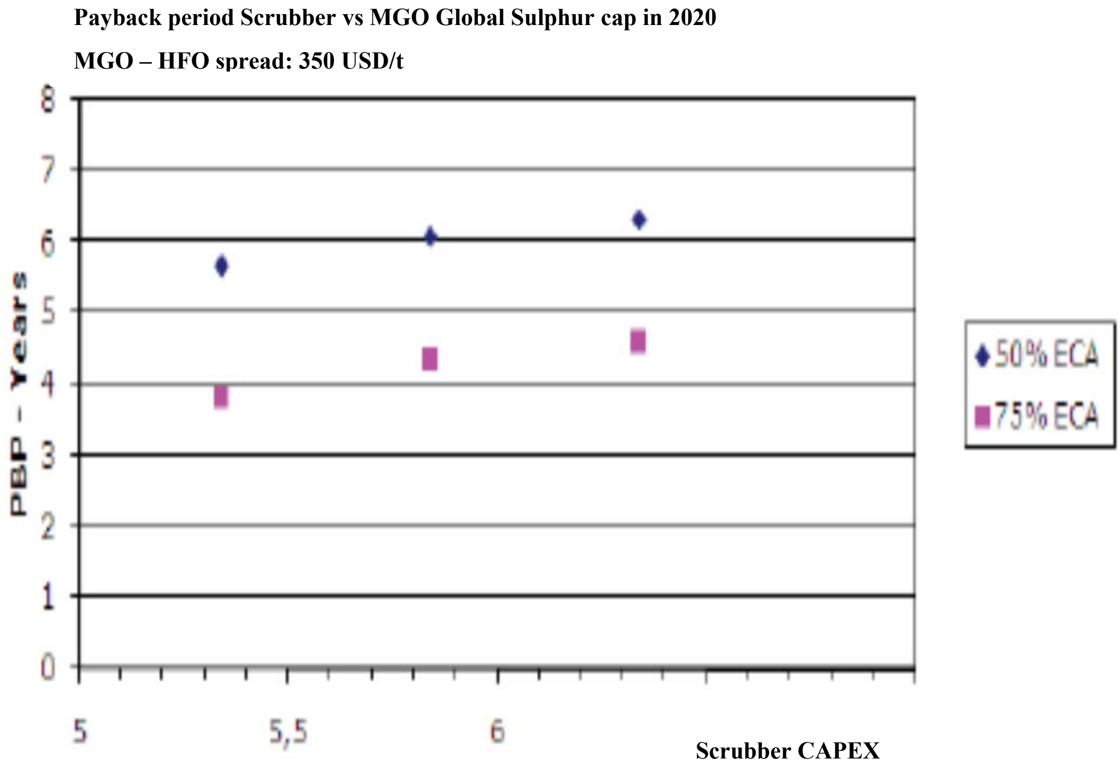


Figure 56: Payback time as function of CAPEX

4.4.2. LNG as fuel System and retrofitting endeavor.

The total cost is providing as follows:

LNG Installation CAPEX								
LNG machinery and equipment, main engine conversion							4,380,000	USD
Steel (300t)							2,000,000	USD
Design & classification costs							500,000	USD
Off-Hire Cost (Installation time)	Off-Hire:	40	days	Rate:	17,000	USD	680,000	USD
Total							7,560,000	USD

Table 18: LNG cost analysis

Based on the resulting CAPEX and OPEX values, the NPV and payback period have been calculated for referred Scenarios. Figure 57 and figure 58 show the values as a function of fuel cost spread between MGO and HFO, where the HFO cost is taken as USD 650/t and LNG at USD 550/t and Global Sulphur cap date is 2020. Just for information purposes the figure 59 shows the payback time values for the same conditions, except that here it is assumed that LNG is burned only inside ECA.

Net Present Value – LNG vs MGO Scenario

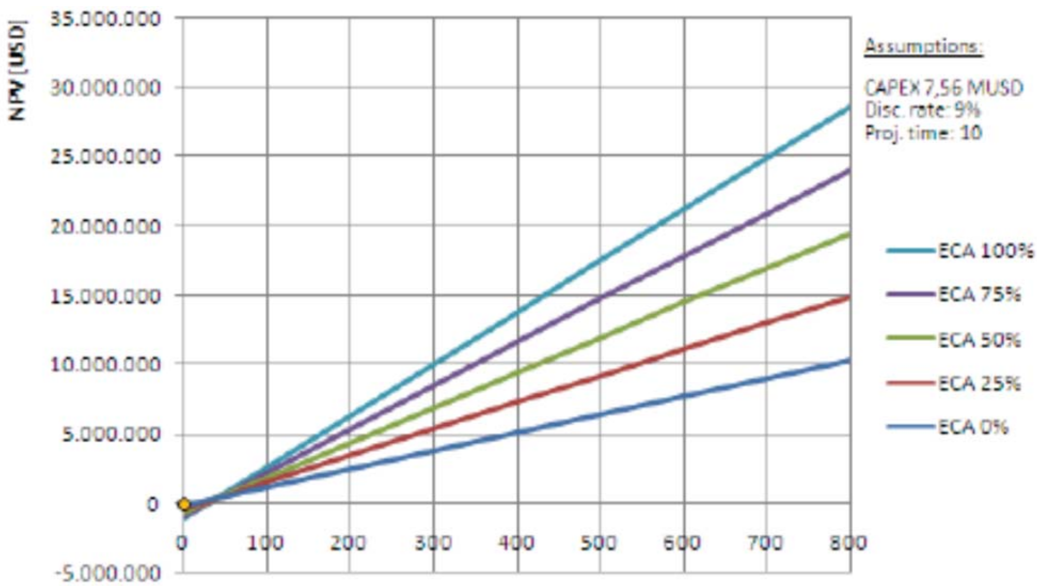


Figure 57: NPV for LNG alternative, operation on LNG inside and outside ECA, HFO cost USD 650/t, LNG cost USD 550/t, global Sulphur cap in 2020

Pay Back Time – LSFO / LNG Scenario

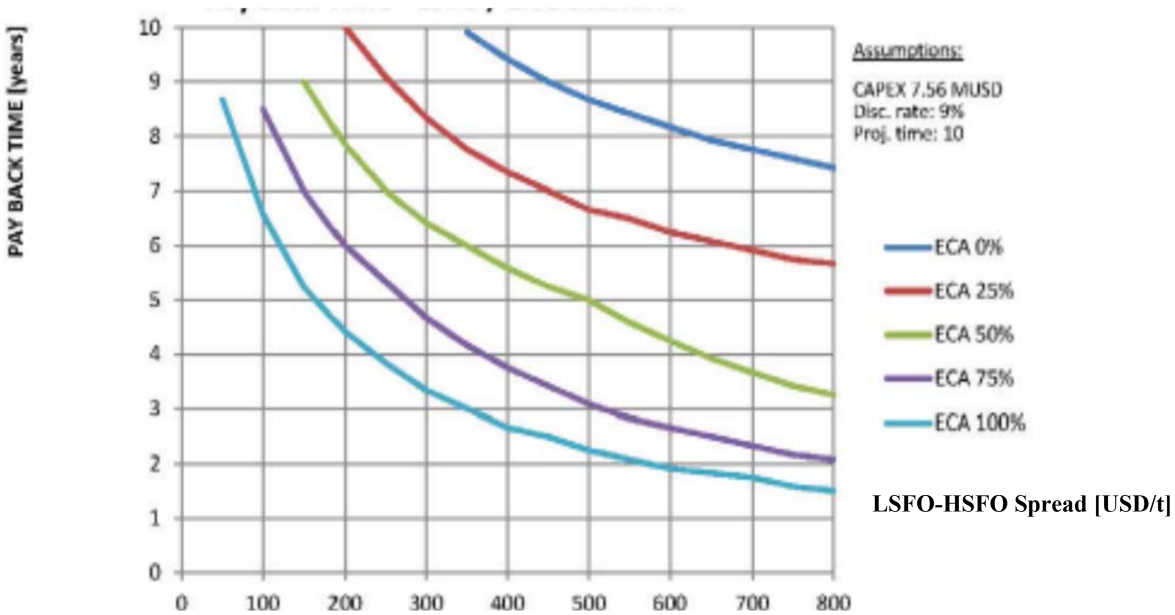


Figure 58: Payback period for LNG alternative, operation on LNG inside and outside ECA. HFO COST usd 650/t, LNG cost USD 550/t, global Sulphur cap in 2020.

Pay Back Time – LNG vs MGO Scenario

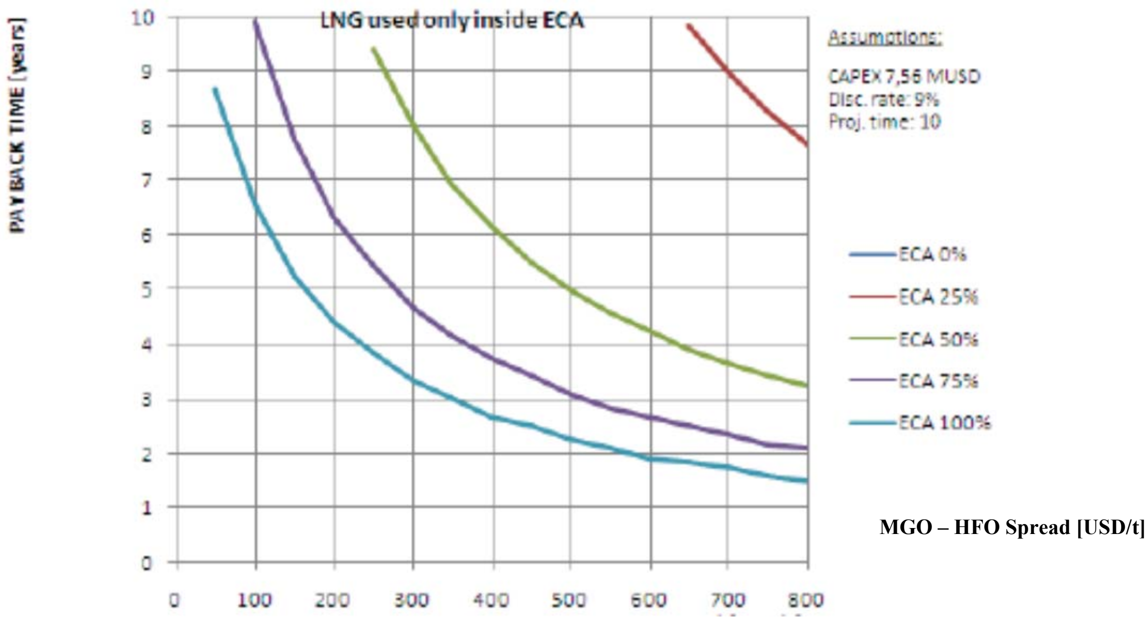


Figure 59: Payback period for LNG alternative, operation on LNG only inside ECA , HFO cost USD 650/t, LNG cost USD 550/t, global Sulphur cap in 2020

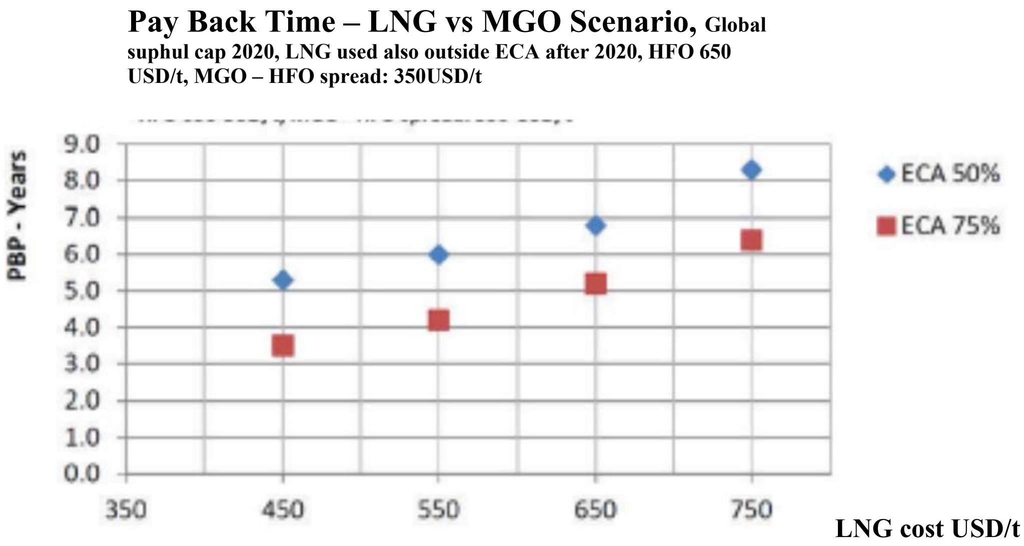


Figure 60: Payback time as a function of LNF cost

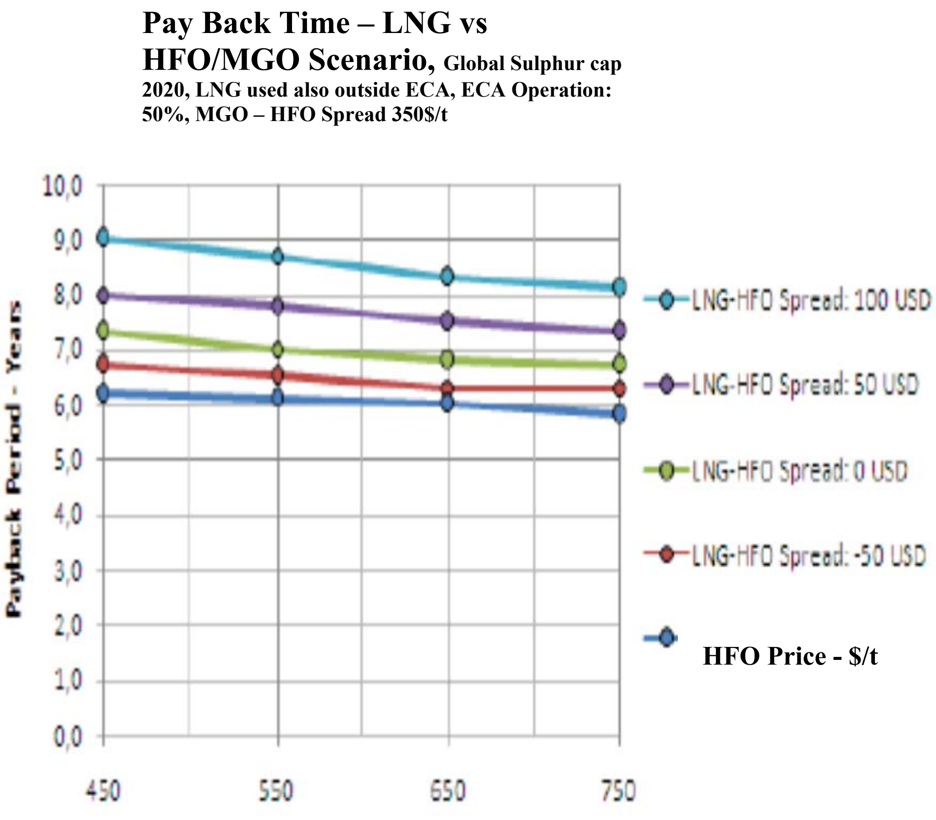


Figure 61: Payback time LNG vs HFO/MGO

The cost of LNG plays a big role. As if LNG can be purchased at a cost that is USD 100 or USD 200 less than HFO, then the LNG alternative is financially attractive for ECA operation of at least 50%, assuming that a payback time of not more than 5 years is acceptable; if the LNG cost is comparable to HFO at USD 650/t, the LNG option is attractive for ECA operation of at least 75%; if LNG is more expensive than HFO, the LNG option is interesting only for very high operational percentages inside ECA.

In addition, the financial benefit of the LNG alternative will depend on the spread between HFO and MGO. If LNG would be used only as a fuel inside ECA, then the payback time would be of such long duration that this option would be of interest only in case of a high percentage ECA operation (exceeding 75). For a cost spread of USD 350 between MGO and HFO and for a cost of USD 550/t for LNG, the NPV and payback time are of the same order as for the scrubber alternative.

With regard to the installed engine model, this is an important issue for the conversion to LNG. Newer engine models with electronically controlled injection are cheaper to convert to LNG operation.

Chapter 5

Conclusions

5.0. Conclusions

In this post graduate thesis it is tried to be analyzed both the Environmental Challenges that Shipping industry facing with regard the Air Emissions and the technical Options that are available as a Solution to outweigh the challenges ahead from retrofitting aspect. Actually how an existing vessel can apply technologies such as Scrubbers and LNG as fuel System against the use of MGO.

This study tried to bring the attention of the readers to understand the Environmental requirements globally for each specific geographical area, the funding tools from each regulatory body such as EU and USA and to provide all the technical difficulties in order for to the vessels to be enable to procced with such modifications.

The solution of the retrofitting LNG engines using both LNG as fuel, Scrubbers technology and MGO were described and deeply reviewed according the Rules and Regulations from other statutory bodies and from the Class aspects. All the difficulties were described for the modification taking into account all the requirement of the Marpol, IGF Code, Class rules and other local legislations.

It is understood that both retrofitting's possible from the technical point of view and it is underlined that both technologies can reduce or even remove SOx by modification of existing vessels.

The important factor is the cost of the modification and the benefit for the long run investment. Another important thing is how frequent the vessel in question is operating in ECA Areas. This is crucial because of the necessity to be incompliance with the Marpol requirement may spread the retrofitting process and will also make the investment payback period more attractive. For example, in our Scenarios above analyzed the cost of retrofitting of the tanker especially for LNG fuel system is approximately 1.7$ million more expensive than the Scrubber system.

Regarding the installation of Scrubber, the price spread between the HFO and MGO is very important for 100% operation or 50% operation in ECA areas showing that a payback period is three and six years respectively assuming that HFO and MGO spread of 300$/t-350$/t.

Regarding the LNG fuel system solution, the beneficial of investment is only if the vessel has 100% operation in ECA areas.

Since in the latest IMO MEPC agreed to retain the current text of MARPOL ANNEX VI, Regulation 14, of the Sulphur content fuel oil used by ships is not exceed 0.5% m/m as of January 1st, 2020, it is going to be interesting because the air emission requirements will be more strictly and outside ECA areas. As a result the Shipping industry must to adapt these technologies and the payback time of the investment can be more attractive due to fully compliance as 2020. The use of new technologies provides an environmental profile which is very important for commercial reasons, made many of shipping companies to proceed with such investment. The truth is that now with the 2020 challenge ahead there is a short of time to take the critical decision the shipping companies of what's next.

One thing is whether the capacity of the refineries of Low Shuphur is adequate but still the option of a scrubber and LNG will give answers to the question. In addition of buying low sulphur fuel, they can reduce their sulphur emissions by installing exhaust gas cleaning systems (EGCS or scrubbers). Quite a few ship-owners have already followed this path. Indeed, there is CE Delft study estimated that around 3,800 ships would be fitted with scrubbers by 2020 (and this was one of the assumptions on which it based its conclusion that the industry would be ready for the 0.50% global cap). It has been estimated that the payback could be anywhere between three and five years – but this will depend on future oil prices and the high/low Sulphur differential.

Using alternative fuels is another avenue that some ship-owners have followed. Liquefied natural gas (LNG) is the best known and has been winning support. The suppliers have slowly been building up their delivery infrastructure. More growth in the short sea shipping sector, where its take-up by ship-owners could develop in tandem with a local supply infrastructure. Technical solutions are always available; it is to the intentions of the Ship owners how they want to procced. Each alteration has it own specific requirements and technical difficulties but eventually with the participation of many technical parties and cooperation the difficulties can be outran.

.

Acknowledgement

For the purpose of the writing of this Thesis evidences and economical and technical information has been extracted from published cases studies namely Presentation "Initiation of an LNG retrofit design on a Cruise Ferry, lessons so far and challenges ahead, and Vessel Emission Study: Comparison of various abatement technologies to meet emission Levels for ECA's. Additionally, the Rules and Regulations of Lloyd's Register have been used for the purpose of the technical review and compliance of different modifications of the vessels in question.

References

References

1) IMO (2016), Sulphur oxides (Sox)–Regulation 14 (http://www.imo.org/en/OurWork/environment/pollutionprevention/airpollution/pages/sulphur-oxides-(sox)-%E2%80%93-regulation-14.aspx) last visit 12/2016)

2) IMO (2016), Volatile organic compounds (VOC) – Regulation 15, http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Pages/Volatile-organic-compounds-%28VOC%29-%E2%80%93-Regulation-15.aspx (last visit 12/2016)

3) IMO (2016), Greenhouse Gas Emissions, http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Pages/ GHG-Emissions.aspx (last visit 12/2016)

4) IMO (2015), Energy Efficiency Measures, http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Pages/ Technical-and-Operational-Measures.aspx (last visit 12/2016)

5) IMO (2016), Ozone-depleting substances (ODS) – Regulation 12 http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Pages/ Ozone-depleting-substances-%28ODS%29-%E2%80%93-Regulation-12.aspx, (last visit 12/2016)

6) IMO (2016), Nitrogen Oxides (NOx) – Regulation 13, http://www.imo.org/en/OurWork/environment/pollutionprevention/airpollution/pages/nitrogen-oxides-(nox)-%E2%80%93-regulation-13.aspx (last visit 12/1/2016)

7) EC (2016), Mobility and Transport, Trans European Transport Network, Tented http://ec.europa.eu/transport/infrastructure/tentec/tentec-portal/site/en/abouttent.htm (last visit 2016)

8) IMO (2016), Prevention of Air Pollution from Ships, http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Pages/Air-Pollution.aspx (last visit 12/2016)

9) Koers & Vaart B.V.,(2015), LNG Applications for Short Sea Shipping (LNGSSS), Public Report, Project no. TKIG01034, Publication date: 08-09-2015

10) John Howell,Jim Harger(2013),Westport, CNG and LNG: what's best for your fleet, A Westport and Clean Energy Webinar

11) John Howell,Jim Harger(2013),Westport, CNG and LNG: what's best for your fleet, A Westport and Clean Energy Webinar

12) Det Norske Veritas (2010), Managing Risk Greener Shipping in the Baltic Sea

13) Lloyd's Register (2014), Options for emissions compliance.

14) Lloyd's Register (2013), LNG as fuel, Marine Training Cource

15) Christian Klimt (FORCE Technology), Christian Schack,(FORCE Technology),Thomas Eefsen (Maersk Maritime Technology), Jean De Kat (Maersk Maritime Technology) (2012-05-02), "ECA Retrofit Technology"

16) EPE (2015), Initiation of an LNG retrofit design on a Cruise Ferry, lessons so far and challenges ahead

Appendix 1: Reference Rules, Regulations, Standards & Guidance

Appendix 1: Reference Rules, Regulations, Standards & Guidance

1. Rules and Regulations for the Classification of Natural Gas Fuelled Ships July 2012
2. What IGF Code means for you, A review of the changes in requirements for natural gas – fueled ships Lloyd's Register 2015

Rules and Regulations for the Classification of Natural Gas Fuelled Ships

July 2012

Lloyd's Register

LIFE MATTERS

Rules and Regulations for the Classification of Natural Gas Fuelled Ships

July 2012

Lloyd's Register

LIFE MATTERS

A guide to the Rules

and published requirements

Rules and Regulations for the Classification of Natural Gas Fuelled Ships

Introduction

The Rules are published as a complete set. A comprehensive List of Contents is placed at the beginning of these Rules.

Numbering and Cross-References

A decimal notation system has been adopted throughout. Five sets of digits cover the divisions, i.e. Part, Chapter, Section, sub-Section and paragraph. The textual cross-referencing within the text is as follows, although the right hand digits may be added or omitted depending on the degree of precision required:

(a) In same Chapter, e.g. *see* 2.1.3 (i.e. down to paragraph).
(b) In same Part but different Chapter, e.g. *see* Ch 3,2.1 (i.e. down to sub-Section).
(c) In another Part, e.g. *see* Pt 5, Ch 1,3 (i.e. down to Section).

The cross-referencing for Figures and Tables is as follows:

(a) In same Chapter, e.g. as shown in Fig. 2.3.5 (i.e. Chapter, Section and Figure Number).
(b) In same Part but different Chapter, e.g. as shown in Fig. 2.3.5 in Chapter 2.
(c) In another Part, e.g. *see* Table 2.7.1 in Pt 3, Ch 2.

Rules updating

Current changes to Rules that appeared in Notices are shown with a black rule alongside the amended paragraph on the left hand side. A solid black rule indicates amendments and a dotted black rule indicates corrigenda.

Rules programs

LR has developed a suite of Calculation Software that evaluates Requirements for Ship Rules, Special Service Craft Rules and Naval Ship Rules. For details of this software please contact LR.

July 2012

Contents

Rules for the Classification of Natural Gas Fuelled Ships

Section

Section 1 General

1.1 Purpose and scope

1.1.1 The purpose of these Rules is to provide requirements for machinery for propulsion and auxiliary purposes using natural gas or methane as a fuel (hereinafter referred to as gas), in order to provide a level of safety and reliability equivalent to that associated with conventional oil-fuelled propulsion and auxiliary machinery.

1.1.2 These Rules specify requirements for gas-fuelled systems in ships other than LNG Carriers. They cover both single-fuelled (gas only) and dual-fuelled (gas and oil fuel) machinery, with gas fuel stored and supplied at low pressure (10 bar or less).

1.1.3 The requirements are in addition to the applicable requirements of the *Rules and Regulations for the Classification of Ships* (hereinafter referred to as the Rules for Ships).

1.1.4 Requirements for fire safety are not included in these Rules, instead they are subject to the satisfactory requirements of the National Administration.

1.1.5 Requirements additional to these Rules, dependent on ship type and service, may be imposed by the National Administration with which the ship is registered and/or by the Administration within whose territorial jurisdiction the ship is intended to operate.

1.1.6 Systems in which gas is stored or supplied at higher pressures (greater than 10 bar), or systems which deviate from the prescriptive requirements of these Rules, will be assessed on the basis of an engineering and safety justification in accordance with Pt 7, Ch 15, Requirements for Machinery and Engineering Systems of Unconventional Design, of the Rules for Ships.

1.2 Class notation

1.2.1 Ships complying with the requirements of these Rules will be eligible for assignment of the **GF** machinery notation.

GF Assigned to ships other than LNG carriers, where the main propelling and/or auxiliary machinery is designed to operate on natural gas as fuel, or a combination of natural gas and oil fuel. The notation also indicates that the gas-fuelled machinery has been installed and tested in accordance with LR's Rules and Regulations.

1.3 Definitions

1.3.1 **Enclosed space** is any space within which, in the absence of artificial ventilation, the ventilation will be limited and any explosive atmosphere will not be dispersed naturally. In practical terms, this is a space bounded either on all sides, or all but one side, by bulkheads and solid decks, such that the required ventilation rate to prevent the accumulation of pockets of stagnant air cannot be achieved by natural ventilation alone.

1.3.2 **Explosive gas atmosphere** is a mixture with air, under atmospheric conditions, of flammable substances in the form of gas or vapour that, after ignition, permits self-sustaining flame propagation.

1.3.3 **Gas-fuelled machinery** for the purposes of these Rules includes:

- dual-fuelled diesel engines of the type employing pilot oil fuel ignition for gas combustion;
- single-fuelled (gas) spark ignition or equivalent reciprocating engines;
- gas-fuelled and dual-fuelled (oil or gas) gas turbines; and
- dual fuel burner systems for boilers suitable to burn either oil fuel or gas fuel alone or oil and gas fuel simultaneously.

1.3.4 **Hazardous area** means an area/space in which an explosive gas atmosphere is or may be expected to be present, in quantities, such as, to require special precautions for the construction, installation and use of apparatus. Hazardous areas are classified into zones based upon the frequency of the occurrence and duration of an explosive gas atmosphere, as follows:

(a) **Zone 0** is an area/space in which an explosive gas atmosphere is present continuously, for long periods or frequently;

(b) **Zone 1** is an area/space in which an explosive gas atmosphere is likely to occur in normal operation occasionally; and

(c) **Zone 2** is an area/space in which an explosive gas atmosphere is not likely to occur in normal operation but, if it does occur, will persist for a short period only.

1.3.5 **Master gas fuel** valve is an automatic valve in the gas supply line to the gas-fuelled machinery which is located outside the machinery space and is close to the gas process equipment.

1.3.6 **Natural gas** for the purposes of these Rules is defined as a mixture of gaseous hydrocarbons, predominantly methane, often containing other gases (UN number 1972).

1.3.7 **Non-hazardous area** means an area/space in which an explosive gas atmosphere is not expected to be present in quantities sufficient to require special precautions for the construction, installation and use of apparatus.

1.3.8 **Semi-enclosed space** is a space limited by decks and/or bulkheads in such a manner that the natural conditions of ventilation in the spaces are noticeably different from those obtained on open deck. In practical terms, this is a space which is open on two opposing sides, but where the natural ventilation conditions within the space are restricted by structures such as decks, bulkheads or windbreaks in a manner such that they are significantly different from those obtained on an open deck, and where dispersion of gas may be impeded.

1.3.9 **Service profile** for the purposes of these Rules is the machinery power/speed operational envelope indicating all the intended operational points applicable to the use of gas as fuel and any short-term high power operation.

1.3.10 **Source of gas release** is a point or location from which a flammable gas, vapour or liquid may potentially be released into the atmosphere such that an explosive gas atmosphere could be formed, for example at valves or detachable pipe joints, or a compressor or pump seal in the fuel gas system.

1.3.11 **Tank master isolating valve** is a remotely operated valve on the gas outlet from a gas storage tank which is located as close to the tank outlet point as possible.

1.3.12 **MARVS** means the maximum allowable relief valve setting.

■ *Section 2* Plans and information to be submitted

2.1 Plans and information to be submitted

2.1.1 In addition to the plans and information required by the relevant Chapters of the Rules for Ships, the following are to be submitted:

(a) Design statement that defines the service profile of the ship, together with a description of the arrangements and the intended operating capability and functionality of the main propulsion and auxiliary systems that use gas as fuel.

(b) Safety and reliability analysis based on an acceptable National or International Standard. The analysis is to demonstrate that suitable risk mitigation has been achieved so that the system can tolerate a single failure in equipment without asphyxiation, fire or explosion and without loss of fuel to the gas-fuelled machinery.

(c) General arrangement plans of machinery spaces containing gas-fuelled machinery and their location in the ship with respect to accommodation, service and control spaces.

(d) Arrangement plans of gas fuel storage tanks and process equipment and their location relative to high fire risk areas, accommodation, service and control spaces, water ballast, oil fuel, and other tanks containing flammable substances.

(e) Hazardous area plans indicating the location of hazardous areas and their openings and access arrangements. Where the classification of hazardous areas has been carried out in accordance with 1.3.4, documentation as required by IEC 60079-10 is to be submitted.

(f) Schedule of electrical and mechanical equipment located in hazardous areas.

(g) Fuel system plans. Details are to include the maximum potential generation of gas and the associated systems to handle it under all envisaged operating conditions.

(h) Plans and details of gas fuel storage tanks and pressure vessels, including filling and relief arrangements. For LNG fuel storage tanks, *see* Chapter LR IV, Information and Plans, of the *Rules and Regulations for the Classification of Ships for the Carriage of Liquefied Gases in Bulk* (hereinafter referred to as the Rules for Ships for Liquefied Gases).

(j) Gas process equipment plans for compressors, coolers/intercoolers and buffer tanks.

(k) Gas fuel piping system plans with details of piping design including installation and insulation, ducting, valves and fittings, pressure relief, expansion, and ventilation and purging arrangements.

(l) Fatigue analysis for all pressurised gas piping arrangements subject to vibration or pulsating pressure where failure of the pipe or its connection or a component would be the cause of a prime mover being unavailable. The analysis is to recognise the pressures and fluctuating stresses that the piping system may be subject to in normal service.

(m) Ventilation system plans for the machinery spaces, machinery enclosures or casings including air-locks, ventilation hoods and pipe ducting. Plans are to indicate hazardous areas where appropriate.

(n) Enclosures or casing plans for gas-fuelled machinery/ equipment and any air locks where access is required.
(o) Fixed gas detection and alarm system plans.
(p) Description of emergency shut-down arrangements, including a list of control, monitoring and alarm points.
(q) Operating manuals that describe the installation particulars, together with operating and maintenance instructions, *see also* 4.3.4. Procedures for modifications to control systems to be included. Equipment manufacturers' instructions are to include the drawings and diagrams necessary for putting into service, maintenance, inspection, checking of correct operation, repair of the machinery, the use of correct spares and tools, and useful instructions with regard to safety.
(r) Description and plans of gas fuel control and monitoring systems and fuel changeover arrangements for dual-fuelled machinery, including line diagrams of control circuits and lists of monitoring, control and alarm points.
(s) Quality plans for sourcing, design, installation and testing of all components used in the gas fuel system installed with the gas machinery.
(t) Evidence of type testing of the engine/turbine with electronic controls or a proposed test plan at the builders with the electronic controls operational, to verify suitability of the electronic control system and correct functioning during normal operation and identified failure modes.
(u) Schedule of testing at engine/turbine builders, to be commissioned prior to sea trials, to demonstrate that the gas-fuelled machinery is capable of operating as described in the design statement, including any testing required to confirm the conclusions of the Failure Mode and Effects Analysis (FMEA) or alternative recognised analysis technique for system reliability. The test schedules are to identify all modes of operation and the sea trials are to include typical port manoeuvres under all intended engine/turbine operating modes. *See* 3.2 and 1.1.6.
(v) A cause and effect diagram to allow the results of activation of each shut-down and cut-out to be established and verified.
(w) A suitable testing and inspection plan for gas storage and supply systems trials.

■ *Section 3* Safety and reliability objectives and analysis

3.1 Safety and reliability objectives

3.1.1 The objectives described below are embodied in the relevant Sections of these Rules.

3.1.2 Ensure the availability of power for propulsion or essential systems during normal operation and in the event of a foreseeable failure by:
(a) ensuring the suitability of machinery, equipment, components;
(b) ensuring redundancy for single-fuelled (gas) machinery; and
(c) ensuring redundant or alternative fuel storage and supply.

3.1.3 Prevent asphyxiation, fire or explosion during normal operation or in the event of a foreseeable failure by:
(a) reducing the likelihood of hazardous atmospheres occurring;
(b) identifying areas in which a hazardous atmosphere may still occur;
(c) eliminating sources of ignition from areas in which a hazardous atmosphere may occur;
(d) restricting access to areas in which a hazardous atmosphere may occur;
(e) detecting hazardous atmospheres as they occur; and
(f) isolating the source of hazardous atmospheres.

3.2 Safety and reliability analysis

3.2.1 A safety and reliability analysis is to be carried out to demonstrate that the gas-fuelled machinery system includes adequate risk mitigation so that the level of safety and reliability is equivalent to that associated with conventional oil-fuelled propulsion and auxiliary machinery. The analysis is to be carried out in accordance with acceptable National or International Standards.

3.2.2 The analysis is to include identification of the hazards associated with the operation and maintenance of the gas-fuelled machinery under all normal and reasonably foreseeable abnormal conditions, and, in the event of a single failure, the potential effects on the safety of the ship and its occupants, its machinery and equipment, and the environment.

3.2.3 The analysis is to be carried out in accordance with an acceptable industry or International Standard, using techniques appropriate for the analysis, and is to include arrangements to mitigate the potential effects of the hazards identified.

3.2.4 The analysis is to consider at least the following hazards:
(a) low rate gas leakage, e.g. from joints, seals, etc;
(b) high rate gas leakage, e.g. from pipe rupture;
(c) corrosion/erosion in gas piping, components and tanks;
(d) failure of the primary barrier of the gas tanks to the extent associated with the design of that type of containment system;
(e) mechanical failure in gas-fuelled machinery, equipment or components;
(f) control/electrical failure in gas-fuelled machinery, equipment or components;
(g) manufacturing defects in equipment and machinery for the containment and combustion of gas fuel;
(h) human error in operation, maintenance, inspection and testing of gas-fuelled machinery, equipment and components;
(j) location of gas-containing tanks, piping, machinery, equipment and components;
(k) fire in areas or spaces containing tanks, piping, machinery, equipment and components; and
(l) fire adjacent to areas or spaces containing tanks, piping, machinery, equipment and components.

3.2.5 In order to facilitate the proper selection and installation of equipment to be used safely in areas where explosive gas atmospheres may occur, an area classification study, in accordance with an acceptable National or International Standard such as IEC 60079-10-1, is to be carried out.

3.2.6 To ensure that mechanical equipment located in hazardous areas does not represent a source of ignition, an ignition hazard assessment, in accordance with an acceptable National or International Standard such as EN 13463-1, is to be carried out.

Section 4 Materials, components and equipment

4.1 General

4.1.1 Materials, components and equipment to be used in the construction of gas bunkering stations, gas storage tanks, gas process equipment and gas-fuelled machinery have to be evaluated in the safety and reliability analysis (*see* Section 3) and considered acceptable to LR. The materials, components and equipment also need to satisfy the requirements of this Section.

4.2 Materials

4.2.1 Materials used in the construction of piping systems, including pressure vessels, valves and other fittings, are to be manufactured and tested in accordance with the applicable requirements of the *Rules for the Manufacture, Testing and Certification of Materials* (hereinafter referred to as the Rules for Materials).

4.2.2 Materials used in gas tanks, gas piping, process pressure vessels and other components in contact with gas are to be in accordance with chapter 6 of the IGC Code.

4.3 Components and equipment

4.3.1 The design, arrangements and selection of equipment for use in hazardous areas are to be such as to minimise sources of ignition. This is to ensure that, with the exception of the interiors of equipment having an appropriate type of protection, the temperatures of surfaces that might be exposed to a flammable fuel gas-air mixture do not reach their auto-ignition temperature and that no ignition-capable arcs or sparks, whether produced by electrical or mechanical means, or by discharge of static electricity, can occur in locations where a flammable fuel gas-air mixture might be present. Temperature monitoring and alarm arrangements are to be provided where a requirement for such an arrangement is identified in the hazard assessment.

4.3.2 Electrical equipment and components intended for use in hazardous areas is to be of a certified type in accordance with Pt 6, Ch 2,13 of the Rules for Ships or an acceptable and relevant National Standard.

4.3.3 Mechanical equipment and components intended for use in a hazardous area are to be designed, constructed and installed to ensure that they are:

(a) capable of safe operation in normal or foreseeable hazardous conditions;
(b) capable of preventing the formation of a hazardous atmosphere that may be produced or released by the components or equipment; and
(c) capable of preventing the ignition of hazardous atmospheres, taking into account the nature of every electrical and non-electrical source of ignition.

4.3.4 Equipment which may produce hot particles or hot surfaces and which is intended to be located less than 3,5 m above a hazardous area is to be either totally enclosed or provided with suitable guards or screens to prevent ignition sources falling into the hazardous area.

4.3.5 Low-pressure sodium vapour discharge lamps are not to be installed above a hazardous area.

4.3.6 Where insulating materials are used to protect against the effects of high surface temperatures, they must prevent the ingress of gas.

Section 5 Location and arrangement of spaces

5.1 General

5.1.1 The locations and arrangements of gas bunkering stations, gas storage tanks, gas process equipment and gas-fuelled machinery are to have been evaluated in the safety and reliability analysis, *see* Section 3, and considered acceptable to LR. The locations and arrangements also need to satisfy the requirements of this Section.

5.1.2 Emergency escape routes are not to pass through hazardous areas.

5.2 Gas bunkering stations

5.2.1 Gas bunkering stations are to be located on the open deck or, where this is not practicable, in enclosed or semi-enclosed spaces.

5.2.2 Gas bunkering stations are to be physically separated or structurally shielded from accommodation, service areas and control stations.

5.2.3 The areas or spaces in which gas bunkering stations are located are to be considered hazardous.

5.3 Gas storage tanks

5.3.1 Gas storage tanks are to be located on the open deck or, where not practicable, in enclosed or semi-enclosed spaces.

5.3.2 Gas storage tanks located on the open deck are to be located in a naturally well-ventilated area and protected from possible mechanical damage.

5.3.3 Gas storage tanks located in enclosed spaces are to be limited to a maximum acceptable working pressure of 10 bar.

5.3.4 The areas or spaces in which gas storage tanks are located are to be considered hazardous.

5.3.5 The spaces in which gas storage tanks are located are to be gas-tight.

5.3.6 The spaces in which gas storage tanks are installed are not to be adjacent to accommodation spaces, service spaces or control stations.

5.3.7 The spaces in which gas storage tanks are located are to be separated from machinery spaces by means of a cofferdam of at least 900 mm in width.

5.3.8 The spaces in which gas storage tanks are located are to be as close as possible to the centreline of the ship. As a minimum, they are to be the lesser of B/5 and 11,5 m from the ship side; the lesser of B/15 and 2 m from the bottom plating though not less than 760 mm from the shell plating anywhere.

5.3.9 For ships other than passenger ships and multi-hulls, a tank location closer than B/5 from the ship side may be accepted by LR.

5.4 Gas process equipment

5.4.1 Gas process equipment is to be located on open deck or, where this is not practicable, in enclosed or semi-enclosed spaces.

5.4.2 The spaces where gas process equipment is located are to be considered hazardous.

5.4.3 The spaces where gas process equipment is located are to be gas-tight.

5.4.4 The spaces where gas process equipment is located are to be separated from the machinery space and above the weather deck, unless the spaces are arranged and fitted in accordance with the requirements of these Rules.

5.5 Gas-fuelled machinery

5.5.1 Gas-fuelled machinery is to be located within machinery spaces.

5.5.2 Gas-fuelled machinery is to be arranged so that the machinery spaces are non-hazardous, *see* Section 6.

5.6 Access

5.6.1 Direct access from a non-hazardous space to the hazardous space is not permitted. Where such access is necessary, an air-lock is to be provided.

5.6.2 Access to hazardous spaces, in which gas bunkering stations, gas storage tanks or gas process equipment are located, is to be via a separate access point from the open deck and not shared with any other spaces. Where separate access from the open deck is not practical, an air-lock is to be provided.

5.6.3 Air-locks are to consist of two self-closing, substantially gas-tight steel doors, spaced at least 1,5 m but no more than 2,5 m apart, without any hold-back arrangements and capable of maintaining the differential pressure.

5.6.4 The air-lock space is to be mechanically ventilated from a non-hazardous area.

5.6.5 The air-lock space is to be maintained with a differential pressure such that gas cannot pass from the hazardous to the non-hazardous area when the door is open, *see* 5.7.

5.6.6 The air-lock doors are to be monitored. Indication is to be provided at the machinery control position and on the navigating bridge when the doors are opened.

5.6.7 The air-lock space is to be monitored for flammable vapour, *see* 8.4.

5.6.8 Maintenance hatches or removable panels providing access to enclosed spaces considered to be hazardous areas, such as gas storage tanks or gas-fuelled machinery enclosures, are to be provided with suitable seals to prevent the passage of gas when closed. The sealing arrangements on hatches and panels are to be capable of being tested for gas-tightness following maintenance.

5.6.9 Access to inerted inter-barrier spaces surrounding storage tanks is to be restricted. Where access to such spaces is not from the open deck, sealing arrangements are to ensure that leakage of inert gas to the adjacent spaces is prevented.

5.7 Pressurisation

5.7.1 Where a space has an opening into an adjacent, more hazardous area, it may be made into a less hazardous space or non-hazardous space in accordance with the requirements of 5.7.2 to 5.7.7.

5.7.2 Where spaces are protected by pressurisation, the ventilation is to be designed and installed in accordance with the requirements of 5.8 and Pt 6, Ch 2,13.8 of the Rules for Ships.

5.7.3 A minimum over-pressure of 25 Pa (0,25 mbar) with respect to the adjacent more hazardous space or areas, is to be maintained at all points inside the space and at any ducts at which leaks are liable to occur with all doors and windows closed.

5.7.4 Where the hazardous area is substantially smaller than the non-hazardous area, the principles of 5.7.3 and Pt 6, Ch 2,13.8 of the Rules for Ships may be used, such that the hazardous area and associated ducts are maintained at an under-pressure in relation to the adjacent less hazardous or non-hazardous area.

5.7.5 During initial start-up or after shut-down, and whatever the classification of the hazardous area, before energising any electrical apparatus within the space that is not suitably protected by the classification if it is not pressurised, it is necessary to:

(a) either ensure that the internal atmosphere is non-hazardous, or proceed with prior purging of sufficient duration so that the internal atmosphere may be considered non-hazardous; and
(b) pressurise the space.

5.7.6 A differential pressure monitoring device or a flow monitoring device, or both, is to be provided for monitoring the satisfactory functioning of pressurisation of spaces that have an opening into a more hazardous zone.

5.7.7 In the event of the loss of differential pressure, the protective measures indicated in Table 1.8.4 are to apply.

5.8 Ventilation

5.8.1 All enclosed hazardous areas are to be provided with fixed mechanical ventilation of negative pressure that has a capacity of at least 30 air changes per hour under all foreseeable operating conditions, including a single failure in equipment or control system. The arrangements are to be such that there will be no regions of stagnant air within the ventilated space.

5.8.2 Non-hazardous enclosed spaces with access to hazardous zones or spaces are to be maintained with an over-pressure of at least 25 Pa (0,25 mbar) in relation to the adjacent hazardous space or zone. The arrangements are to be such that the pressure differential can be maintained under all foreseeable operating conditions, including single failure in equipment or control system. The access arrangements are to comply with 5.6.

5.8.3 Ventilation of all normally entered spaces where there are potential sources of gas release are to be such that they are continuously in operation when gas may be present in the system, including purging. Provision is to be made to ventilate such spaces prior to entry.

5.8.4 Ventilation of machinery spaces is to be arranged to provide a pressure above atmospheric pressure by a ventilation system that is independent and separate from hazardous spaces.

5.8.5 Air supplied for combustion in gas-fuelled machinery and equipment is in addition to the air required for ventilation.

5.8.6 Ventilation intakes are to be located in non-hazardous areas and arranged to ensure that the required number of air changes for the spaces that are served can always be achieved under all foreseeable operating conditions. Ventilation exhausts are to discharge to atmosphere at least 3 m from the nearest air intakes or open decks that are accessible to personnel, or openings to accommodation and enclosed working spaces, and from any possible source of ignition, to ensure that any such opening, air intake or source of ignition lies outside the hazardous area associated with the ventilation exhaust, as identified by 3.2.5.

5.8.7 Unless certified for the same hazardous zone as the space served, electric motors for ventilation fans are to be located outside the airflow stream and ventilation ducts from hazardous spaces, and are not to be led through accommodation, service or machinery spaces or control stations.

5.8.8 Fans located in hazardous spaces or ventilation ducts serving such spaces are to be of the non-sparking type, in accordance with Pt 5, Ch 15,1.8 of the Rules for Ships.

5.8.9 'Fail-safe' automatic closing fire dampers of an approved type are to be fitted in the ventilation trunks for the machinery and gas storage tank spaces. The characteristics of the 'fail-safe' operation are to be evaluated, not only on the basis of the function of the fire damper, but also the availability of the space that it serves.

5.8.10 Any ducting used for the ventilation of hazardous spaces is to be separate from that used for the ventilation of non-hazardous spaces. The ventilation is to function at all temperatures and environmental conditions in which the ship will be operating.

5.8.11 Any loss of the required ventilating capacity is to give an audible and visual alarm on the navigation bridge or at a permanently manned location.

5.8.12 Air inlets for hazardous enclosed spaces are to be taken from areas that, in the absence of an inlet, would be non-hazardous.

5.8.13 Air inlets for non-hazardous enclosed spaces are to be taken from non-hazardous areas at least 1,5 m away from the boundaries of any hazardous area. Where an inlet duct passes through a more hazardous space, the duct is to have over-pressure relative to this space (over-pressure is to be continuously monitored), unless mechanical integrity and gas-tightness of the duct ensures that gases will not leak into the duct.

5.8.14 Air outlets from non-hazardous spaces are to be located outside hazardous areas.

5.8.15 Air outlets from hazardous enclosed spaces are to be located in open areas that, in the absence of an outlet, would be the same or a lesser hazard than in the ventilated space.

Section 6
System design

6.1 General

6.1.1 The system design, including gas bunkering stations, gas storage tanks, gas process equipment and gas-fuelled machinery, is to have been evaluated in the safety and reliability analysis, *see* Section 3, and considered acceptable to LR. The system design is also to satisfy the requirements of this Section.

6.1.2 The design and construction of gas-fuelled machinery is to permit stable and complete combustion under all expected operating conditions. The requirements are applicable to gas-fuelled machinery, for either propulsion or auxiliary purposes, and of either a single (gas) fuel or dual fuel type, *see* 1.3.3.

6.1.3 Where power for the propulsion of the ship or essential systems is solely dependent on gas-fuelled power generation machinery or equipment, no fewer than two independent sources of power are to be provided so that one source is retained in operation or is capable of being brought into operation in the event of closure of a master gas valve for one of the gas-fuelled power units. Complete loss of power for propulsion and essential systems is not acceptable.

6.1.4 In a non-hazardous area, a single failure within the gas system will not lead to a gas release into the machinery space.

6.1.5 When more than one machinery space is provided and these spaces are separated by a single bulkhead, arrangements are to be such that the effects of a gas explosion in either space can be contained or vented without affecting the integrity of the adjacent space and the equipment within that space.

6.1.6 Mechanical and electrical equipment located within hazardous areas is to be limited to that considered necessary for operational purposes.

6.1.7 Where it is necessary for mechanical equipment or machinery to be installed in a hazardous area, it is to comply with 4.3.3, *see* Pt 5, Ch 1,4.5 of the Rules for Ships.

6.1.8 Installations within hazardous areas are to be designed, and equipment and materials installed, in order to provide ease of access for inspection and maintenance.

6.2 Gas bunkering system

6.2.1 Bunkering operations are to be capable of being controlled from a safe location where gas storage tank pressures and level indictors are provided. Overfill alarm and automatic shut-down is to also be indicated at this location.

6.2.2 The bunkering system is to be arranged so that no uncontrolled venting of gas to atmosphere occurs under normal operating conditions during the filling of storage tanks.

6.2.3 A manually operated stop valve and a remote operated shut-down valve in series, or a combined manually operated and remote shut-down valve, is to be fitted at each bunkering station close to the shore connection point. The remote operated valve has to be capable of being operated locally from a bunkering control station or any other suitable safe location.

6.2.4 Bunkering lines are not to pass through accommodation, service spaces or control stations. Where bunkering lines pass through a non-hazardous space, they are to comply with the requirements of 7.2.17 or 7.2.18.

6.2.5 Means are to be provided for draining any liquid from the bunkering lines at isolating valves. The drainage positions are to be considered as sources of gas release.

6.2.6 Bunkering lines and bunkering tanks are to be capable of being inerted and gas freed.

6.2.7 If the ventilation in the ducting enclosing the gas bunkering lines stops, audible and visual alarms are to be provided at the bunkering control station.

6.2.8 If gas is detected in the ducting around the bunkering lines, audible and visual alarms are to be provided at the bunkering control station.

6.2.9 Drip trays are to be fitted below the bunkering connections and where leakage may occur. The drip trays are to be made of stainless steel, and are to be capable of being drained over the ship's side by a pipe that leads down into the sea. This pipe may be a portable connection that is temporarily fitted for bunkering operations. The surrounding hull or deck structures are not to be exposed to unacceptable cooling in the event of liquid gas leakage.

6.2.10 For compressed gas bunkering stations, low-temperature steel shielding is to be provided to prevent the possible escape of cold jets impinging on the surrounding hull structure. Where flanged joints are proposed, the circumference of the flange is to be covered with a shield, fabricated from a suitable material, so that any cold liquid formed during expansion will be caught and drained to the drip tray.

6.3 Gas storage system

6.3.1 Gas storage tanks, including their design, materials, construction and testing, are to be in accordance with the requirements for liquefied gas cargo tanks in chapters 2, 3, 4 and 6 of the IGC Code, and Class 1 fusion welded pressure vessels in Pt 5, Ch 11 of the Rules for Ships.

6.3.2 If it is not practical to comply with any IGC Code requirements by reason of the function or size of the ship, alternative proposals will be considered if they can be shown to be of equivalent safety in a comparative safety assessment, conducted and recorded in accordance with a recognised Standard.

Rules for the Classification of Natural Gas Fuelled Ships

6.3.3 Gas storage tank containment systems are to be so designed that a leak from the tank or its connections cannot lead to any danger for the ship. Potential dangers to be avoided include:

(a) low temperature being transferred to ship materials not designed for such temperature (for cryogenic or compressed gas); and

(b) flammable gases spreading to locations with ignition sources.

6.3.4 The material of the bulkheads of a fuel containment system space is to be designed to withstand the maximum pressure build-up. Alternatively, pressure relief venting to a safe location mast may be provided.

6.3.5 Where tanks are installed below the weather deck, the bilge drainage arrangements for the fuel gas storage tank rooms are to be independent of the bilge drainage arrangements for other compartments, and are to be capable of draining the bilge to a dedicated place of safety to allow vaporisation and ventilation. Bilge suctions from a space where gas may be present are to be separate from other bilge systems or spaces.

6.3.6 Pressure relief valves as required in IGC Code chapter 8 are to be fitted. The outlet from the pressure relief valves are normally located at least $B/3$ or 6 m, whichever is greater, above the weather deck and 6 m above the working area and gangways, where B is the greatest moulded breadth of the ship in metres. The outlet from pressure relief valves is to be led to the open at least 10 m from the nearest air intake or opening to accommodation spaces, service spaces and control stations, or open decks which are accessible to personnel, or other non-hazardous spaces. It is also to be located at least 10 m from the nearest exhaust outlet from machinery installations. As an alternative to the distance equirements given above, a safe release of gas vented from the pressure relief valves may be permitted by the Administration.

6.3.7 Storage tanks with a connection below the highest liquid level are to be fitted with drip trays below the tank of sufficient capacity to contain the volume which could escape in the event of a pipe connection failure. The drip tray is to be capable of fulfilling its function at a static angle of heel of up to 30°. The drip tray is to be made of stainless steel, and there is to be efficient separation or insulation so that the hull or deck structures are not exposed to unacceptable cooling in case of leakage of liquid gas.

6.3.8 Storage tanks are to have a tank master isolating valve located as near to the tank as is practicable. This valve is to be capable of local manual operation and provide full closure.

6.3.9 For single fuel installations (gas only), the gas storage is be provided in no fewer than two tanks so that, in the event of any one tank becoming unavailable, the remaining tank(s) will provide sufficient gas to enable the ship to operate within its service profile, as defined in 3.1.1(a). The tanks are to be located in separate fire-protected compartments.

6.4 Gas supply system

6.4.1 The main gas supply to each gas-fuelled machine or set of machines is to be equipped with a manually operated stop valve and an automatically operated master gas fuel valve coupled in series. The master gas fuel valve is to shut off the gas supply automatically in the event of gas leakage, fire detection, loss of the required ventilation from the pipe duct or casing, or loss of pressurisation of double-walled piping, *see* 7.2 and 8.2.

6.4.2 For installations with a single source of propulsion power, arrangements are to be such that, in case of loss of the gas supply, a secondary separate and independent fuel supply is to be available. Dual-fuelled machinery is to be capable of operating at its maximum continuous rating on oil fuel alone.

6.4.3 Where necessary, the gas system is to include suitable treatment equipment to provide gas at constant temperature and pressure. In all cases, arrangements are to be such that the gas storage and delivery systems are maintained at a pressure below any relief device set pressure.

6.4.4 Gas supply compressors (where fitted) are to be suitably sized to achieve the required supply through-put of gas when operating at both the maximum and minimum ambient temperatures for which the gas system is designed.

6.4.5 The master gas fuel valves and pressure regulators/ reducing valves are not to be located within any machinery space(s).

6.4.6 Depending on the propulsion and machinery arrangement, a separate and independent gas supply line is to be provided for each item of gas-fuelled machinery. The gas supply line to each item of gas-fuelled machinery is to be fitted with a block-and-bleed valve system that has three automatic valves with two of the valves in series, enabling the gas supply to be shut off and vented to atmosphere at a safe location via a third valve.

6.4.7 Block-and-bleed valves are to be arranged so that failure of the required ventilation, gas or fire alarms, a fault in gas-fuelled machinery, abnormal gas supply pressure or loss of the valve actuating medium, will cause the two valves in series to close and the vent valve between them to open.

6.4.8 Block-and-bleed valves are to be arranged for manual reset. Where a remote reset is fitted, the arrangements are to ensure that the gas supply is not resumed until the abnormal condition that caused the shut-off of the valves has been rectified and it is safe to resume supply.

6.4.9 All master gas fuel valves and block-and-bleed valves are to be arranged for both local operation and remote operation from the machinery control station.

6.4.10 Provision is to be made for gas-freeing and inerting gas piping.

6.4.11 All gas supply piping within machinery space boundaries is to be enclosed in a gas-tight enclosure, i.e., double wall-piping or ventilated ducting.

6.4.12 The spaces in which gas process equipment prime movers, such as engines and motors, are located, are to be of a certified safe type suitable for the space in which they are installed or are to be located in an adjacent non-hazardous area. Prime mover shafts passing through bulkheads or decks are to be fitted with gas-tight seals of an approved type.

6.5 Gas-fuelled reciprocating internal combustion engines and gas turbines

6.5.1 All gas engine components, gas engine systems and gas engine subsystems are to be designed to prevent any explosion in all possible situations.

6.5.2 When gas is supplied in a mixture with air through a common manifold, sufficient flame arrestors are to be installed before each cylinder head. The inlet system is to be designed to withstand explosion of a gas-air mixture by means of:
(a) explosion relief venting to prevent excessive pressure build-up: where explosion relief venting is installed, it is to discharge the combustion products to a safe location; and
(b) having sufficient strength to contain a worst-case explosion, in which case, documentary evidence is to be submitted.

6.5.3 The requirements in 6.5.2 may be omitted if the gas concentration within the manifolds is controlled and if combustion of an unburnt mixture within the manifolds can be excluded. A justification to demonstrate how this can be achieved is to be submitted.

6.5.4 The exhaust system is to be designed to withstand combustion of unburnt gas-air mixture by means of:
(a) explosion relief venting to prevent excessive pressure build-up: where explosion relief venting is installed, it is to discharge the combustion products to a safe location;
(b) having sufficient strength to contain a worst-case explosion, in which case, documentary evidence is to be submitted; or
(c) temperature limiting arrangements to prevent the exhaust system exceeding the auto-ignition temperature of the fuel gas.

6.5.5 The requirements in 6.5.4 may be omitted if the gas concentration within the manifolds is controlled and if combustion of an unburnt mixture within the manifolds can be excluded. A justification to show how this can be achieved is to be submitted.

6.5.6 The combustion of gas-fuelled engines is to be monitored to detect knocking combustion and misfiring. The knock monitoring system is to be designed so that an alarm is to be raised when one of the knock sensors becomes defective. Furthermore, the engine is not to be permitted to start with defective knock sensors.

6.5.7 Dual fuel diesel engines are to be of the type employing pilot oil fuel ignition and capable of immediate changeover to oil fuel at any load in the event of the gas supply being shut off and thereafter capable of continuous operation at any load up to full load on oil fuel alone. In general, oil fuel is to be used when starting the engine, when the operation of the engine is unstable, and/or during manoeuvring and port operations.

6.5.8 For dual fuel diesel engines, changeover to gas operation is to be possible only at a load and under conditions where it can be done reliably, as demonstrated by testing. On power reduction, the changeover to oil fuel is to be automatic. The changeover process itself to and from gas operation is to be automatic. Manual interruption is to be possible in all cases.

6.5.9 In the case of a normal stop or an emergency shut-down, the gas supply is to be shut off no later than the oil fuel. It is not to be possible to shut off the supply of pilot fuel without first or simultaneously closing the gas supply to each cylinder or to the complete engine.

6.5.10 All reciprocating internal combustion engines are to be provided with crankcase explosion relief valves fitted in way of each crankthrow. The valves are to be in accordance with Pt 5, Ch 2,6 of the Rules for Ships.

6.5.11 All reciprocating internal combustion engines are to be fitted with oil mist monitoring equipment that is in accordance with the requirements of Pt 5, Ch 2,6 of the Rules for Ships, or engine bearing monitoring devices or equivalent devices.

6.5.12 Where trunk piston type engines are used, the crankcase is to be protected by the following measures. If such an arrangement cannot be achieved, equivalent safety measures are to be provided by the manufacturer and accepted by LR.
(a) The provision of breathing equipment, the outlet for which is to be led to a safe location in the open through a flame arrestor.
(b) The provision of gas detection or equivalent electronic equipment which is suitable for hazardous areas **zone 1**, *see* Table 1.8.3, and means for the injection of inert gas.

6.5.13 Gas detection equipment for the piston underside space of crosshead type engines is to be provided to activate engine shut-down arrangements in the event of high levels of gas concentration. Means for the injection of inert gas are also to be provided.

6.5.14 The exhaust gas manifold of gas-fuelled and dual fuel engines is to be so designed as to allow the combustion of unburnt charge from an individual cylinder without detrimental effect.

6.5.15 Each cylinder is to be provided with its own individual fuel gas inlet valve, admitting gas either to the cylinder or the air inlet port. The functioning of this valve is to be such that no fuel gas can pass to the exhaust during the scavenging period or to the inlet port after closure of the air inlet valve.

6.5.16 An isolating valve and flame arrestor are to be provided at the inlet to the gas supply manifold for each engine. The isolating valve is to be arranged to close automatically in the event of low gas pressure or cylinder misfire.

6.5.17 Arrangements are to be provided to enable purging of the exhaust system before the starting of an engine, after failure to start and following loss of ignition during operation of the engine. Interlocking devices are to be fitted to ensure that purging can be carried out only when the isolating valve required by 6.5.16 is closed. The purge is to be of sufficient duration to displace at least three times the volume of the exhaust system.

6.5.18 The exhaust pipes of gas-fuelled engines are not to be connected to the exhaust pipes of other engines or systems.

6.5.19 Indication is to be provided for identifying poor combustion from each combustion chamber, flame-out and failure-to-ignite conditions, and arrangements are to be made to ensure that the fuel supply to the combustion chambers is cut off unless satisfactory ignition has been established and maintained.

6.5.20 Arrangements are to be provided to purge automatically the gas turbine before ignition commences on starting, or recommences after failure to start, or following a loss of ignition in operation. Arrangements are also to be provided to allow manual purging. Interlocking devices are to be fitted to ensure that purging can be carried out only when the fuel supply valves are closed. The purge is to be of sufficient duration to displace at least three times the volume of the exhaust system.

6.5.21 For engines fitted with single wall piping, a suitable ventilation hood or casing is to be provided, arranged over the gas-fuelled machinery and associated valves and pipes, but without restricting the airflow to the machinery. The hood or casing is to be arranged to permit the ventilating air to sweep across gas-fuelled machinery and be exhausted at the top of the ventilation hood or casing. The arrangements of hoods and casings permit inspection of, and access to, the gas-fuelled machinery, valves and pipes.

6.5.22 The hood or casing required by 6.5.21 is to be fitted with a ventilation duct led to atmosphere at a safe location. At least two 100 per cent capacity extraction fans with spark-proof impellers are to be fitted to maintain a pressure inside the hood less than that of the boiler room or machinery space. The fans are to be arranged for automatic changeover to the standby fan upon failure of the operational fan. The fan prime movers are to be placed outside the duct with gas-tight drive shaft penetrations through the duct casing and the electrical power supplies are to be arranged in accordance with Pt 6, Ch 2,5.2 of the Rules for Ships. In the event of total loss of ventilation for the hood or casing, the master gas fuel valve required by 6.4.1 is to be arranged to close automatically.

6.6 Gas-fuelled boilers

6.6.1 The arrangement of boilers and burner systems is to comply with the requirements of Pt 5, Ch 10 and Pt 5, Ch 14 of the Rules for Ships and 16.5 of the *Rules and Regulations for the Construction and Classification of Ships for the Carriage of Liquefied Gases in Bulk,* as applicable. The whole boiler casing is to be gas-tight and each boiler is to have a separate uptake.

6.6.2 Combustion chambers and furnaces of boilers are to be designed such that pockets of gas cannot accumulate.

6.6.3 Boilers and combustion units are to be provided with forced draught arrangements.

6.6.4 Means are to be provided so that, in the event of flame failure, the gas supply to the burners is shut off automatically, and alarms are activated.

6.6.5 Inert gas or steam arrangements are to be provided for automatically purging the gas supply piping to the burners after these burners have been extinguished. Arrangements are also to be provided to allow manual purging. Interlocking devices are to be fitted to ensure that purging can be carried out only when the burner fuel supply valves are closed.

6.6.6 For dual fuel burner units, the firing equipment is to be suitable to burn either oil fuel or gas alone, or oil and gas simultaneously. The gas nozzles are to be so disposed as to obtain ignition from the oil flame. An interlocking device is to be provided to prevent the gas supply being opened until the oil and air controls are in the firing position. It is to be possible to change from gas to oil fuel operation easily and quickly.

6.6.7 Each burner supply pipe is to be fitted with a gas shut-off valve and a flame arrestor, unless this is incorporated in the burner.

6.6.8 In addition to the low water level fuel shut-off and alarm required by Pt 5, Ch 10,15.7 or 16.7 of the Rules for Ships for oil-fired boilers, equivalent arrangements are to be made for gas shut-off and alarms when the boilers are being gas fired. *See* Pt 6, Ch 1 of the Rules for Ships for requirements for control, alarm and safety systems, and additional requirements for unattended operation.

■ *Section 7* Piping

7.1 General

7.1.1 The design and construction of piping is to be in accordance with Chapter 5 of the IGC Code and Pt 5, Ch 12 of the Rules for Ships, as applicable. Piping material selection is to consider the system operating temperatures.

7.1.2 The design and construction of low-temperature piping is to be in accordance with the requirements of Table 6.4 of the IGC Code.

7.2 Piping design

7.2.1 Piping connections are to be reduced to the minimum required for installation and machinery maintenance. All piping is to be suitably and adequately supported so as to avoid, as far as is practicable, vibration that could lead to fatigue failure.

7.2.2 All valves and expansion joints used in pressurised gas piping are to be of an approved type.

7.2.3 Joints on the entire length of the gas piping are to be butt-welded with full penetration and are to be fully radiographed, except where alternative means of NDE are approved by LR.

7.2.4 Gas pipe joints other than welded joints at the locations approved by LR are to comply with an appropriate Standard recognised by LR, or with those joints whose structural strength has been verified through tests and analysis to the satisfactory requirements of LR.

7.2.5 Welding procedures are to be established for welding of pressurised gas piping and submitted to LR for approval. Suitable post-weld heat treatment is to be performed where indicated in the approval.

7.2.6 Gas piping is to be clearly identifiable by means of a suitable colour code based on a recognised Standard.

7.2.7 Piping installed on the open deck is to be suitably located and protected from corrosion and mechanical damage.

7.2.8 The wall thickness of gas piping is not to be less than that given by the requirements of the IGC Code, Section 5.2.2.

7.2.9 The greater of the following design conditions is to be used for selection of piping and piping system components, as appropriate:

(a) for systems or components that may be separated from their relief valves and that contain only vapour at all times, the superheated vapour pressure at 45°C, or higher or lower if agreed upon by the Administration (ref. IGC Code paragraph 4.2.6.2), assuming an initial condition of saturated vapour in the system, at the system operating pressure and temperature;
(b) the MARVS of the gas tanks and gas processing systems;
(c) the pressure setting of the associated pump or compressor discharge relief valve is of sufficient capacity;
(d) the maximum total discharge or loading head of the gas piping system;
(e) the relief valve setting on a pipeline system is of sufficient capacity; or
(f) a pressure of 10 bar.

7.2.10 If the gas contains heavier components that may condense in the system, a vapour-liquid separator or equivalent for the safe removal of the liquid is to be fitted.

7.2.11 All piping and components that may be isolated containing liquid gas are to be provided with relief valves.

7.2.12 Where tanks or piping are separated from the ship's structure by thermal isolation, provision is to be made for electrically bonding both the piping and the tanks to the ship's structure. All gasketed pipe joints and hose connections are to be electrically bonded.

7.2.13 Piping into the tank, fittings, flanges, valves or other equipment in the tank space or inter-barrier space is to be minimised. If possible, these installations are to be located in a separate room.

7.2.14 Gas piping is not to be located less than 760 mm from the ship's side.

7.2.15 Gas piping is to be entirely separate from other piping systems and is not to pass through accommodation, service spaces or control stations.

7.2.16 Gas piping within a machinery space is to comply with the applicable requirements in 7.2.17 or 7.2.18. Alternative arrangements to those stated in 7.2.17 and 7.2.18 will be considered where an equivalent level of safety for personnel, equipment and the ship can be demonstrated.

7.2.17 Where gas piping is a double-walled piping system with the gas contained in the inner pipe, the following requirements are to be satisfied:

(a) the annular space between pipes is to be pressurised with inert gas to a pressure greater than the fuel pressure;
(b) alarms are to be provided to indicate loss of pressure between the pipes;
(c) the pressure in the annular space is to be monitored continuously and, before the pressure falls below the inner pipe pressure, the master gas fuel valve specified in 6.4.1 is to be arranged to close and the automatic valve system specified in 6.4.6 arranged to be actuated;
(d) construction and strength of the outer pipes are to comply with the requirements of chapter 5.2 of the IGC Code; and
(e) arrangements are to be made for fuel gas supply piping between the master gas fuel valve required by 6.4.1 and the gas-fuelled unit to be purged with inert gas when the valve is closed.

7.2.18 Where the fuel gas piping is installed within a ventilated gas-tight duct, the following requirements are to be satisfied:

(a) the air space between the gas piping and the duct inner wall is to be provided with mechanical ventilation having a capacity that takes into account the construction and arrangement of protective pipes or ducts and, in general, is to ensure at least 30 air changes per hour so that any gas leakage at the maximum foreseeable rate is diluted to below the LEL;
(b) ventilation is to maintain a pressure less than the atmospheric pressure. The fan motors are to be placed outside the ventilated pipe or duct;
(c) ventilation outlets are to be located to discharge at least 3 m above deck and 3 m away from the nearest air intakes or openings to accommodation and enclosed working spaces, and from possible sources of ignition;

(d) ventilation intakes are to be provided with automatic non-return devices that prevent the escape of gas or alternatively, a gas detector is to be fitted at each air intake;
(e) ventilation is to be arranged to be in operation whenever there is gas in the piping;
(f) continuous gas detection is to be arranged in the ventilation system to provide an indication of gas leaks at the machinery control station and to shut down the gas supply to the machinery space in accordance with 8.4.11;
(g) the master gas fuel valve required by 6.4.1 is to be arranged to close automatically if the required airflow is not established and maintained by the exhaust ventilation system;
(h) the materials, construction and strength of protection pipes or ducts and the mechanical ventilation systems are to be capable of withstanding the sudden emission and rapid expansion of high pressure gas in the event of failure of a fuel gas pipe; and
(j) the number of flange joints of protective pipes or ducts is to be minimised.

7.2.19 Low temperature liquefied gas piping is to have suitable insulation supplied in two layers, with joints staggered and covered with an efficient vapour barrier.

7.2.20 Where pipes, ducts or cables pass through decks or bulkheads between non-hazardous areas and hazardous areas, the penetration is to be designed to prevent the passage of hazardous gases.

■ *Section 8* Control and monitoring

8.1 General

8.1.1 Control, alarm and safety systems are to comply with the relevant requirements of Pt 6, Ch 1 of the Rules for Ships.

8.2 Control, alarm and safety functions

8.2.1 Tables 1.8.1 to 1.8.3 indicate the additional alarms, monitoring and safeguards for gas-fuelled machinery arrangements.

8.2.2 Additional alarms and shut-downs determined on the basis of the hazard analysis, *see* 2.1.1(b), are to be provided.

8.2.3 Arrangements are to be made so that the gas supply to the gas-fuelled machinery and equipment can be shut off manually from the starting platform or any other control position.

8.2.4 A local reading pressure gauge is to be fitted between the stop valve and the connection to shore at each bunker pipe.

8.2.5 Pressure gauges are to be fitted to gas pump discharge lines and to the bunkering lines.

Table 1.8.1 Gas detection: Locations – Alarms, monitoring and safeguards

Alarm	Monitored locations	Note
Gas concentration above 30% LEL	Locations described in 8.4.1(a) (b) (c) (e) (f)	*See* Notes 1, 2 and 5
	Gas supply line ventilated pipe or ducts as described in 8.4.1(d)	*See* Notes 1 and 2 *See* 6.4.2 for alternative gas supply requirements
	Within hood or casing	*See* Notes 1 and 2
	In ventilated pipe or duct of gas bunkering lines, *see* 6.2.4	*See* Note 6 For gas fuel shore connection shut-down arrangements, *see* 6.2.3
	Within air intakes as described in 7.2.18(d)	*See* Notes 1 and 2
	Gas analysing equipment cabinet	

NOTES
1. Alarm to be given additionally in the machinery space and the machinery control station.
2. Continuous gas detection is required and fuel supply is to be shut down by automatic closing of supply line master gas fuel valve when the gas concentration reaches 60% LEL, *see* 8.4.11.
3. *See* 8.4 for gas detection equipment requirements.
4. For gas detection within machinery, *see* Table 1.8.3.
5. Separate alarms for each location to be provided in accordance with 8.4.5.
6. Alarm to be given at the gas fuel bunkering control station.

Table 1.8.2 Gas fuel supply and storage: Alarms, monitoring and safeguards

Item	Alarm	Note
Supply pressure	Abnormal	Gas fuel supply shut-down, *see* Notes 1 to 3
Valve actuating medium	Loss	Gas fuel supply shut-down, *see* Note 1
Supply line pipe duct or casing ventilation	Failure	Gas fuel supply shut-down, *see* Notes 1 to 3 Automatic closing of supply line master gas fuel valve. *See* 7.2.18
Double-walled piping	Loss of pressurisation	Gas fuel supply shut-down, *see* Notes 1 to 3 Automatic closing of supply line master gas fuel valve. *See* 7.2.17 For bunkering lines, *see* Note 6 For gas fuel shore connection shut-down arrangements, *see* 6.2.3
Hood/casing extraction fan	Failure	*See* 6.5.21 and 6.5.22
Gas fuel storage tanks	Failure	
Gas fuel storage tanks	Over-pressure, overfill, automatic shut-down	Gas fuel bunkering alarms are to be given in bunkering control station, *see* 6.2.1 for monitoring
Space ventilation system	Failure	

NOTES
1. Gas fuel supply shut-down by automatic operation of gas supply line double block-and-bleed valves. *See* 6.4.6 to 6.4.9.
2. Alarms associated with gas fuel supply and ventilation arrangements are to be given in the machinery space and machinery control station.
3. *See* 6.4.2 for alternative gas fuel supply requirements.
4. Actual valve position is to be positively indicated at the required remote control position.
5. Arrangements are to prevent automatic or remote starting under conditions which could cause a hazardous situation, *see* 8.2.11.
6. Alarm is to be given at the gas fuel bunkering control station.

8.2.6 A bilge well in each fuel containment system containing an independent liquefied gas storage tank is to be provided with both a level indicator and a temperature sensor. An alarm is to be raised when the level is high in the bilge well. Low temperature indication is to lead to automatic closing of the main tank valve.

8.2.7 Each tank is to be monitored with at least one indicating instrument for pressure and remote pressure indication at the control position. The pressure indicators are to be clearly marked with the highest and lowest pressure permitted in the tank. In addition, a high pressure alarm and, if vacuum protection is used, a low pressure alarm, is to be provided on the navigation bridge or in a continuously manned central control station. The high pressure alarms are to be activated before the set pressures of the safety valves are reached.

8.2.8 Gas compressors are to be fitted with audible and visual alarms both on the navigation bridge and in the engine room. As a minimum, the alarms are to include low gas input pressure, low gas output pressure, high gas output pressure and compressor operation.

8.2.9 An audible and visible alarm system to give a warning on both sides of the air-lock is to be provided. The visible alarm is to indicate if one door is open. The audible alarm is to sound if doors on both sides of the air-lock are moved from the closed positions.

8.2.10 In addition to the instrumentation provided in accordance with SOLAS Chapter II-1, Part C, indicators are to be fitted on the navigation bridge, the engine control room and the manoeuvring platform for:

(a) operation of the engine in case of gas-only engines; or
(b) operation and mode of operation of the engine in the case of dual fuel engines.

8.2.11 Where machinery is arranged to start automatically or from a remote control station, interlocks are to be provided to prevent start-up under conditions that could hazard the machinery, *see* Pt 6, Ch 1,3.1.2 of the Rules for Ships.

Table 1.8.3 Gas-fuelled machinery: Alarms, monitoring and safeguards

Item	Alarm	Note
Engine crankcase protection	Gas concentration above 30% LEL High oil mist concentration, *see* Note 1	Engine shut-down and automatic closing of supply line master gas fuel valve, *see* Note 2 *See* 8.4 for gas detection equipment requirements
Crosshead type engine piston underside spaces	Gas concentration above 30% LEL	Engine shut-down and automatic closing of supply line master gas fuel valve *See* 8.4 for gas detection equipment requirements
Engine gas supply pressure	Low	Automatic closing of gas supply manifold isolating valve *See* 6.4.2 for alternative gas fuel supply requirements
Engine gas fuel injection	Cylinder misfire Gas fuel or pilot fuel injection valve failure	*See* Note 3 *See* 6.4.2 and 6.5.16
Exhaust gas temperature	High	Per cylinder, *see* Note 3
Exhaust gas temperature deviation from average	High	Per cylinder, *see* Note 3
Cylinder pressure	Low	Alternatively, ignition failure monitoring and alarms of each cylinder are permitted, *see* Note 3
Engine shut-down		Automatic closing of gas supply manifold isolating valve
Burner flame and ignition	Failure	Each burner to be monitored, *see* Note 5
Boiler shut-down		*See also* Notes 4 and 5
Fuel injection valve cooling water pressure	Low	
Fuel injection valve cooling water temperature	High	

NOTES
1. Bearing temperature monitoring is permitted in lieu of oil mist monitoring for dual fuel crosshead type engines.
2. Means of injection of inert gas are to be provided, capable of being operated remotely from a safe location.
3. Automatic operation of gas supply line double block-and-bleed valves and closing of supply line master gas fuel valve.
4. Automatic operation of gas supply line double block-and-bleed valves, *see* 6.4.6 to 6.4.9.
5. Combustion spaces are to be purged automatically before re-ignition takes place in the event of flame-out on all burners. *See also* 6.6.5.
6. Machinery alarms are to be given in the machinery space and the machinery control station, in accordance with Pt 6, Ch 1,2.3.2 of the Rules for Ships.

8.3 Pressurisation

8.3.1 For protective measures to be taken in the event of failure of pressurisation, *see* Table 1.8.4.

8.4 Gas detection

8.4.1 A permanently installed system of gas detection and audible and visual alarms is to be fitted in:

(a) all enclosed spaces containing gas piping, gas equipment or gas consumers;
(b) other enclosed or semi-enclosed spaces where gas vapours may accumulate including exhaust uptakes;
(c) air-locks;
(d) ventilation hoods and gas ducts where required by 5.8, 7.2, 6.5.21 and 6.5.22;
(e) auxiliary piping system serving gas-fuelled machinery where a single failure can result in gas leakage; and
(f) any spaces identified as requiring gas detection by safety and reliability analysis, *see* 3.2.

8.4.2 Gas detection equipment is to be designed, installed and tested in accordance with IEC 60079-29-1, and is to be suitable for the gases to be detected.

Rules for the Classification of Natural Gas Fuelled Ships

Table 1.8.4 Protective measures to be taken in the event of failure of pressurisation

Classification of the space, *see* Note	Electrical equipment installed		
	Equipment suitable for use in zone 1	Equipment suitable for use in zone 2	Equipment not protected for any hazardous area
Zone 1 - -	No action necessary	• Suitable alarm (visible and audible) • Immediate action to restore pressurisation • Programmed disconnection of power supplies if the pressurisation cannot be restored for an extended period or if the concentration of flammable gas rises to a dangerous level	• Suitable alarm (visible and audible) • Immediate action to restore pressurisation • Automatic interruption of the power supplies as rapidly as practicable within a prescribed delay time, with regard to the needs of a programmed shut-down
Zone 2	No action necessary	No action necessary	• Suitable alarm (visible and audible) • Immediate action to restore pressurisation • Programmed disconnection of power supplies if the pressurisation cannot be restored for an extended period or if the concentration of flammable gas rises to a dangerous level
NOTE Classification of the space or area into which the opening leads.			

8.4.3 The number and the positions of detection heads or sampling heads is to be determined with due regard to the size and layout of the compartment, the dilution from compartment purging or ventilation and stagnant areas, and the manufacturer's recommendations.

8.4.4 The detector or sampling heads of the fuel gas detection systems are not to be located where liquid can collect. Pipe runs from sampling heads are not to be led through non-hazardous spaces, except as permitted by 8.4.9.

8.4.5 Alarms from gas detection equipment required by 8.4.1 are to initiate an audible and visual alarm:
(a) on the navigating bridge;
(b) at the relevant control station(s) where continuous monitoring of the gas levels is recorded; and
(c) in the bunkering control position.

8.4.6 Permanently installed gas detection is to be of the continuous detection type, capable of immediate response. Where not used to activate safety shut-down functions required by these Rules, the sampling type detection may be accepted.

8.4.7 When sampling type gas detection equipment is used, the following requirements are to be met:
(a) the gas detection equipment is to be capable of sampling and analysing for each sampling head location sequentially at intervals not exceeding 30 minutes;
(b) individual sampling lines from sampling heads to the detection equipment are to be fitted; and
(c) pipe runs from sampling heads are not to be led through non-hazardous spaces, except as permitted by 8.4.8.

8.4.8 The gas detection equipment may be located in a non-hazardous space, provided that the detection equipment such as sample piping, sample pumps, solenoids and analysing units are located in a fully enclosed steel cabinet with the door sealed by a gasket. The atmosphere within the enclosure is to be continuously monitored. At gas concentrations above 30 per cent LEL inside the enclosure, the entire gas detection unit is to be automatically shut down including all power to external equipment.

8.4.9 Additionally, where gas detection equipment is located in a non-hazardous space, the following conditions are also to be satisfied:
(a) fuel gas sampling lines are to have shut-off valves or an equivalent arrangement to prevent cross-communication with hazardous spaces; and
(b) exhaust gas from the detector is to be discharged to the atmosphere in a safe location.

8.4.10 Gas detection equipment is to be designed so that it may be readily tested. Testing and calibration is to be capable of being carried out at regular intervals. Arrangements are to be made for suitable equipment and span gas for testing and calibration purposes to be carried on board. Wherever practicable, provision is to be made for permanent connections for attachment of testing and calibration equipment.

8.4.11 Gas detection system(s) are to be suitable for measuring gas concentrations of 0 to 100 per cent by volume of the LEL. Alarms are to be activated when the fuel gas concentration reaches 30 per cent of the LEL and automatic closing of supply line master gas fuel valve is to occur when the gas concentration reaches 60 per cent of the LEL. Common sampling lines to the detection equipment are not to be fitted.

8.5 Fire detection and alarm system

8.5.1 A fire detection and alarm system, satisfying the requirements of Pt 6, Ch 1,2.8.2 to 2.8.14 of the Rules for Ships, is to be fitted in all spaces containing potential sources of gas leakage and ignition.

Section 9 Electrical

9.1 General

9.1.1 The electrical installation is to be designed, constructed and installed in accordance with the requirements of Pt 6, Ch 2 of the Rules for Ships.

9.2 Electrical engineering

9.2.1 Electrical equipment and cabling is to be, as far as is reasonably practical, located in non-hazardous areas. Where this is not possible for operational purposes, it is to be located in an area with the least onerous hazardous area zonal classification.

9.2.2 Where electrical equipment is installed in the hazardous areas identified in 3.2.4, it is to be selected and installed in accordance with the applicable requirements of Pt 6, Ch 2,13 of the Rules for Ships, relevant to the zonal classification.

9.2.3 The lighting systems in hazardous areas are to be divided between at least two branch circuits. All switches and protective devices are to interrupt all poles or phases and are to be located in a non-hazardous area.

Section 10 Testing and trials

10.1 Testing and trials

10.1.1 Testing of gas-fuelled machinery and equipment is to be carried out in accordance with test schedules agreed by LR. In general, the arrangements for testing are to be equivalent to those required for oil-fuelled machinery and equipment.

10.1.2 Consideration will be given to carrying out gas fuel tests when the ship is at sea where the engine and its control systems have previously been tested in the oil-fuelled operating mode to the satisfaction of LR.

10.1.3 Commissioning tests and trials are to be carried out in accordance with the testing program which is required to be submitted by 2.1.1(t). The testing program is to be agreed by LR and all tests are to be carried out in the presence of a Surveyor.

10.1.4 Trials are to include the testing of all alarms and safeguards associated with the gas supply system and gas-fuelled machinery and equipment.

10.1.5 In addition to the relevant Chapter of the Rules for Ships, gas storage and containment systems for liquefied gas are to be tested in accordance with Chapters 4, 10 and 11 of the IGC Code.

Published by Lloyd's Register
Registered office
71 Fenchurch Street, London, EC3M 4BS
United Kingdom

Lloyd's Register
71 Fenchurch Street
London EC3M 4BS
UK
T +44 (0)20 7709 9166
F +44 (0)20 7488 4796

www.lr.org

NGR/12

Lloyd's Register
Marine

Working together
for a safer world

What the IGF Code means for you

A review of the changes in requirements for natural gas-fuelled ships

A Lloyd's Register Guidance Note

Contents

Introduction

In 2003, the IMO formally recognised the need to address the use of liquefied natural gas (LNG) as fuel on ships not covered by the IGC Code. Initial development of requirements for natural gas fuelled ships began in 2006 and led to the adoption of interim guidelines in July 2009[1].

Development of the International Code of Safety for Ships using Gases or other Low flashpoint Fuels (the IGF Code) began in parallel with these guidelines, initially focusing on requirements for natural gas as fuel, but with additional low-flashpoint fuel requirements planned for future inclusion. The Code (with requirements for natural gas as fuel) was adopted in June 2015[2] and enters into force on 1 January, 2017. This date is when it takes legal effect, but the requirements will apply in practice from 1 July, 2016, to ships built (having their keel laid) on or after this date.

The requirements of the IGF Code provide an increased level of detail as a result of the technological developments and experience gained since the adoption of the interim guidelines.

Lloyd's Register's Rules and Regulations for the Classification of Natural Gas Fuelled Ships (the Rules for Gas Fuelled Ships) came into force in 2012, replacing the provisional rules that were in place before. Every year, these Rules have been updated to incorporate experience gained from our involvement in this fast-changing sector. The Rules are currently undergoing a further update to incorporate the requirements of the IGF Code and they will continue to provide clarifications and requirements to attain LR class for a natural gas fuelled ship.

In addition to our Rules for Gas Fuelled Ships, we provide a design screening service to identify critical issues and so provide confidence that key IGF Code requirements are met. Essentially, the design is assessed against key aspects of the IGF Code and helps identify items early in planning and design that might otherwise result in significant costs and delays if uncovered later – for example, during ordering, manufacturing or installation of equipment. We continue to offer an approval in principle (AiP) service to give confidence in early stage designs that they are generally compliant with the applicable LR Rules.

We also offer a 'Gas Fuelled Readiness' (GR) notation that goes to a greater level of detail and, together with a suite of associated characters, provides a higher level of confidence that a ship is capable of conversion to gas fuel after delivery. This provides flexibility to owners who want to prepare their vessels to be able to meet a variety of potential future fuel price and availability scenarios.

In this guidance note, we review the IGF Code, identifying the main changes from the interim guidelines. We highlight the points that impact on the design of a gas fuel system that we believe will have the most impact on designers and operators, and provide an analysis of what they mean for you[3].

1 The interim guidelines were adopted by Resolution MSC.285(86)

2 The IGF Code was adopted by Resolution MSC.391(95)

3 The guidance in this note does not take precedence over the requirements or interpretations found in the IGF Code or Lloyd's Register's Rules

How to use this note

Throughout this note we refer to the IGF Code as the 'Code' and MSC.285(85) as the 'interim guidelines' we use the same paragraph numbering and headings as the IGF Code to allow for easy cross referencing. Where appropriate, reference to specific locations in the interim guidelines is clearly indicated.

IGF Code chapter goals

Under each chapter heading, the chapter's goal is labelled in light blue and quoted in dark blue italics:

Goal *The goal of this Code is to provide for safe and environmentally-friendly design, construction and operation of ships and in particular their installations of systems for propulsion machinery, auxiliary power generation machinery and/or other purpose machinery using gas or low-flashpoint fuel as fuel.*

Other text quoted from the IGF Code

All other text quoted directly from the Code is shown in small italics with the relevant paragraph numbering:

2.3.1 This Code contains functional requirements for all appliances and arrangements related to the usage of low-flashpoint fuels.

Commentary

Commentary sections use plain text and describe aspects of the Code that could have a significant impact on design and arrangements. Numbering from the Code is used to identify the part of the text being discussed:

3.2 Lists functional requirements that are written to be applicable to any low-flashpoint fuel.

Analysis

These sections are labelled in orange and provide analysis of the preceding paragraphs' application and implications.

Analysis This code is designed to have a mutually exclusive link to the IGC Code. Any ship using a low-flashpoint fuel is required to comply with either the IGC or the IGF Code but they cannot both be applied to the same ship.

1. Preamble

The purpose of this Code is to provide an international standard for ships using low-flashpoint fuel, other than ships covered by the IGC Code.

Analysis

This code is designed to have a mutually exclusive link to the IGC Code. Any ship using a low-flashpoint fuel is required to comply with either the IGC or the IGF Code but they cannot both be applied to the same ship.

The code is mandated by amendments to SOLAS Chapter II-1 (new Part G, regulations 56 and 57); while it does not explicitly apply to ships of less than 500 gross tonnes the Resolution invites contracting governments to apply the Code voluntarily to all ships using gases or other low-flashpoint fuels.

Part A

2. General

2.2 Expands on the definitions previously included in the interim guidelines. There are no changes to the definitions that have been incorporated from the interim guidelines.

2.3 The Code follows a goal-based approach. This sub-section provides a means of compliance with the Code where the design deviates from the more prescriptive elements of the Code or proposes to use fuels not currently covered by the Code (i.e. any low-flashpoint fuel other than natural gas).

2.3.3 Emphasises good engineering practice that the safety of the system should be built into the design and not reliant on following operational methods or procedures.

3. Goal and Functional Requirements

Goal

The goal of this Code is to provide for safe and environmentally-friendly design, construction and operation of ships and in particular their installations of systems for propulsion machinery, auxiliary power generation machinery and/or other purpose machinery using gas or low-flashpoint fuel as fuel.

3.2 Lists functional requirements that are written to be applicable to any low-flashpoint fuel. Some functional requirements verge on providing prescription – e.g., 3.2.14 mandating gas detection – but the majority are broad statements of intent to achieve particular aspects of the overall goal of the Code.

This is a new approach and is the major difference between the Code and the interim guidelines. By providing clearly defined goals and functional requirements it is possible to develop and assess alternative designs and establish if the intent of the Code has been achieved.

4. General Requirements

Goal

The goal of this chapter is to ensure that the necessary assessments of the risks involved are carried out in order to eliminate or mitigate any adverse effect to the persons on board, the environment or the ship.

4.2 Mandates risk assessment for all low-flashpoint fuel systems to ensure that 'risks arising from the use of low-flashpoint fuels affecting persons on board, the environment, the structural strength or the integrity of the ship are addressed.'

4.2.2 For ships to which part A-1 applies, the risk assessment required by 4.2.1 need only be conducted where explicitly required by paragraphs 5.10.5, 5.12.3, 6.4.1.1, 6.4.15.4.7.2, 8.3.1.1, 13.4.1, 13.7 and 15.8.1.10 as well as by paragraphs 4.4 and 6.8 of the annex.

Analysis

Reference to specific paragraphs is a reminder that the scope of the risk assessment may be limited to specific items where:

1. there is no deviation from prescription; and
2. items have been previously subjected to a risk assessment, provided
   a. equipment operation, location and arrangements are the same;
   b. equipment is installed on the same type of ship, that is a cargo ship or passenger ship;
   c. all measures taken as a result of the previous risk assessment (to eliminate risks or mitigate them as necessary) are incorporated; and
   d. the previous risk assessment has been approved by the Administration or its recognized organization.

4.3 Provides information on the damage scenarios to be considered in spaces where there is potential for explosion in the event of a leak of a low-flashpoint fuel.

Part A-1 – Specific Requirements for Ships Using Natural Gas as Fuel

5. Ship Design and Arrangement

Goal

The goal of this chapter is to provide for safe location, space arrangements and mechanical protection of power generation equipment, fuel storage systems, fuel supply equipment and refuelling systems.

5.2 References several of the generic functional requirements defined in the general requirements chapter and develops them further specific to natural gas (and LNG):

5.2.1 .1 *the fuel tank(s) shall be located in such a way that the probability for the tank(s) to be damaged following a collision or grounding is reduced to a minimum taking into account the safe operation of the ship and other hazards that may be relevant to the ship;*

.2 *fuel containment systems, fuel piping and other fuel sources of release shall be so located and arranged that released gas is lead to a safe location in the open air;*

.3 *the access or other openings to spaces containing fuel sources of release shall be so arranged that flammable, asphyxiating or toxic gas cannot escape to spaces that are not designed for the presence of such gases;*

.4 *fuel piping shall be protected against mechanical damage;*

.5 *the propulsion and fuel supply system shall be so designed that safety actions after any gas leakage do not lead to an unacceptable loss of power; and*

.6 *the probability of a gas explosion in a machinery space with gas or low-flashpoint fuelled machinery shall be minimized.*

5.3.3 Sets the deterministic limits for tank location with fixed dimensions for the minimum spacing between the tank boundary (which includes all tank valves) and the ship side, fore and aft terminals and bottom plating.

5.3.4 Provides an alternative to the deterministic limit for tank location by setting a probability criterion (f_{CN}) and a calculation method for location based on the factors given in SOLAS Regulation II-1/7. This alternative is commonly referred to as the probabilistic approach.

Analysis Compared with the deterministic limits, the probabilistic approach may result in a reduced distance between the fuel tank and shell plating. However, it should be recognised that as the distance reduces so does the permissible length of the tank. Such a reduction limits the quantity of LNG stored and hence, reduces voyage distance or increases the frequency of LNG bunkering. The permissible tank length with respect to a distance less than B/5 is illustrated in Figures 1 and 2.

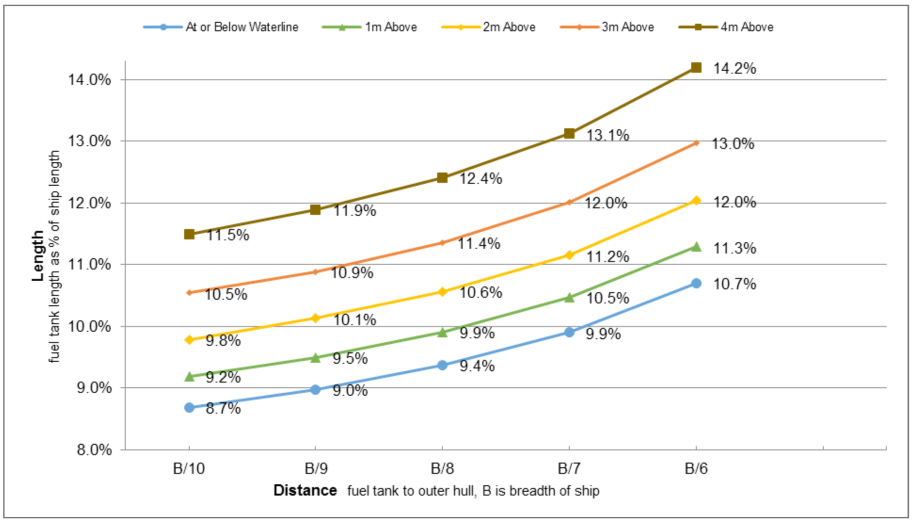


Figure 1: Permissible tank length with respect to distance for passenger ships

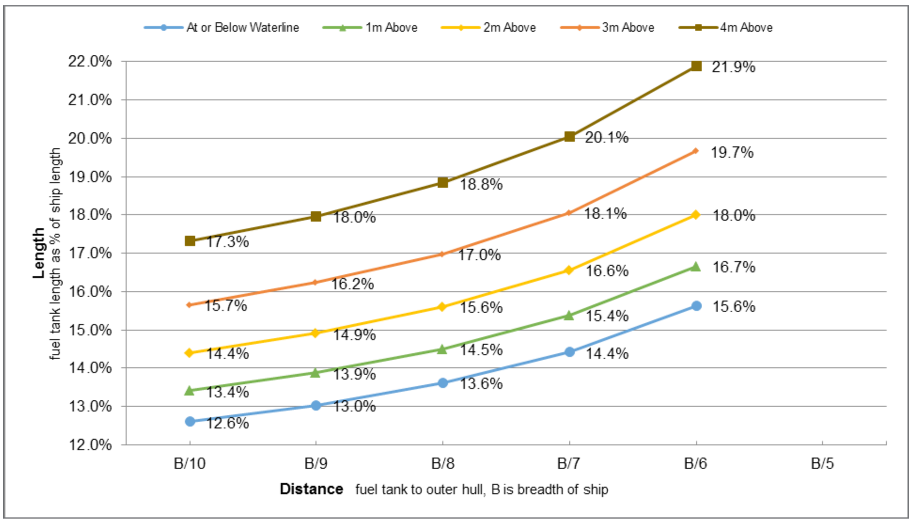


Figure 1: Permissible tank length with respect to distance for cargo ships

5.4.1 *In order to minimize the probability of a gas explosion in a machinery space with gas-fuelled machinery one of these two alternative concepts may be applied:*

.1 Gas safe machinery spaces: Arrangements in machinery spaces are such that the spaces are considered gas safe under all conditions, normal as well as abnormal conditions, i.e. inherently gas safe.

In a gas safe machinery space a single failure cannot lead to release of fuel gas into the machinery space.

.2 ESD-protected machinery spaces: Arrangements in machinery spaces are such that the spaces are considered non-hazardous under normal conditions, but under certain abnormal conditions may have the potential to become hazardous. In the event of abnormal conditions involving gas hazards, emergency shutdown (ESD) of non-safe equipment (ignition sources) and machinery shall be automatically executed while equipment or machinery in use or active during these conditions shall be of a certified safe type.

In an ESD protected machinery space a single failure may result in a gas release into the space. Venting is designed to accommodate a probable maximum leakage scenario due to technical failures.

Failures leading to dangerous gas concentrations, e.g. gas pipe ruptures or blow out of gaskets are covered by explosion pressure relief devices and ESD arrangements.

Analysis These two options are carried over from the interim guidelines without any significant changes. LR recommends the gas safe machinery space concept (also known as the 'inherently safe machinery space' concept). This is because it is more aligned with the normal approach to classification Rules which are written to account for a single failure scenario without increasing risk to the ship, cargo, crew or surrounding environment. This approach is also in line with the approach given in IEC 60079-14 'Explosive atmospheres. Electrical installations design, selection and erection' for the management of potentially explosive atmospheres which places the emphasis on protection on physical controls rather than mitigation through systems like the ESD system that is relied on by the ESD-protected machinery space concept.

5.7.2 *Fuel piping shall not be led directly through accommodation spaces, service spaces, electrical equipment rooms or control stations as defined in the SOLAS Convention.*

Analysis This is the governing requirement for the location of piping systems on gas fuelled systems and on some ship types (notably passenger ships) it can have a significant impact on the location of fuel system components.

5.8 Requires all fuel preparations rooms be located on open deck unless they comply with the regulations for tank connection spaces. This ties together the different terminology that may be used for spaces containing fuel processing equipment.

5.9.1 Highlights that separation of bilge systems is critical to prevent potential cross-contamination of other systems/spaces if there is a leak of natural gas.

5.9.3 *The hold or interbarrier spaces of type A independent tanks for liquid gas shall be provided with a drainage system suitable for handling liquid fuel in the event of fuel tank leakage or rupture.*

Analysis This extends to bilges for fuel tank hold spaces for under deck tank locations.

5.10.5 *Each tray shall have a sufficient capacity to ensure that the maximum amount of spill according to the risk assessment can be handled.*

Analysis As well as sizing the drip tray for the maximum leakage, if possible LR recommends including design features that will allow control over the direction of leakage from the drip tray if larger quantities of LNG are released, this may include provision of an elevated drain to direct excess LNG to a safe location.

5.11.1 *Direct access shall not be permitted from a non-hazardous area to a hazardous area. Where such openings are necessary for operational reasons, an airlock which complies with 5.12 shall be provided.*

5.11.2 *If the fuel preparation room is approved located below deck, the room shall, as far as practicable, have an independent access direct from the open deck. Where a separate access from deck is not practicable, an airlock which complies with 5.12 shall be provided.*

5.11.3 *Unless access to the tank connection space is independent and direct from open deck it shall be arranged as a bolted hatch. The space containing the bolted hatch will be a hazardous space.*

Analysis Especially for under deck tank locations, there is potential impact on the hazardous area rating of the tank hold space and surrounding spaces depending on the access arrangements to the tank connection space (airlock or no airlock). This should be considered as early as possible in the design process as this may limit the use of adjoining spaces or result in the need for additional airlocks.

6. Fuel Containment System

Goal *The goal of this chapter is to provide that gas storage is adequate so as to minimize the risk to personnel, the ship and the environment to a level that is equivalent to a conventional oil fuelled ship.*

6.2 References several of the generic functional requirements defined in the general requirements chapter and develops them further specific to natural gas (and LNG):

.1 the fuel containment system shall be so designed that a leak from the tank or its connections does not endanger the ship, persons on board or the environment. Potential dangers to be avoided include:

.1 exposure of ship materials to temperatures below acceptable limits;

.2 flammable fuels spreading to locations with ignition sources;

.3 toxicity potential and risk of oxygen deficiency due to fuels and inert gases;

.4 restriction of access to muster stations, escape routes and life-saving appliances (LSA); and

.5 reduction in availability of LSA.

.2 the pressure and temperature in the fuel tank shall be kept within the design limits of the containment system and possible carriage requirements of the fuel;

.3 the fuel containment arrangement shall be so designed that safety actions after any gas leakage do not lead to an unacceptable loss of power; and

.4 if portable tanks are used for fuel storage, the design of the fuel containment system shall be equivalent to permanent installed tanks as described in this chapter.

6.3.4 All tank connections, fittings, flanges and tank valves must be enclosed in gas tight tank connection spaces, unless the tank connections are on open deck. The space shall be able to safely contain leakage from the tank in case of leakage from the tank connections.

6.3.8 The probable maximum leakage into the tank connection space shall be determined based on detail design, detection and shutdown systems.

6.3.12 Highlights the system requirement to be capable of removing LNG from the fuel storage tank and purging and venting to make it safe. Where tanks are mounted on deck this may be possible using gravity but for under deck tank locations this may require special arrangements.

Analysis The worst case leakage that the tank connection space needs to be designed to accommodate is generally considered to be a failure of the largest liquid connection, the size of leak to be considered may vary depending on Flag Administration criteria. The tank connection space is then designed to withstand the cryogenic liquid, the weight of LNG and the pressure increase caused by vaporisation of leaking LNG.

6.4 Incorporates the detailed design requirements for different tank types already developed as part of the IGC Code, there are no substantial differences.

6.5 States that portable tanks are to be designed in accordance with the regulations for independent type C tanks. Each tank is to be independent from any others and there is to be a permanent connection to a fixed venting system.

6.6 Permits CNG tanks with requirements that have been developed slightly from those in the interim guidelines to include regulations for the safety measures for CNG including controlled depressurisation and inerting in the event of fire.

6.7 Clarifies that the requirements for pressure relief arrangements are independent from and in addition to the pressure control system required for operation of the system; and are intended to protect the system from pressures above or below the design pressure.

6.7.2.2 Liquefied gas fuel tanks shall be fitted with a minimum of 2 pressure relief valves (PRVs) allowing for disconnection of one PRV in case of malfunction or leakage.

Analysis The arrangement for isolation/disconnection of one valve is to incorporate means that prevents both PRVs from being isolated at the same time so that the tank is always protected from excessive pressure build up. Inclusion of this provision allows for the periodic maintenance and testing of relief valves without the need for draining, inerting and venting of the tank.

6.7.2.7 & 6.7.2.8
Set the minim criteria for vent mast location in relation to working areas and ventilation intakes and outlets.

6.7.2.13 PRVs shall be connected to the highest part of the fuel tank. PRVs shall be positioned on the fuel tank so that they will remain in the vapour phase at the filling limit (FL) as given in 6.8, under conditions of 15° list and 0.015L trim, where L is defined in 2.2.25.

Analysis This criteria means that the entrance to the PRV will always remain in the vapour space, however experiments have shown that there is likely to be two phase flow through the PRV in the event of over pressurisation of the fuel tank. Consequently the vent arrangements should be designed for two phase flow. LR recommends pressure drop calculations to be undertaken in accordance with IMO Resolution A829(19).

6.8 Sets a maximum filling limit of 98% and a maximum loading limit (under certain conditions) of 95%. This is the same as previously given in the interim guideline but has been reworded to improve clarity.

6.9.1.2 Venting of fuel vapour for control of the tank pressure is not acceptable except in emergency situations.

This is the critical design criteria for the gas fuel system; zero release is the primary goal in terms of safety to the ship, personnel and the environment.

6.9.2.1 For worldwide service, the upper ambient design temperature shall be sea 32oC and air 45oC. For service in particularly hot or cold zones, these design temperatures shall be increased or decreased, to the satisfaction of the Administration.

Other factors to consider include the solar heating effect on deck storage tanks on board gas fuelled ships operating in equatorial regions.

6.9.4 States that thermal oxidation systems may also be installed for the management of pressure in fuel storage tanks during bunkering operations. This requirement also includes guidance that periods of slow steaming and/or non-consumption should be included in the design process when boil off gas management is considered.

6.12.1 *Spaces surrounding liquefied gas fuel tanks shall be filled with suitable dry air and be maintained in this condition with dry air provided by suitable air drying equipment. This is only applicable for liquefied gas fuel tanks where condensation and icing due to cold surfaces is an issue.*

Analysis Experience has shown that this requirement may need to be extended to tank connection spaces where the large number of exposed cold surfaces for valves and pie connections can lead to significant ice build-up if the ventilating air is not sufficiently dry.

6.14 Contains stripped down requirements for IG systems similar to those located in the IGC and FSS Codes.

7. Material and general pipe design

Goal *The goal of this chapter is to ensure the safe handling of fuel, under all operating conditions, to minimize the risk to the ship, personnel and to the environment, having regard to the nature of the products involved.*

7.2 References several of the generic functional requirements defined in the general requirements chapter and develops them further specific to natural gas (and LNG):

7.2.1.1 *Fuel piping shall be capable of absorbing thermal expansion or contraction caused by extreme temperatures of the fuel without developing substantial stresses.*

7.2.1.2 *Provision shall be made to protect the piping, piping system and components and fuel tanks from excessive stresses due to thermal movement and from movements of the fuel tank and hull structure.*

7.2.1.3 *If the fuel gas contains heavier constituents that may condense in the system, means for safely removing the liquid shall be fitted.*

7.2.1.4 *Low temperature piping shall be thermally isolated from the adjacent hull structure, where necessary, to prevent the temperature of the hull from falling below the design temperature of the hull material.*

Analysis The cryogenic aspects of LNG pose the greatest challenge, as a fluid LNG is neither toxic nor corrosive and due to the low temperatures levels of damaging contaminants are very low or negligible. Correct design of the fuel processing equipment can limit the amount of cryogenic piping required and consequently the associated costs.

7.3.1.5 *Piping other than fuel supply piping and cabling may be arranged in the double wall piping or duct provided that they do not create a source of ignition or compromise the integrity of the double pipe or duct. The double wall piping or duct shall only contain piping or cabling necessary for operational purposes.*

Analysis Proposals for using double walled piping or ducts to run other cables or piping will be considered but only where it can be demonstrated that the cabling or piping will have no impact on the fuel piping and that it does not cause back pressure or constrictions that will detrimentally impact the ventilation of the double wall space or duct.

7.3.2, 7.3.3 & 7.3.4
Piping design criteria are duplicated from Chapter 5.2 of the IGC Code with no technical changes.

7.3.5.1 Installation methods for piping are to include adequate support arrangements and if necessary provision for pipe expansion and contraction during warming/cooling of the system.

7.3.6 Pipe fabrication and joining requirements are based on Chapter 5.4 of the IGC Code with small modifications to make them applicable to natural gas/LNG as fuel.

7.4 Materials regulations for piping are based on those in the IGC Code Chapter 6.2.

7.4.1.4 Sets the design temperature for outer pipe or duct containing high pressure piping to accommodate the Joule-Thompson cooling effect in the event of a leak.

8. Bunkering

Goal *The goal of this chapter is to provide for suitable systems on board the ship to ensure that bunkering can be conducted without causing danger to persons, the environment or the ship.*

Analysis The Code does not contain extensive guidelines for bunkering as the scope of the Code does not extend beyond the receiving manifold of the gas fuelled ship. LNG bunkering has been the subject of many guidelines published by different organisations and industry groups, the main bunkering guidelines are ISO TS 18683 and the bunkering safety guidelines published by SGMF. IACS is also currently developing guidelines that will be a development of these two guidelines.

8.3.1.1 States the preference for the bunkering location to be located on an open deck; any deviation requires a specific risk assessment.

8.3.2.2 *Hoses subject to tank pressure, or the discharge pressure of pumps or vapour compressors, shall be designed for a bursting pressure not less than five times the maximum pressure the hose can be subjected to during bunkering.*

Analysis It should be noted that the test pressure of five times operating pressure is different to the normal test pressure for flexible hoses (four times design pressure).

8.4.1 *The bunkering manifold shall be designed to withstand the external loads during bunkering. The connections at the bunkering station shall be of dry-disconnect type equipped with additional safety dry break-away coupling/ self-sealing quick release. The couplings shall be of a standard type.*

Analysis The external loads that the manifold is to be designed for should include self-weight (including fully loaded), loads due to relative motion between receiving ship and bunker supplier, and loads due to any lifting equipment used to handle the hose.

8.5.7 *A ship-shore link (SSL) or an equivalent means for automatic and manual ESD communication to the bunkering source shall be fitted.*

Analysis The type of ship shore link employed will need to be compatible with the type used by the bunker supplier, there are three general types of system – electric, pneumatic and optical fibre.

9. Fuel Supply to Consumers

Goal *The goal of this chapter is to ensure safe and reliable distribution of fuel to the consumers*

9.2 References several of the generic functional requirements defined in the general requirements chapter and develops them further specific to natural gas (and LNG):

.1 the fuel supply system shall be so arranged that the consequences of any release of fuel will be minimized, while providing safe access for operation and inspection;

.2 the piping system for fuel transfer to the consumers shall be designed in a way that a failure of one barrier cannot lead to a leak from the piping system into the surrounding area causing danger to the persons on board, the environment or the ship; and

.3 fuel lines outside the machinery spaces shall be installed and protected so as to minimize the risk of injury to personnel and damage to the ship in case of leakage.

Structural protection of the fuel lines is needed to guard against damage during normal operations (dropped objects, etc.).

9.3.3 *For type C tank only, one tank may be accepted if two completely separate tank connection spaces are installed for the one tank.*

Analysis If this option is selected for single fuel (gas fuel only) installations then the method of bunkering (and the necessary fuel supply pressure from the tank for continued engine operation during bunkering needs to be considered to ensure that there is no loss of power during bunkering operations.

9.4.2 *The main gas supply line to each gas consumer or set of consumers shall be equipped with a manually operated stop valve and an automatically operated "master gas fuel valve" coupled in series or a combined manually and automatically operated valve. The valves shall be situated in the part of the piping that is outside the machinery space containing gas consumers, and placed as near as possible to the installation for heating the gas, if fitted. The master gas fuel valve shall automatically cut off the gas supply when activated by the safety system required in 15.2.2.*

9.4.8 *There shall be one manually operated shutdown valve in the gas supply line to each engine upstream of the double block and bleed valves to assure safe isolation during maintenance on the engine.*

9.4.9 *For single-engine installations and multi-engine installations, where a separate master valve is provided for each engine, the master gas fuel valve and the double block and bleed valve functions can be combined.*

Analysis Where the 'double block and bleed' arrangement (DBB) is situated inside the machinery space containing gas consumers, the gas fuel supply line to each gas fuel consumer requires a minimum of three isolation valves, two as part of the DBB and one master gas fuel valve outside the machinery space (assuming that has combined manual and automatic functionality). The functions of the valve required by 9.4.8 and the master gas fuel valve required by 9.4.2 can be combined into one valve where the gas fuel supply line only feeds one consumer.

In cases where the DBB is located outside the machinery space each consumer requires a minimum of two isolation valves, in this case the master gas fuel valve and one of the DBB isolation valve functions can be combined into a single valve.

It should be noted that, where the second option is selected to minimise the number of valves, the length of piping between the DBB and the consumer should be minimised as far as possible to reduce the volume of fuel that will be vented every time the gas supply is closed (during normal operations and emergency conditions).

9.5.2 Clarifies that ducting arrangements for fully welded vent pipes are only necessary where the pipes are required to pass through spaces where fuel piping is prohibited by 5.7.2 (accommodation spaces, service spaces, electrical equipment rooms or control stations as defined in the SOLAS Convention). In these situations the ducting is to form a cofferdam arrangement to protect the surrounding space from any potential failure of the vent pipe.

9.6.1 *Fuel piping in gas-safe machinery spaces shall be completely enclosed by a double pipe or duct fulfilling one of the following conditions:*

.1 the gas piping shall be a double wall piping system with the gas fuel contained in the inner pipe. The space between the concentric pipes shall be pressurized with inert gas at a pressure greater than the gas fuel pressure. Suitable alarms shall be provided to indicate a loss of inert gas pressure between the pipes. When the inner pipe contains high pressure gas, the system shall be so arranged that the pipe between the master gas valve and the engine is automatically purged with inert gas when the master gas valve is closed; or

Analysis The Code defines any gas fuel system over 1MPa (i.e. 10 bar) as 'high pressure', high pressure gas fuelled consumers to date have operating pressures in the order of 30MPa. Compliance with 9.6.1.1 in these cases is impractical due to the thickness of the outer pipe or duct necessary to contain a pressure in excess of the fuel supply pressure. In most cases the option of ventilated double walled piping or ducts is selected and designed in accordance with the requirements of 9.8.

9.7 Prohibits the ESD protected machinery space concept for gas fuel systems with a supply pressure greater than 1MPa.

9.8.4 Effectively duplicates part of 9.8.1, clarifying the test pressure to be applied to piping.

9.9.3 Arrangements shall be made to ensure that under no circumstances liquefied gas can be introduced in the gas control section or gas-fuelled machinery, unless the machinery is designed to operate with gas in liquid state.

Analysis Measures to prevent LNG from entering the gas fuel supply system may include excess heat exchanger capacity in the vaporisers and temperature detection prior to the master gas isolation valve linked to ESD operation in the event that low temperatures are detected.

10. Power Generation Including Propulsion and Other Gas Consumers

Goal *The goal of this chapter is to provide safe and reliable delivery of mechanical, electrical or thermal energy.*

10.2 References several of the generic functional requirements defined in the general requirements chapter and develops them further specific to natural gas (and LNG):

.1 the exhaust systems shall be configured to prevent any accumulation of un-burnt gaseous fuel;

.2 unless designed with the strength to withstand the worst case over pressure due to ignited gas leaks, engine components or systems containing or likely to contain an ignitable gas and air mixture shall be fitted with suitable pressure relief systems. Dependent on the particular engine design this may include the air inlet manifolds and scavenge spaces;

.3 the explosion venting shall be led away from where personnel may normally be present; and

.4 all gas consumers shall have a separate exhaust system.

10.3.1.2 For engines where the space below the piston is in direct communication with the crankcase a detailed evaluation regarding the hazard potential of fuel gas accumulation in the crankcase shall be carried out and reflected in the safety concept of the engine.

Analysis It is recognised that gas accumulation can be found in the crankcase during normal operation. The level of gas concentration is dependent on the type of engine and the cycle employed by that engine i.e. trunk piston or crosshead, Diesel or Otto respectively.

The safety concept should identify the engine type, engine cycle employed, levels of gas concentration which can be expected in the engines lifecycle i.e. new and worn conditions and the safety systems employed to monitor gas build up and reduce the risk of explosion. These safety systems can include a combination of: pressure monitoring; gas detection; oil mist detection; temperature sensing etc. In support of the safety concept, a cause and effect matrix should be included.

11. Fire Safety

Goal *The goal of this chapter is to provide for fire protection, detection and fighting for all system components related to the storage, conditioning, transfer and use of natural gas as ship fuel.*

11.2 References several of the generic functional requirements defined in the general requirements chapter, these are not developed any further to make them specific to natural gas (and LNG).

11.3.3 The space containing fuel containment system shall be separated from the machinery spaces of category A or other rooms with high fire risks. The separation shall be done by a cofferdam of at least 900 mm with insulation of A-60 class. When determining the insulation of the space containing fuel containment system from other spaces with lower fire risks, the fuel containment system shall be considered as a machinery space of category A, in accordance with SOLAS regulation II-2/9. The boundary between spaces containing fuel containment systems shall be either a cofferdam of at least 900 mm or A-60 class division. For type C tanks, the fuel storage hold space may be considered as a cofferdam.

Analysis The passive and active fire-fighting requirements are driven by the potential impact and fire hazards that the surrounding spaces may have on the gas fuel equipment. For type C tanks, the hold space may be considered as the cofferdam provided there is sufficient separation for inspection/maintenance between the outer boundary of the tank and the hold space bulkhead, we recommend a separation of at least 900mm but other separations may be accepted depending on the arrangement.

11.5.1 A water spray system shall be installed for cooling and fire prevention to cover exposed parts of fuel storage tank(s) located on open deck.

Analysis Consideration needs to be given to the interaction between fire-fighting systems required because of the gas fuel system and those required by other regulations linked to the ship type. One example of this may be the requirement for deck foam firefighting on a gas fuelled oil tanker, the vessel design would need to be such that the water spray arrangement on the deck mounted gas fuel tank does not wash the deck foam away if both fire-fighting systems are used simultaneously.

12. Explosion Prevention

Goal *The goal of this chapter is to provide for the prevention of explosions and for the limitation of effects from explosion.*

12.2 References several of the generic functional requirements defined in the general requirements chapter and develops them further by drawing from IEC60079:

The probability of explosions shall be reduced to a minimum by:

.1 reducing number of sources of ignition; and

.2 reducing the probability of formation of ignitable mixtures.

12.3.2.2 In ESD protected machinery spaces, the upper limit (for gas detection) at which point any electrical equipment that is not rated for zone 1 hazardous areas is to be disconnected is changed from 20% to 40% of the LEL. This change from the interim guidelines is based on practical experience of these systems.

13. Ventilation

Goal *The goal of this chapter is to provide for the ventilation required for safe operation of gas-fuelled machinery and equipment.*

13.3.10 Provides an alternative to requiring an over pressure in the non-hazardous space where it is possible to ventilate the hazardous space to achieve an under pressure. This is a new requirement and is the only requirement in the Ventilation chapter that was not already provided in Chapter 2.10.1 of the Code.

13.4 Was titled Tank Room, 10.2.2 of the interim guidelines, there is no change in the technical requirements.

13.5.3 Introduces a new requirement for redundancy and availability in ESD protected machinery spaces, not previously in the interim guidelines.

13.7 & 13.8
Provide new sets of requirements specifically for fuel preparation rooms and the bunkering station, not previously covered in the interim guidelines.

13.8.3 The ventilation inlet for the double wall piping or duct shall always be located in a non-hazardous area away from ignition sources. The inlet opening shall be fitted with a suitable wire mesh guard and protected from ingress of water.

Analysis The air inlet to the ventilated double walled pipes may be at the gas fuelled consumer, drawing air from the engine room through the annular space. A flap-type non return valve may be required to prevent back flow into the machinery space in the event of ventilation failure.

13.8.4 The capacity of the ventilation for a pipe duct or double wall piping may be below 30 air changes per hour if a flow velocity of minimum 3 m/s is ensured. The flow velocity shall be calculated for the duct with fuel pipes and other components installed.

Analysis In order to maintain the flow velocity it may be necessary to provide additional ventilation fans supplying pressure (i.e. not relying on induced draught ventilation). This is especially the case for double walled piping systems where the machinery arrangement results in convoluted piping arrangements with large back pressures.

14. Electrical Installations

Goal *The goal of this chapter is to provide for electrical installations that minimizes the risk of ignition in the presence of a flammable atmosphere.*

This chapter has been significantly developed from the electrical systems requirements in Chapter 4 of the interim guidelines and contains general requirements for the electrical system along with some more specific regulations.

14.3.3 Where electrical equipment is installed in hazardous areas as provided in 14.3.2 it shall be selected, installed and maintained in accordance with standards at least equivalent to those acceptable to the Organization.

Equipment for hazardous areas shall be evaluated and certified or listed by an accredited testing authority or notified body recognized by the Administration.

Analysis Any electrical equipment installed in a hazardous area should be in accordance with IEC 60079 and the arrangements should be approved by LR.

14.3.5 Clarifies that complete isolation is required to prevent any residual current or stored charge from presenting an ignition hazard.

14.3.7 Gives alarm and automatic shutdown requirements to prevent dry running of pumps which may lead to over-heating and associated ignition hazards.

15. Control, Monitoring and Safety Systems

Goal *The goal of this chapter is to provide for the arrangement of control, monitoring and safety systems that support an efficient and safe operation of the gas-fuelled installation as covered in the other chapters of this Code.*

15.2 References several of the generic functional requirements defined in the general requirements chapter and develops them further specific to natural gas (and LNG):

.1 the control, monitoring and safety systems of the gas-fuelled installation shall be so arranged that the remaining power for propulsion and power generation is in accordance with 9.3.1 in the event of single failure;

.2 a gas safety system shall be arranged to close down the gas supply system automatically, upon failure in systems as described in table 1 and upon other fault conditions which may develop too fast for manual intervention;

.3 for ESD protected machinery configurations the safety system shall shutdown gas supply upon gas leakage and in addition disconnect all non-certified safe type electrical equipment in the machinery space;

4 the safety functions shall be arranged in a dedicated gas safety system that is independent of the gas control system in order to avoid possible common cause failures. This includes power supplies and input and output signal;

.5 the safety systems including the field instrumentation shall be arranged to avoid spurious shutdown, e.g. as a result of a faulty gas detector or a wire break in a sensor loop; and

.6 where two or more gas supply systems are required to meet the regulations, each system shall be fitted with its own set of independent gas control and gas safety systems.

In the interim guidelines the control and monitoring requirements were referred out to the IGC Code, these have now been incorporated directly into the IGF Code.

15.3.1 *Suitable instrumentation devices shall be fitted to allow a local and a remote reading of essential parameters to ensure a safe management of the whole fuel-gas equipment including bunkering.*

Analysis For bunkering management the 'local' monitoring position for instrumentation and controls is expected to be a space adjacent or near to the bunkering station with a lower hazardous area classification so that there is no need for personnel in the bunkering station during the operation. This is reinforced in 15.5.1.

15.4.1 *Level indicators for liquefied gas fuel tanks*

.1 Each liquefied gas fuel tank shall be fitted with liquid level gauging device(s), arranged to ensure a level reading is always obtainable whenever the liquefied gas fuel tank is operational. The device(s) shall be designed to operate throughout the design pressure range of the liquefied gas fuel tank and at temperatures within the fuel operating temperature range.

.2 Where only one liquid level gauge is fitted it shall be arranged so that it can be maintained in an operational condition without the need to empty or gas-free the tank.

.3 Liquefied gas fuel tank liquid level gauges may be of the following types:

.1 indirect devices, which determine the amount of fuel by means such as weighing or in-line flow metering; or

.2 closed devices, which do not penetrate the liquefied gas fuel tank, such as devices using radio-isotopes or ultrasonic devices;

Analysis The Code does not have any requirements for the accuracy of the gauging; as with the IGC Code this would need to be defined in the owner's specification. Depending on the method selected for measurement of bunker quantity the accuracy of the level gauge may be of commercial importance.

15.4.2 *Overflow control*

.3 The position of the sensors in the liquefied gas fuel tank shall be capable of being verified before commissioning. At the first occasion of full loading after delivery and after each dry-docking, testing of high level alarms shall be conducted by raising the fuel liquid level in the liquefied gas fuel tank to the alarm point.

Analysis The maximum fill level stated in the code is 98%, however during bunkering this is reduced to a maximum loading limit of 95% (and depending on the tank conditions and pressure relief valve settings this maximum may not be possible). Consequently, care should be taken during testing to ensure that if the tank is filled beyond the loading limit for the purposes of testing then the tank is returned to a satisfactory condition before the gas-fuelled ship sails. This will reduce the risk of venting of the natural gas due to over pressurising the tank.

15.4.11 Provides requirements for temperature sensors to give an indication of any stratification occurring in the tank that may be a precursor to a roll-over event if not correctly managed.

15.5 Provides limited bunkering control requirements, this subject was not previously covered by the interim guidelines.

15.5.1 Implicitly sets the expectation that no personal are to be in the bunkering station during the transfer operation, access is only generally permitted during connection and disconnection.

15.5.2 *If the ventilation in the ducting enclosing the bunkering lines stops, an audible and visual alarm shall be provided at the bunkering control location, see also 15.8.*

Analysis Ventilated ducting of vacuum insulated bunkering lines is only necessary if the bunkering lines are passing through spaces where fuel lines are not permitted by the code (in which case the ventilated duct acts as a cofferdam to provide protection by separation).

15.6.2 Introduces a new requirement not previously in the interim guidelines, requiring condition monitoring of bulkhead shaft seals. These parts will form a potential leakage path if they fail.

15.8.7 Changes the limit for activation of the safety system if gas leakage is detected in ventilated ducts around gas fuel pipes is increased to 60% LEL (interim guideline had limit for activation across all systems as 40% LEL). This increased limit is intended to reduce alarms and avoid unwanted trips of the safety system.

15.11.4 Provides a more detailed list of locations where emergency controls and indications for critical gas fuelled machinery items may be located.

Table 1 The language has been amended to improve clarity and change reference from compressor room to fuel preparation room but aside from the changes in LEL alarm and shutdown limits described above there are no significant changes to the alarm requirements.

PART B-1

16. Manufacture, Workmanship and Testing

This chapter provides testing and materials specification for metallic piping and materials used in fuel containment systems. Requirements for non-destructive testing and hydrostatic testing of different tank types are detailed including acceptance criteria.

Requirements for construction of welded structures including post-weld heat treatment and non-destructive testing are provided as well as testing for piping components and expansion bellows.

Table1 summarises the containment system test requirements.

Analysis This chapter has greater detail than chapter 7 of the interim guidelines, is structured differently but does not introduce any new requirements. Requirements for piping and bellows are essentially identical. Test requirements for tank types other than type C are not very clearly defined (for example test duration is not specified). In practice, it is expected that test schedules will be broadly equivalent to those used for liquefied gas cargo tanks. Provision is given to allow hydro-pneumatic or pneumatic testing of type C pressurised independent tanks but this should only be carried out where absolutely necessary due to the inherent hazards associated with pneumatic testing.

PART C-1

17. Drills and Emergency Exercises

This short chapter specifies the types of drills that should be included in the vessel's ISM system to take account of the different fuel system. This provides more detail than was previously included in the chapter 8 of the interim guidelines.

Tank type	Test required	Test duration
A and B	Hydrostatic or hydro-pneumatic testing at MARVS to simulate tank loading condition	Not specified
C	Hydrostatic test at 1.5p	Two hours per 25mm of thickness, minimum two hours
Membrane	Hydrostatic testing of surrounding spaces that may normally contain liquid	Not specified

Table 1: Containment system test requirements

18. Operation

Goal *The goal of this chapter is to ensure that operational procedures for the loading, storage, operation, maintenance, and inspection of systems for gas or low-flashpoint fuels minimize the risk to personnel, the ship and the environment and that are consistent with practices for a conventional oil fuelled ship whilst taking into account the nature of the liquid or gaseous fuel.*

This chapter provides general requirements for the continued safe maintenance and operation of gas fuel systems with particular focus on the bunkering operation. A high level breakdown is given of responsibilities for the different parties involved in the bunkering and procedures to be followed before and during bunkering. A template for a bunker delivery note is provided that confirms the composition of delivered gas.

Analysis This is new to the Code and was not covered to this extent in chapter 8 of the interim guidelines. However, the operational requirements and divisions of responsibilities are still not very detailed. LR has contributed to the development of more detailed guidance for safe bunkering operations through IACS and SGMF.

PART D

19. Training

Goal *The goal of this chapter is to ensure that seafarers on board ships to which this Code applies are adequately qualified, trained and experienced.*

This Chapter simply references the training requirements now provided by STCW.7/Circ.23 as amendments to STCW chapter V new Regulation V/3 "Mandatory minimum requirements for the training and qualifications of masters, officers, ratings and other personnel on ships subject to the IGF Code"

Analysis Chapter 8 of the interim guidelines had some detailed training requirements breaking down the levels of training into three categories: basic training and more advanced training for deck and engine room officers. This has been removed from the Code as it is now covered by the STCW convention with the training requirements more closely aligned with two tier training requirements for LNG carrier crews.