gas as a marine fuel

an introductory guide.

environmental
technical
safety
contractual
training & competence

sgmf
the society for gas as a marine fuel

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Natural gas as a marine fuel

Increasing concern over the impact of human activities on our environment is encouraging the maritime transport industry to move towards using natural gas on board ships as a prime source of energy for propulsion and electricity generation. This trend is being reinforced by national and international regulation, led by the International Maritime Organization (IMO), with its Emission Control Areas (ECAs).

The use of natural gas as a fuel is one way of complying with the increasingly strict regime governing emissions of harmful atmospheric pollutants, such as nitrogen oxides (NOx) and sulphur oxides (SOx) and reduces the carbon footprint of ship operations. Liquefied natural gas (LNG) is the most cost-effective way of transporting natural gas over very long distances. It has been produced and transported internationally in bulk for 50 years. The gas-as-fuel industry builds on this expertise – but the bulk trade and the gas-as-fuel business differ in significant ways.

The Society for Gas as a Marine Fuel (SGMF) is a non-governmental organisation (NGO) established to promote safety and industry best practice in the use of gas as a marine fuel. This high-level document links to more technically and commercially rigorous guidelines aimed at assisting the emerging gas-as-fuel industry to develop, with safety as the paramount concern.

Introduction

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, power stations and/or used as transport fuel.

LNG is a mixture of hydrocarbons, predominately methane (80 – 99%). 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, burns only when in its vapour state. Its 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.

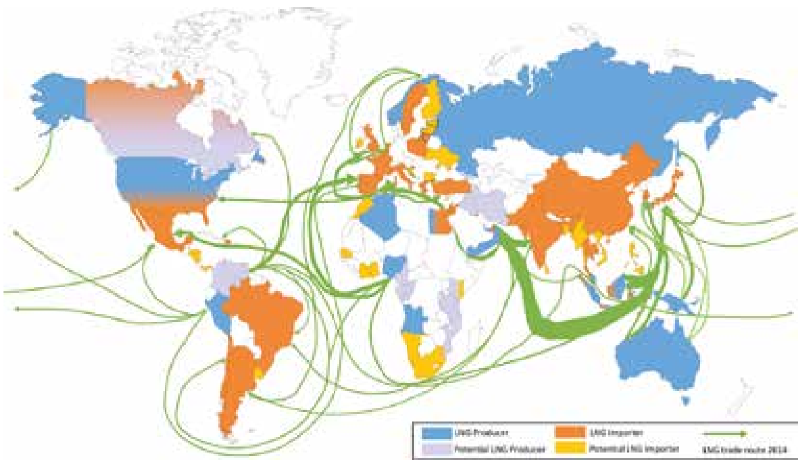
The scale and cryogenic temperatures involved make LNG production much more difficult than the underlying physics would suggest.

Liquefaction plants are frequently valued in billions, or tens of billions, of US dollars, require several hundred megawatts of electricity generation capacity (a megawatt (MW) of electricity is sufficient to power 500 – 1000 European homes), and can occupy an area of up to 1.5 km^2.

As of early 2017, 19 countries were producing LNG in bulk, with another eleven producing smaller quantities for domestic consumption. According to the LNG importers group GIIGNL, the biggest producers in 2016 were Qatar (79.62 million tonnes), Australia (44.8 million tonnes) and Malaysia (25 million tonnes).

LNG industry overview

Some 263.6 million tonnes of LNG were traded worldwide in 2015. Japan was by far the biggest importer (83.3 million tonnes) followed by South Korea (34.2 million tonnes) and China (27.4 million tonnes). Virtually all the LNG produced was used for electricity generation, industrial and commercial gas use, and by residential customers.



Bulk International LNG trade during 2015 with the arrows showing direction of flow and their size the scale of the trade

Introduction

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 occurs in India and Russia and is being trialled in the USA and Canada, while Australian miners and American shale gas/oil producers are replacing diesel with LNG at their mines and production sites.

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Why should I use gas?

Shipping is the most efficient way to move most goods globally, making it essential to world commerce. However, some ship fuels contain 10,000 times as much sulphur as road fuel. So, while shipping accounts for only 2.7% of world carbon dioxide (CO_2) emissions, it causes 14% of the sulphur oxide pollution. These and other pollutants damage the environment in several ways (see page 7).

IMO regulations for emissions reduction

The International Maritime Organization (IMO), a United Nations body, controls and regulates many aspects of the global shipping business. IMO, through its marine pollution protocol (MARPOL), is working to reduce emissions of sulphur and particulate matter. From 2020 there will be a global sulphur cap of 0.5% for all marine fuel oils.

MARPOL Annex VI also requires reductions in nitrogen oxide emissions worldwide, but these limits depend on engine size and speed. The current limits worldwide are based on the tier system which has been tightening limits since 2011.

Emissions levels of fuels

Sulphurous Oxides, so called SOx emissions, depend on the amount of sulphur in the fuel. The gas used for LNG production is cleaned prior to liquefaction. Typical sulphur specifications in LNG are less than 30 parts per million (ppm) of total sulphur, making them practically negligible. This calculates to about 0.004% of sulphur by mass. LNG sulphur levels are therefore 1/875th of current heavy fuel oil (HFO) limits and 1/25th of ECA limits.

In comparison marine diesel oil (MDO) can contain up to 1% sulphur and marine gas oil (MGO) 0.1% sulphur. Fuel oil producers have started to market new ranges of Ultra Low Sulphur Fuel Oils which are based on

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traditional heavy fuel oils but are refined to have sufficiently low sulphur contents to be used within ECAs. Refining capacity to produce these fuels is limited so only small volumes of the fuels are available primarily in Europe and North America. MDO and HFO would need scrubber technology to comply with ECA limits. European EN 590 diesel (road fuel diesel used by inland waterway vessels) has only 0.001% of sulphur.

NOx emissions are very dependent on engine load and technology. None of the oil-fuelled options are able to meet Tier III limits unaided. HFO has NOx levels marginally higher than, but generally comparable with, MDO. Oil-fired systems will need to be equipped with Selective Catalytic Reduction (SCR) technology or Exhaust Gas Recirculation (EGR) to reduce NOx emissions to levels comparable with LNG-fuelled engines. Some LNG engines may also need SCR.

LNG produces minimal quantities of particulate matter (PM) but dual-fuel engines using LNG and diesel will create marginal PM from the non-gas contribution. Using LNG reduces PM emissions compared with HFO engines by about 90%. MDO is also better than HFO on PM.

What is an Emission Control Area?

An Emission Control Area (ECA) is an area in which the emission limits for SOx (sulphur oxides) and NOx (nitrogen oxides) are lowered to reduce their impacts on health and the environment.

Within an ECA the maximum allowed sulphur content in ship fuel is 0.1% (by mass). Similarly NOx will be set at Tier III limits within ECAs from 2016.

There also exist Sulphur Emissions Control Areas (SECAs). The first was the Baltic Sea (since 2006) followed by the North Sea (2007).

China has announced its own SECA which will be implemented in stages from April 2016 through to 2019. This will require 0.5% sulphur content in fuel and may be amended to 0.1% sulphur.

Sulphur oxides (SOx)

SOx is a mixture of sulphur dioxide (SO_2) and sulphur trioxide (SO_3) which quickly converts to sulphuric acid (H_2SO_4) in the presence of water. The latter is solid and ends up in the particulate matter (see below). SOx combines with water to form "acid rain", which acidifies oceans and damages plant life.

Nitrogen oxides (NOx)

NOx consists of nitric oxide (NO) and nitrogen dioxide (NO_2). NOx with water can form corrosive acids and has a role in lung diseases, such as asthma, and in heart disease. It is also a primary constituent of smog and contributes to the formation of atmospheric ozone.

Particulate matter (PM)

Particulate matter consists of particles of soot or smoke resulting from the burning of, primarily, heavier oils. It is considered to be a major health hazard. Particulates are the deadliest form of air pollution because they penetrate deep into the lungs and blood and can cause cancer.

Carbon dioxide (CO_2)

Carbon dioxide is a greenhouse gas, a contributor to global warming. The main focus on CO_2 reduction has been through improving the efficiency of engines and ships. CO_2 emission benchmarking across ship type and age is covered by the IMO's Energy Efficiency Design Index (EEDI) and Ship Energy Efficiency Management Plan (SEEMP) regulations.

Methane (CH_4)

Methane is a greenhouse gas with a 100-year global warming factor of 25 compared with the 1 of CO_2. There are two broad types of engine, two-stroke and four-stroke. Losses of methane can occur in four-stroke engines as fuel gas is pre-mixed outside the cylinders and then injected at low pressure. This is called methane slip.

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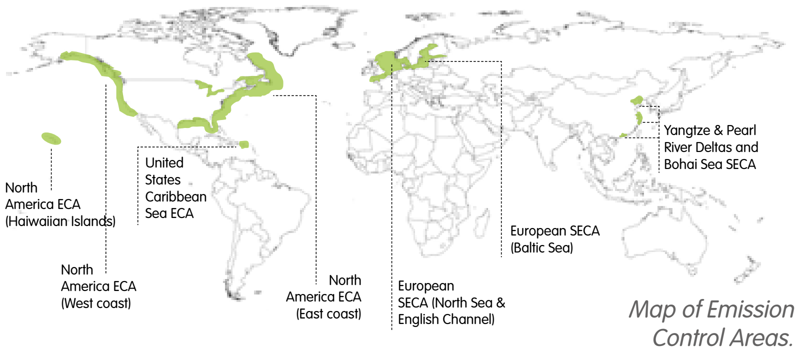
The first complete ECA is the North American ECA (2013). A smaller ECA around the US Caribbean Islands (Puerto Rico and the US Virgin Islands) came into force in January 2014.

Inland waterway traffic in western Europe (Belgium, Germany, Netherlands and Switzerland) already effectively operates as a SECA, with a limit of 10 ppm of sulphur in diesel fuels.

ECAs have been proposed for many other areas but are yet to be fully defined, accepted or have any certain timescale for implementation.



Map of Emission Control Areas.

How will ECAs be regulated?

Each country implements the IMO rules under its own laws and will enforce the law through national procedures. Various penalty regimes have been suggested, including:

- large fines
- prison sentences
- a vessel not being allowed to leave port until it has the right amount of fuel on board with the correct sulphur content
- a vessel being detained in its next port of call if the results of sampling come in late
- fines based on what a ship could earn on cargo / fuel costs

Are there alternative options?

ECA regulations specify that NOx and SOx emissions must be reduced but are not specific about how this should be achieved. So there are various options for meeting the tighter emissions limits. Three options are generally regarded as the main alternatives: a switch to a clean oil fuel such as MGO or ULSHFO, installation of scrubbers, or a switch to a variety of other fuels.

MGO & ULSHFO

Marine Gas Oil (MGO), Marine Diesel oil (MDO) and Ultra Low Sulphur Heavy Fuel Oil (ULSHFO) can be used in many existing ship engines that have traditionally operated on heavy fuel oil (HFO). MDO tends to create more particulate matter and potentially SOx – so would need careful specification to ensure compliance with ECA limits. MGO generally comprises lighter hydrocarbons and is more likely to meet ECA limitations. Again, the exact specification requires careful analysis before purchase. Therefore MGO, and where available, ULSHFO, may be a direct replacement option on a technical basis. However, MGO and ULSHFO costs are currently similar and substantially more than HFO.

Scrubbing

Ships may continue to burn conventional HFO in their engines if they then treat the exhaust gases to reduce SOx and NOx emissions to comply with the limits. CO_2 production is not reduced. Scrubbers can be fitted to the engine exhaust system. The cost of installation is significant, and the space requirements and weight of the equipment will also need to be considered.

Scrubbers usually only remove SOx and either pump directly overboard (open loop) or, recirculate on board for discharge ashore later (closed loop). It is unknown whether open loop scrubbers will be permitted in future with a current world fleet of 55,000 ships over 500 [GT], scrubbing would result in 120 [MT] of sulphur being added to the world's oceans or ashore. It is hard to imagine current regulatory uncertainity remaining that way.

Additional NOx abatement technology will need to be fitted to most vessels to comply with Tier III limits. This uses a catalytic process (SCR) based on injecting urea into the exhaust gas or recirculating exhaust gases (EGR) to change combustion temperatures and chemistry.

Alternative fuels

A variety of alternative fuels are under consideration, with hydrogen seen by many as the long term fuel of the future. Hydrogen can be used in fuel cells to generate electricity, which can then be used to drive ship propulsion systems. A move towards electric propulsion using traditional engines as power generators is already under way. Electricity generation using photovoltaic cells is also available as a hybrid propulsion system.

Methanol is gaining some popularity as an alternative fuel. It is widely available as it is a petrochemical feedstock. It is also used in a limited way as an engine fuel ("wood alcohol"). A few ferries are trialling methanol on the Scandinavian/Baltic trades. However, it is highly toxic, is miscible with water, and has a low energy content per unit volume (energy density) of 15.6 million Joules/cubic meter [MJ/m^3], so extra space is needed for fuel tanks. Methanol is only seen as interesting for bunker fuel if it is available at very low cost.

Liquid ethane carriers are using ethane as fuel, just as some bulk LNG carriers use natural gas.

Why can't I just use compressed natural gas (CNG)?

Compressed natural gas has been used for many years as a road transportation fuel and more recently for ships. A CNG-fuelled ferry is operating in Brazil. The problem with CNG, and to a lesser extent LNG, is its energy density. CNG stored at 250 times atmospheric pressure has an energy density of only about 9 [MJ/m^3]. LNG is more than twice as good as CNG at 22.2 [MJ/m^3]. Petroleum fuels remain better at about 35-40 [MJ/m^3]. This means that CNG vessels will have to have large fuel tanks or short distances between refuelling.

Large scale CNG containment results in very heavy equipment, even as a fuel not cargo so it is unlikely to be used on larger vessels engaged in deep sea trade.

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Who is doing it?

Interest is the use of LNG as a bunker fuel is growing rapidly, not just in ECAs but around the world.

Europe

Norway, the country that pioneered the technology, continues to push forward with more vessels. The European Union (EU), with 28 member states, is attempting to develop a co-ordinated approach to the use of LNG as a marine fuel, with a particular emphasis on the SECAs in the Baltic Sea and the North Sea/English Channel.

Most of the gas-fuelled vessels in service are in Norway. The first vessel entered service in 2000 and by mid 2017 the Norwegian fleet had increased to 53 vessels. Elsewhere in Europe there are now 38 vessels operating in 10 countries with over 25 on order. The lead nations within the EU are Denmark and Sweden but other countries – including the Netherlands, Estonia, Finland, Belgium, Germany, Spain, France, Portugal and the UK – are also involved or have ordered vessels for their coastal or short-sea trades.

USA/Canada

Both the USA (6 ships) and Canada (7 vessels) now have LNG fuelled ships in operation. Order books for both countries are healthy (total of over 10 ships) so the business will continue to grow.

Far East

South Korea built the first LNG fuelled vessel which is in service in Incheon harbour. However, China is the leading player with four LNG-fuelled tugs in service with CNOOC, one of the Big Three national oil and gas companies, and three deep water vessels on order. China has ordered several hundred inland waterway vessels. Japan's first LNG-fuelled vessel, a tug has been delivered and operates in Tokyo Bay.

Rest of the world

Probably the world's most advanced LNG-fuelled ship operates between Argentina and Uruguay. The gas- fuelled, gas turbine-driven, high-speed

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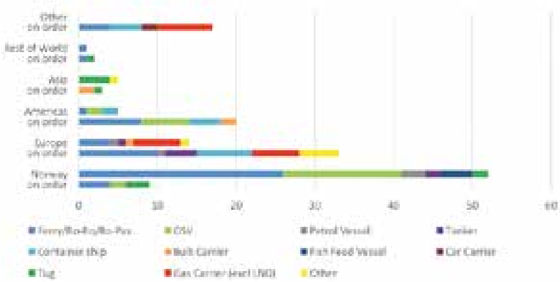
ferry entered service in 2013. Brazil and the Netherlands have CNG ferries in operation. Australia is now using LNG fuelled OSVs and a ferry between Melbourne and Tasmania is now in service.

None of these vessels operate in ECA zones.



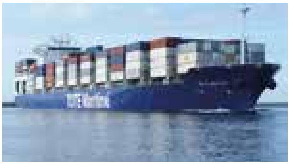
Gas-Fuelled Ships by Region and Type

LNG-fuelled fleet

Historically car ferries and Offshore support vessels (OSVs) made up most of the LNG-fuelled fleet accounting for about 50% and 30% of all LNG fuelled ships respectively.

The last two years have seen a broadening of the range of ships taking up LNG as fuel with most ships types now having a vessel in service and the remainder with vessels on order. Container ships and gas carriers are the most popular options but product tankers, bulk carriers, car carriers and tugs are well represented. More specialist ships such as cruise liners and construction support vessels such as dredgers and heavy lift vessels complete the order list.

Gas Fuelled Ferry
BC Ferries Salish Eagle



Gas Fuelled Container ship

MS Helgoland

Projections for the future

Forecasts for the number of ships using gas as fuel are normally based on two factors; firstly the relative costs of LNG and alternative clean fuels or abatement technologies and secondly the growth, age and replacement of the current shipping fleet. Also considered is the size and location of the current and future ECAs and the timing of the change to 0.5% Sulphur fuel proposed by the IMO. These numbers have been interpreted in many ways to produce a range of forecasts.

Check **sgmf.info** for the latest fleet statistics for gas-fuelled shipping.

Forecasts of ships have been about 1000 by 2020 rising to as high as 2000 – 3000 vessels by 2030. These forecasts now look too optimistic, at least in the short term. Perhaps half that number will be built by 2020.

Currently there are just over 100 ships globally using methane as fuel, this represents 0.2% of the world fleet. Perhaps in 5-7 years this might reach 1500 with the global sulphur cap of 2020 approaching, this would still only be 2% of the world fleet. 20% of the world fleet fuelled by gas equates very roughly to the total consumption rate of a country such as Korea or Germany to give a perspective.

Firstly, the significant reduction in oil prices has allowed shipping companies to burn ECA compliant MGO at similar prices to HFO. Secondly, the shipping industry remains over supplied with vessels in many trades which is discouraging investment in new vessels and extending where possible, the life of existing ships. Therefore there is little incentive to invest in new LNG fuelled ships in the short term and the number of "LNG ready" ships ordered demonstrates this.

In the longer term the fundamental economics remain positive. The price of LNG has fallen at almost similar rates (outside of the US) to oil and vessels will need to be replaced in the medium term. The growth of LNG shipping may be slow now, but should return to predicted levels in the medium term.

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The IMO decision in 2016 to implement the 0.5% sulphur cap from 2020 is starting to change ship owner behaviours. Now there is regulatory certainty scrapping of non compliant vessels and replacement with vessels using clean fuels or scrubbers can be planned. Since the announcement the interest in LNG fuelled ships has increased significantly and the order book has started to grow at a faster pace.

The number and types of ships converted to LNG and their usage patterns is then used to estimate the volumes of LNG used as fuel within the industry. Obviously the amount of time that the vessel spends within an ECA is an important factor but so is the vessel's chartering behaviour. A vessel like a Ropax ferry or container ship which operates on a liner trade between a handful of ports is more likely to convert to LNG as those ports can make LNG available rather than a general cargo ship or bulk carrier that operates wherever its latest charter determines. All these factors again lead to a range of numbers.

While industry commentators do not seem to be able to agree on how much LNG will be used as bunker fuel, they all agree it will be a substantial amount. The lowest estimates suggest that a couple of the large, international, baseload LNG plants will be required (7-8 mtpa) while many suggest that about 20 – 30 mtpa will be required. This is equivalent to 4 – 6 base load LNG trains or the whole output of number 3 LNG producer Malaysia. High end estimates suggest that 25% of all world LNG demand will be for fuel. In all cases marine fuel demand for LNG is eclipsed by LNG for road fuel. At several billions of dollars investment each there must be a concern that all these LNG plants can be designed, permitted, constructed and financed in the time period required.

What does a LNG-fuelled ship look like?

The fuel storage and use systems on a LNG-fuelled vessel differ to those on a conventional oil-fuelled ship. The requirements for an LNG-fuelled ship are covered by the IMO's International Code of Safety for Ships using gases or other Low Flashpoint fuels (IGF Code). These rules are part of SOLAS (Safety Of Life At Sea) and were published in 2015 and came into force in 2017.

This section discusses the general principles of ship design influenced by the IGF Code. Specialist consultancies and classification societies will be able to provide more specific advice.

Ship design

The factors to be considered during ship design are:

- Protection of the LNG storage tank and LNG/gas pipework from damage through collisions with other vessels and/or cargo or by dropped objects
- Redundancy of fuel systems to ensure that the vessel can continue to navigate if one system is damaged or fails
- Minimisation of any hazards provided by the use of gas as fuel
- Safety systems that provide a safe shut-down of hazardous systems and in worst case scenarios, removal of their inventories to prevent the build-up of potentially flammable atmospheres

LNG storage

The IGF Code does not specify any type of LNG storage technology but instead allows the owner to select what is best for them. This allows the use of low pressure membrane and self-supporting tanks (IMO A & B) tanks and pressure vessels (Type C). Type C tanks are more robust and do not require vapour return systems but their cylindrical shape are not easily accommodated in a space-efficient way in many parts of the hull.

The code is wholly concerned with monitoring the conditions within the tank (temperature and pressure), providing pressure-relief systems to dispose of gas safely in emergency scenarios, as well as boil-off gas management systems to control tank pressure during normal operations and to ensure that leaks are minimised by pipework design and/or by providing specific protection for a ship's structural elements.

Ship fuel systems

The code provides specific advice on pipe design and layout between the LNG supply and the engines. LNG is very cold so the pipework (up to the point where the LNG is evaporated) must be allowed to contract without

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damage as it cools. Valves must be included to isolate the LNG storage tank or any other significant volume of LNG. If the pipes start to warm, pressure-relief valves must be provided to allow vapour to escape.

m/t Bit Viking with two 500[m^3] Type C tanks

As with the LNG storage tanks, leaks, both LNG or gas, must be detected and contained. This is typically achieved by using a pipe-in-pipe (or duct) system with the LNG running through the inner pipe and a leak detection system provided in the outer pipe.

Redundancy of the fuel system is considered essential. This is preferably based on multiple LNG tanks, each with its own fuel system providing fuel to multiple engines.

Power generation and propulsion

The code covers gas-only engines, dual-fuel gas or oil engines, multi-fuel engines (such as methanol), gas turbines and fuel cells. Redundancy is the key issue – with a vessel needing to continue to operate with the failure of one engine. The use of multiple engines, each in a separate machinery space, is the preferred option in the code.

For dual- and multi-fuel engines, an automatic fuel changeover system is required, which must operate on the failure of one fuel supply system.

Control systems

The engines, LNG tanks and fuel systems should be capable of being monitored, controlled and shut down from outside any potentially gas containing space. Suitable instrumentation should be provided to monitor tank levels, pressures and temperatures, to review the operation of ventilation systems, and to detect the escape of gases or – in the worst case – the outbreak of fires.

An Emergency Shut-Down (ESD) system is required. It should be capable of being triggered manually from multiple locations on the ship and automatically by specific occurrences, for example gas detection. Safety monitoring systems should have their own dedicated and independent control systems.

Bunkering facility

The bunkering system should be on an open deck with plenty of natural ventilation. If this is not possible, forced ventilation will be required.

Spill management and the need to protect the ship's steel structures are also highlighted.

A ship-to-shore (or bunker vessel) communication system with ESD linkage is recommended.

The IGF Code does not consider any form of standardisation of the bunkering interface which will be required if gas fuelled ships wish to bunker in different ports and particularly different countries/continents. Best practice documents in this regard are being developed by SGMF and the International Standards Organization (ISO).

Hose connected to ship's bunkering manifold

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What does a bunkering system look like?

There are four different options for refuelling an LNG-powered vessel.

LNG terminals

LNG terminals can transfer LNG to ships directly without using any intermediate transfer system. This, however, will require the ship needing fuel to sail to the LNG terminal. Large terminals will have storage tanks that operate at atmospheric pressure and bunkering will take place using pumps. This type of terminal will be supplied by large LNG tankers and will often be the supply source for road tankers and bunker vessels. Small terminals are similar to road tankers and most bunker vessels as they use pressurised tanks to store their LNG. They will receive LNG either from LNG carriers or manufacture it themselves. LNG transfer will normally be by pressure differential.

Bunkering options

LNG terminal

Road tanker

Bunker Vessel - ENGIE Zeebrugge

LNG Container

Bunker vessels

LNG can be transferred from bunker vessels or even small LNG carriers, which can be moored alongside ships anywhere in a port. Transfer of LNG can be by pressure difference or, if high speeds are required, by dedicated LNG pumps. There are no physical restrictions on the amount of LNG that can be stored on a bunker vessel, so one bunker vessel may be able to service more than one ship.

Road trucks

LNG road tankers are limited by weight through road transport legislation so bunkering via a road tanker typically serves the smaller end of the LNG transfer market. Emptying a single road tanker can be achieved using a pressure differential between the tanker and the ship, or a pump, and typically takes about an hour. Multiple road tankers can be unloaded simultaneously, depending on the LNG volume required and the piping arrangement.

Containerised LNG

LNG tanks can be provided within standard 20 foot and 40 foot container sizes and comprise a Type C LNG tank, similar to a road tanker, inside a container-shaped steel frame. Many road transport operations now use LNG containers on flat-bed trucks rather than custom-built road tankers.

For gas as a marine fuel, LNG could be provided and stored by such "cassette"-type cell systems. Whole containers would be lifted or driven on board and connected to the fuel system. Empty tanks would be disconnected and removed.

LNG bunkering facilities

Bunkering with LNG is potentially available wherever LNG road tanker infrastructure exists provided the port facility can accommodate the weight and size of these vehicles. Bunkering in most ports in Europe and North America and many in China, South Korea, Japan and Australia is therefore possible.

China, Denmark and Norway have developed small bunkering terminals and these are also under construction in the US. These terminals primarily serve dedicated vessel fleets such as ferries and offshore support vessels or inland waterway vessels.

LNG transfer using bunkering vessels has seen a major growth over the last 2 years. The original vesel, “Seagas” in Stockholm has now undertaken over a 1000 bunkerings and has been joined in Europe by two more specialist ships, one in Zeebrugge (Belgium) and the other in Rotterdam (Netherlands). Skangas has also used a small LNG carrier to bunker in Gothenburg (Sweden). Two more bunker vessels are on order for Europe and a tug propelled barge for Jacksonville (USA). China now has multiple bunker vessels operating on its inland waterways.

SeaRoad shipping, a ferry company in Australia, is now regularly bunkering its vessel with containers of LNG. This is the first containerised or casette bunkering system to enter operation.

By the end of mid 2017, bunkering had taken place in over 50 locations worldwide. Most of these were in Europe (25 sites including Belgium, Denmark, Estonia, Finland, Italy, Netherlands, Spain, Sweden, Turkey and the UK with Norway with 11 locations being the most abundant). Other countries represented worldwide include Argentina, Canada, China, India, Japan, South Korea and the USA. 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.

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 additional facilities at Ulsan and Busan. China offers bunkering at Gaolan Port and Yidu City with several more sites under consideration.

Elsewhere in Asia, Singapore, Japan, Oman, Sri Lanka and the United Arab Emirates are looking at LNG bunkering facilities.

Algeria is the sole announced project in Africa while two projects are being considered in the Caribbean, one of them around the enlarged Panama Canal.

Bunkering system components

The bunkering system consists of an LNG tank to hold the LNG, a transfer system that connects this to the tank on the ship that is to be filled, and a control system to enable the transfer.

LNG Storage tanks

A variety of LNG storage tanks are (or will be) available to hold LNG. Most of these tanks have operated successfully on LNG carriers in the bulk international LNG business.

IMO Type C tanks are pressure vessels whose internal pressure may be increased to several times atmospheric pressure. This is very attractive for the LNG bunkering process as it avoids venting any cold gas. The disadvantages of this technology are that it is not space-efficient, particularly if located within the hull, and is relatively expensive. All the tanks currently in service on gas fuelled ships are Type C tanks.

The iconic, free-standing, Moss Rosenberg spheres are extremely robust in terms of strength and operability but take up very large amounts of space. It is therefore difficult to envisage any LNG-fuelled ships adopting this tank technology. Self-supporting Prismatic type B (SPB) tanks are effectively cuboid in shape and can be designed to fit comfortably within most hull shapes. The tanks have internal strengthening and structural systems which make them very robust but also expensive and relatively heavy.

Membrane containment systems use thin metallic barriers supported by the strong hull structure via load-bearing insulation arrangements. The membrane is subject to deflection loads as the hull moves, and therefore

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requires a duplicate "secondary barrier" to protect the hull in case of failure of the primary membrane. Membrane tanks can be made into any shape so can be used space efficiently within a hull. However, the membrane is thin and can be damaged by "sloshing", waves generated within the LNG tank by ship movement. The shape of the tank and the strength of the insulation needs careful consideration to avoid sloshing issues.

As LNG storage tanks become bigger to enable larger ships to undertake longer voyages Type C tanks will become less cost effective and prismatic and membrane tanks will be preferred. The first membrane tank for bunkering is currently under construction for a bunker vessel.

LNG bunker transfer system

The LNG bunker transfer system consists of valves, a flexible piping system, safety valves and a connector system to the ship's pipework and control system.

Flexible piping system

There are two options for flexible piping: firstly, a hose made from a stainless steel inner pipe, layers of insulation and an external armour; and, secondly, hard arms that consist of lengths of pipe linked together by an articulated joint called a swivel. The swivel allows movement in one or two dimensions, meaning that two swivels are required.

Flexible hoses have been used for many years to unload LNG road tankers into small onshore tanks and more recently to transfer bulk LNG cargoes between ships and floating terminals. Hard arms are the workhorse of

Flexible hose

Hard arm

the bulk LNG industry, used in almost all liquefaction plants and import terminals. They are also increasingly popular for loading LNG road tankers. As the pipes are rigid, hard arms are more robust than flexible pipes and have potentially better safety performance. That said, the continuous movement of the swivels during bunkering may lead to maintenance and component lifetime issues.

Flexible hoses have dominated the bunkering industry with the first hard arm for bunkering only entering service in a Norwegian terminal during 2015.

Emergency release coupling

Emergency release couplers (ERCs) have been introduced to limit – indeed almost eliminate – LNG spills should the system need to be disconnected in an emergency. An ERC consists of two valves that close automatically in an emergency shut-down scenario. Between the two valves is a coupler that can break away, allowing separation of the two vessels with the only spillage being the small amount of LNG trapped between the two valves.

Emergency release coupler

Control systems

Best practice is to connect the two LNG tanks and control systems to allow each side to monitor the filling process and prevent any hazardous scenarios – such as over-filling or over-pressurisation – developing. This is difficult to do when road tankers are the bunkering option as there are many different tanker options.

Bunkering process

Bunkering an LNG-fuelled vessel involves many stakeholders and has several stages.

The master of the vessel to be fuelled retains control over the ship. The master is acting on behalf of and in the interests of the buyer of the LNG. In this capacity the master must approve the quantity and quality of the

Technical

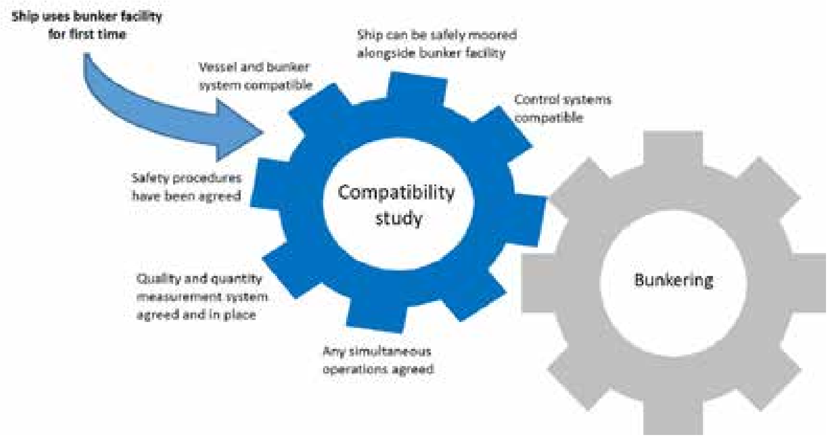
LNG that will be bunkered. The master must also ensure that the LNG transfer process is safe and that environmental impacts are minimised. If these basic requirements do not continue to be met at any time during bunkering, the master has the right to terminate the process.

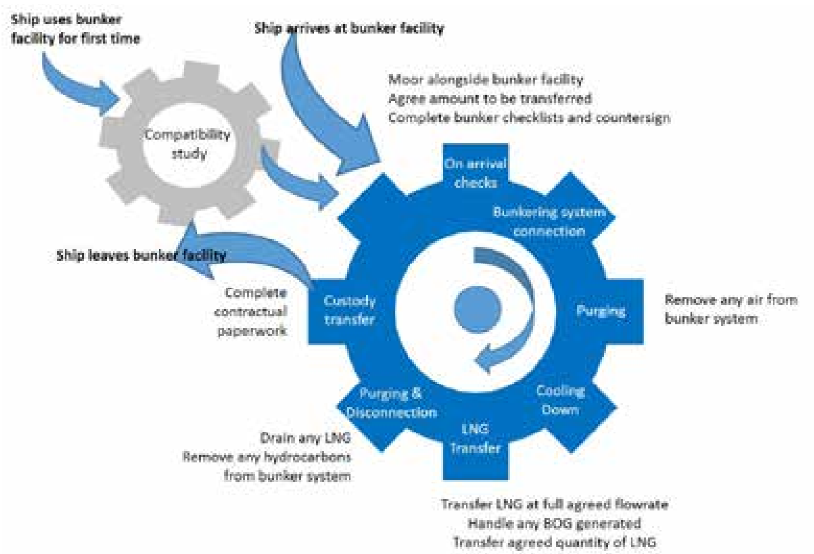
The Person In Charge (PIC) is in control of the transfer of LNG. In most scenarios the PIC will act on behalf of the seller of the LNG. In this capacity the PIC will provide the correct amount and quality of LNG. The PIC is responsible for the safety of the LNG supply and transfer equipment. The PIC will also be responsible for complying with any local safety, environmental and maritime requirements. If, at any stage, the transfer process fails to comply with the local regulations, the PIC should terminate the transfer.

The choice of filling method will depend on many factors, including: the compositions of the LNG in the tank and the LNG fuel; the temperatures of both LNG volumes; the filling rate; and the pressure ratings of the LNG tanks.

The bunkering process is summarised in the flow diagram on the right.

Flow diagram of a typical bunkering process





environmental technical safety contractual training & competence

Safety

Is LNG safe?

The cryogenic nature of LNG introduces new hazards that differ to those of conventional oil-based marine fuels. However, one benefit of LNG's cryogenic nature is that it will start to vaporise on contact with air, ground or water. This means that LNG spills tend to leave fewer lasting environmental impacts than marine oils.

Almost all LNG-based safety incidents will start with a spill of LNG or an escape of cold gas. For very small LNG spills, particularly onto water, the LNG may vaporise very quickly and become a cold gas. This gas may disperse into the atmosphere. If the LNG leak is larger than the rate of vaporisation can immediately dissipate, the LNG will form a pool that may stay in one place or spread out, depending on the physical obstructions in its vicinity and the degree of movement of the vessel involved.

Handling cryogenic liquids

Extremely low temperatures will cause standard ship steel to become brittle and fracture – so areas at risk must be protected against accidental LNG spills using drip trays and/or water curtains. Carbon steels used for shipbuilding start to become brittle below -20°C. Stainless steel and aluminium do not become brittle so are normally used for cryogenic pipework and valves.

Spills on earth or the concrete structures of quaysides are unlikely to cause damage but may take some time to vaporise and disperse. Spills of cryogenic fluids onto water lead to very rapid boiling of the LNG. In unusual circumstances the expansion caused by the rapid boiling can create a blast wave. This is called a Rapid Phase Transition (RPT).

Cold gas is heavier than air so leaks will roll along a deck or flow downwards to lower levels or the water surface. They are usually very apparent as the cold gas condenses water vapour in the air to form a white cloud. As it spreads, the cold gas starts to warm. Its density therefore decreases and the gas becomes more buoyant. At about -110°C the cold gas becomes lighter than air and starts to rise. The direction and speed of gas dispersion is highly dependent on prevailing weather conditions. If the gas does not ignite, it should safely disperse in the atmosphere.

Dense white cloud formed by vaporising a liquefied gas (nitrogen in this case) spreading over water

Fires & firefighting

Vapour from boiling LNG is flammable, which is why LNG is used as a fuel. If LNG spills and starts to evaporate, there is potential for a fire to start if an ignition source is close by. Natural gas ignites only in mixtures of between about 5% and 14% by volume in air. Wherever the gas cloud ignites, the gas will rapidly burn back to the leak source, where it will continue to burn until it is extinguished or all the LNG has combusted. In very specific circumstances the ignition of a fire may be so violent that a form of explosion can occur.

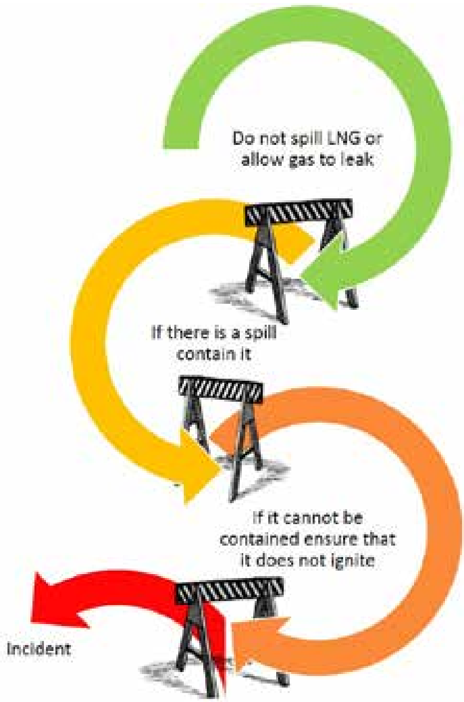
Designing in safety

The greatest benefits of safety analysis are at the design stage, which is when most proposed safety improvements can be accommodated relatively easily. During and after construction some safety improvements may no longer be possible at reasonable cost, for example if they require the altering or moving of major systems or hull components.

The bulk LNG industry has a good safety record, having developed very rigorous design guidelines for both ships and shore facilities, as well as high standards of training and operational procedures. LNG facilities and LNG carriers are regarded in the marine and hydrocarbon industries as best practice. This view is based on their high-quality, robust safety systems and overall attention to detail in design, solid construction and stringent operational practices. These factors combine to minimise accidents, incidents and product releases.

Multiple layers of protective measures are implemented to prevent a hazardous scenario escalating into an actual safety incident.

Simultaneous failure of multiple layers of protection is unlikely.



Layers of protection principles

Safety distances and exclusion zones

Safety distances are designed to keep ignition sources away from the LNG and any potential leaks, while simultaneously minimising the potential for scenarios that could lead to damage, such as collisions.

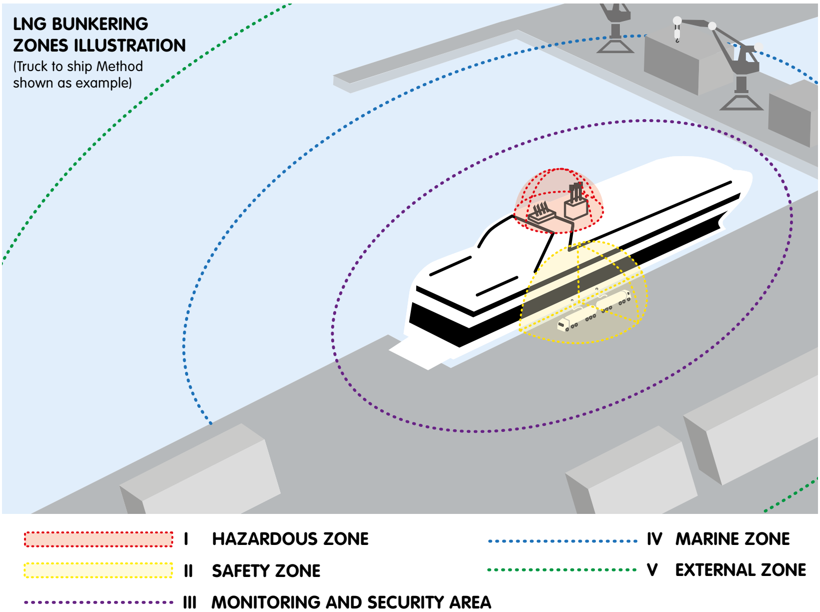
A series of safety zones are recommended to protect the bunkering vessel for harm these include:

- hazardous zone - where a flammable atmosphere may always be present as a result of leaking flanges, valves, etc and potential venting
- safety control zone - only present during bunkering where precautions are taken to minimise the impact of any leak during LNG transfer

- monitoring and security area - where activities which could impact the safety control zone are monitored to prevent impact
- marine exclusion zone - to stop other passing ships impacting the LNG bunkering
- External zone - in some jurisdiction a certain level of risk to the public needs to be considered

Guidance on the configuration and physical dimensions of these zones, based on a deterministic or group of credible release scenarios and local conditions is nearing completion. Defining the credible scenarios is the main area of contention and in this case they have been set by a committee of industry experts and participants.

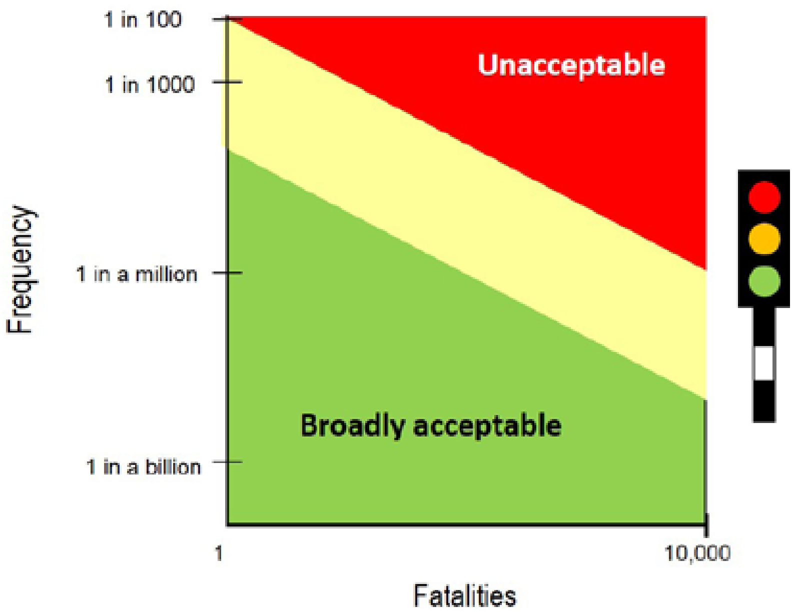
Some supposedly credible scenarios may lead to large safety distances, of perhaps up to 100 metres or more.



* Truck to ship bunkering method shown as the example
** Hazardous zone around the ship/truck manifold(s) and truck relief valve not shown for clarity
*** Relative sizes and distances are for illustration purposes only

Safety

The alternative – probabilistic – approach predominates in many onshore LNG facilities. It uses the same consequence calculations as the deterministic method but also assigns probabilities or frequencies to the chance of an event occurring. The safety distances generated are examined on the maximum risk to an individual worker/member of the public and the societal risk to the wider community. Safety distances here can be small to very small. The weakness of this method is the ability of the hazard assessor to source appropriate frequency data and independently assess hazard scenarios.



Probablistic risk-based assessment

Risk assessment

Risk assessments will need to be carried out on equipment and components, on individual vessels, and on the whole bunkering process. Some risk assessments will be performed to ensure that design work is safe while others will be carried out to demonstrate to the local and/or national authorities that the design meets or exceeds their requirements.

Risk assessment is normally carried out during the design and planning phases – addressing construction, operation and maintenance.

The results of such risk assessments must be incorporated into the operational and maintenance procedures as appropriate. Full risk assessment consists of much more than just a Quantitative Risk Assessment! A HAZard and OPerability (HAZOP) study – in which each major equipment component is examined for a variety of mal-operations and the impact of the effects of poor performance is quantified – is particularly appropriate.

Risk assessment is not a one-off process; it needs to be repeated every time something significant changes. This may be a new vessel to be fuelled (if substantially different from others fuelled), the use of different bunkering equipment, and/or changes in operating procedures.

Safety management systems

Management systems and procedures must reinforce staff behaviours around the implementation of safety to ensure that policies are effective. Alongside risk assessment, the use of safety manuals, appropriate working procedures/practices and training are crucial.

Any work also needs to be seen in the context of the whole plant or vessel – to ensure that one task does not interfere with or cause safety concerns for other tasks/workers. Particular emphasis should be placed on non-routine operations, where it may not be straightforward to understand all the hazards involved.

Modifications should go through a risk assessment process before being authorised.

Will simultaneous operations be allowed?

Whether simultaneous operations will be allowed will be for the port authority and/or the safety regulator to decide, on the basis of risk assessments and safety management systems.

There is nothing in the regulations forbidding simultaneous operations (SIMOPs), but they introduce additional hazards, for example the dropping of a container on the bunker vessel, or the consequences of an incident being greater. For example, passengers are likely to be more vulnerable during boarding and also represent multiple potential ignition sources because of their mobile phones and/or vehicle engines. They also potentially distract staff from the bunkering activity.

In most scenarios SIMOPs should be possible with careful planning and management. However, there may be restrictions, for example, containers can be loaded but working in some locations above the bunker vessel may be prohibited while it is alongside.

Detailed guidance is nearing completion.

How do I plan for emergencies?

Accidents can happen. Planning therefore should consider all possible eventualities, so that if the worst happens, the most appropriate response clicks in.

Generally there should be two levels in an emergency plan. The first level looks after the site of a potential incident. The second level looks after the wider community.

The site emergency response would probably involve the bunker company/facility owner and fire and ambulance authorities. The purpose of this is to handle the immediate hazard, controlling and extinguishing any fire and treating any injured people.

The offsite emergency response plan aims to handle the consequences of an event for the wider community. Typically the police are the main agency and the local authority will need to be involved, particularly if a public evacuation is required. Dealing effectively with media interest is an important part of this activity. Both the bunker supplier and the ship owner should be involved.

Fire and ambulance authorities are very good at fighting normal fires and attending a range of accidents. However, an LNG spill is not a normal accident and the bunkerer – especially in the case of a terminal – is likely to have more experience and knowledge in LNG fire-fighting and first aid than the emergency services. This can be a cause of conflict. Supporting the training of key members of the emergency services and regular visits and drills to familiarise first responders are strongly recommended.

The emergency plan needs to be tested at least annually. Tests can range from desk-top exercises involving only senior staff from the emergency services to full-blown simulated emergencies, with fire appliances in attendance and ambulances treating simulated casualties.

Contractual

Custody transfer process

Custody transfer takes place each time there is a change of ownership of the LNG, between an LNG Supplier (or seller) and an LNG Receiver (or buyer). The purpose of custody transfer is to define the amount and quality of the product so that an accurate financial value can be assigned to the transaction and to ensure that the agreed quality parameters have been met.

Third party bunkerers, that own the road tankers or the bunker vessel may be used to distribute the LNG to the fuel consumer. Normally these distribution companies will not own the LNG but have an obligation to ensure that the LNG remains within specification and that the correct quantity is delivered/measured. Depending on commercial terms, custody transfer may occur at any LNG movement between the supplier, distributor and fuel consumer.

LNG is not fuel oil

Traditional fuels oils for bunkering are sold by volume to an accepted standard and paid for by mass.

LNG, although fulfilling a common purpose, varies in composition depending on where it is produced (see table for two extreme examples). The bulk LNG industry sells or transfers LNG on an energy basis to reflect this variation in composition.

LNG as a road fuel is sold either by mass or volume, with the fuel dispenser normally delivering mass and volume being used only for billing purposes. However, most road fuel is sourced from one producer so is consistent in its composition and energy content and sold in small amounts so allowing a simplified sales process. The larger transfers for ship bunkering and the different LNGs provided at different ports means that this simplification would be difficult to achieve. Therefore both the quantity transferred and the quality (or composition) of the material transferred have to be measured and documented each time to allow the energy transferred to be calculated.

Several proven techniques are available for measuring both LNG quantity and quality, all of which provide sufficient accuracy and auditability to support the custody transfer process. Some industry participants are however, attempting to define a "standard LNG" to simplify the process.

	Volume transferred m^3	Density kg/m^3	Mass transferred kg	Energy Content MJ/Nm^3	Gas to liquid ratio Nm^3/m^3	Energy transferred million MJ
North West Shelf, Australia	1000	467.35	467,350	45.32	562.46	25.490
Tangguh, Indonesia	1000	431.22	431,220	41.00	581.47	23.840
Difference	-	7.7%	7.7%	9.5%	-3.4%	6.5%

Differences in LNG Properties by Source of LNG

Buying LNG

There are essentially two types of LNG. Firstly, there is the international bulk trade, in which LNG moves from one country to another, often over very long distances, in large LNG carriers. This LNG may be redistributed to smaller terminals by road tankers or small ships. Secondly, there are the smaller local producers that produce LNG for local markets. The price of LNG will depend on which of these models is used, where in the world it is sourced from and the competitiveness of LNG with alternative bunker fuels.

The minimum price of LNG as bunker needs to be built up by combining all the costs accumulated from the gas well to the LNG bunker (see diagram). LNG bunker prices could be based on the market gas price plus the cost of producing and distributing LNG at small scale or the costs of importing, storing and redistributing internationally supplied bulk LNG. If the latter, the LNG would compete with other international gas trading options.

The maximum price of the LNG would be the equivalent price, on an energy basis, for example in British thermal units (Btu). (Because a Btu is a very small measure of energy, the most common unit is a million Btu, or M[MBtu], of the competing bunker fuel, probably Marine Gas Oil, but

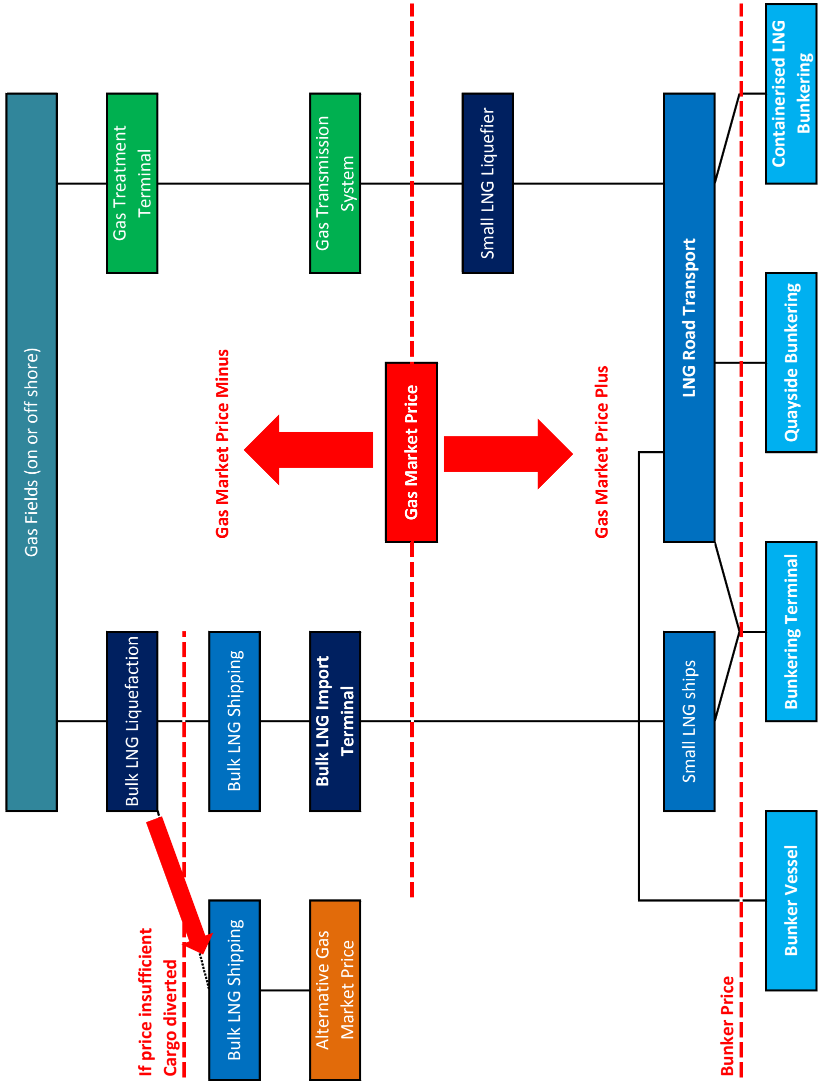
Contractual

potentially also the cost of running on HFO with scrubbers installed.

The actual price of the LNG sold will be somewhere between these maximum and minimum values. On the bulk LNG market prices are normally based on internationally traded oil prices, for example, Brent (UK sector of the North Sea), WTI (West Texas Intermediate in the US) or JCC (Japanese Crude Cocktail or Japanese Custom Cleared in Japan) or alternatively on the value of gas at a major gas hub, for example Henry Hub in the USA, NBP (National Balancing Point) in the UK or TTF (Title Transfer Facility) in the Netherlands.
As bunker prices will either be based on oil prices (eg MGO) or bulk LNG they can be hedged financially.

Comparing the economics of LNG bunker with oil is difficult, because they depend on the precise compositions of the LNG (location based) and the oil. They also depend on engine type and efficiency.

Bunker supply options



Contractual

Impact on engine performance

Engine performance and emissions are affected in different ways by changes in gas composition (see page 39). Impacts are quantified through three variables:

- Calorific Value
- Methane Number
- Wobbe Number

Calculated on the basis of gas composition.

Calorific value

The calorific value, or heat content of the fuel is determined by its composition - hydrocarbons with more carbon atoms give out more heat per molecule when combusted compared with methane. Bulk LNG is normally sold for use in gas combustion equipment in industry and power generation and is priced against its Gross Calorific Value – which means that benefit is taken for condensing water vapour formed during combustion. Published price trends are based on this premise. Marine fuels are normally sold on a Nett Calorific Value basis (no condensation). The difference between Gross and Nett depends on composition but is typically about 10%.

To calculate any calorific value the temperature reference conditions governing the combustion process must be known. These vary from country to country and variations between countries can be as much as 6%.

Wobbe Number

Wobbe Number is a flow parameter that quantifies the amount of heat that flows through a burner nozzle of a specific size in a given time. If the Wobbe Number is the same for two fuels, whatever their composition, a burner will deliver the same amount of heat. Modified Wobbe Numbers are important in the operation of

- boilers/steam turbines
- gas turbines
- high pressure gas diesel engines

Pure gas engines

Pure gas engines are spark ignition engines which run under the Otto cycle. They are designed for a range of gas compositions but when the fuel falls outside of the design range, the control system may reduce power or shut down the engine. Pre-ignition, also known as knocking, is possible. Varying gas composition can require adjustable combustion timing for effective operation of the engine.

Dual fuel engines

Dual fuel engines can run on gas or liquid fuel using the Otto cycle. When running on gas a small amount of liquid fuel (1-3%) is used as pilot fuel. During the compression stroke the fuel-air mixture warms until the liquid fuel ignites and combusts the rest of the gas mixture. When the fuel composition falls outside the design range, the control system changes the gas-diesel fuel ratio to maintain power in the engine. Pre-ignition (knocking) is possible.

Gas diesel engines

These engines can run on gas or liquid fuel but use the Diesel cycle. When running on gas a small amount of liquid fuel (3-5%) is used as pilot fuel to ignite the gas. Gas and liquid pilot fuel are injected separately at high pressure after the compression stroke has completed causing them to mix within the cylinder (in a similar way to a gas burner) and ignite. Pre-ignition/knocking is not possible. These engines have a low sensitivity to composition change.

Gas turbines

Aero-derivative gas turbines ("jet engines") are used for marine propulsion. Gas turbines utilize the Brayton cycle. The combustion system for gas turbines can be designed to burn a wide range of fuels, but normally the commercial guarantees limit fuel range for emissions and longer term maintenance concerns. The fuel composition limitations are determined more by flame shape and stability.

Contractual

Methane Number

The Methane Number (MN) is used to define the knock resistance of a gaseous fuel in Otto cycle engines. Knock is mostly caused by pre-ignition of the gas inside the cylinder when the fuel is injected into the chamber during the compression stroke. During pressurisation, heat builds up in the cylinder which can cause components in the gas to self-ignite, subsequently causing premature ignition of the rest of the injected gas-air mixture.

Methane Number is determined experimentally using a test engine and is a scale based on the combustion characteristics of methane (MN=100) and hydrogen (MN=0). Heavier hydrocarbons have lower methane numbers than pure methane. Many compositions can result in the same calculated Methane Number, so MN is therefore only a guide to engine performance and not a guarantee.

There are also many different equations available to calculate the Methane Number and they give different results for the same gas compositions.

Otto cycle engine output and efficiency performance are constant over a wide range of Methane Numbers but when the engine design point is reached performance starts to decrease. The design point varies between different engine technologies, manufacturers, engine types and even between individual installations, depending on owner preferences. Methane Number depends on the source of the LNG. LNGs that normally supply Europe and the southern and eastern coasts of North America, have Methane numbers in the range 75 to 89. This is currently where most gas-fuelled vessels operate and no major problems with LNG quality have been reported to the engine manufacturers. In the Asia Pacific area, LNG can be much richer in heavier hydrocarbons so has lower Methane Numbers, more typically in the range 68 to 89.

Most existing LNGs (86% by volume produced) have Methane Numbers over 70 and all are above 65. Therefore only a few LNGs (MNs of 65 – 70) are expected to impact engine operations. These very rich LNGs could result in a maximum loss of 10% of maximum engine rating.

The trend in future LNG supply is towards LNG with lower contents of heavier hydrocarbons (ethane, propane and butane) and therefore higher Methane Numbers (80+).

Aging/Weathering

LNG differs from oils in that it is an evaporating liquid. Any heat ingress boils off some of the LNG to create what is called Boil-Off Gas (BOG). It consists of the most volatile components, normally nitrogen and methane. As BOG is generated, the composition (or quality) of the LNG gradually changes. However it takes several weeks for significant changes in composition to occur. This is called "aging" or "weathering".

Measuring quantity

Measurement of the quantity of LNG transferred is relatively simple, with both volume and mass measuring systems in use within the wider LNG industry. These techniques are similar to those used in fuel oil bunkering and may involve measurements before and after transfer - for example sounding, with the quantity transferred calculated from the difference. Alternatively, meters are available to measure the flow rate of the LNG continuously.

LNG in bulk has always been measured by recording tank levels before and after the transfer. To ensure accuracy – this type of LNG custody transfer is accurate to +/- 1% – many corrections need to be made for cargo temperature and pressure, list and trim of the LNG tanker, and from calibration of the tanks and the measuring instrument. The LNG importers' group GIIGNL provides detailed guidance on this method.

A similar method is anticipated for bunker vessels. The apparently laborious measurement and corrections are computerised and so require only occasional cross-checking and calibration.

The alternative from the LNG road fuel market, and to a certain extent LNG road trucking, is to use a mass measurement device. Road tankers are frequently loaded on weighbridges to accurately determine the mass of LNG transferred. Filling LNG-fuelled trucks uses a system similar to a petrol or diesel pump with a totaliser system based on a mass flow meter. Coriolis meters are the normal technology choice. Ultrasonic meters are also available and perform equally well.

Mass Coriolis Meter in LNG Service

Boil Off Gas/Vapour return

Depending on the LNG tank type, rate of bunkering and composition of the LNG, BOG may need to be returned to the LNG supplier, (for example, the bunker vessel) and may have a financial value. This is typical of bulk LNG industry practice. Therefore two flows potentially need to be measured, both the liquid LNG and the gaseous BOG. In reality the BOG returned can usually be calculated to sufficient accuracy to avoid further measurements.

Assessing LNG quality

Determining the quality of LNG – essentially its calorific value – is more difficult and costly. LNG quality is usually calculated from its composition. LNG quality measurement therefore involves the sampling and analysis of LNG to determine which hydrocarbons are present and in what quantities.

Techniques to measure the quality of natural gas are widely used and accepted for billing purposes throughout the gas pipeline industry. The bulk LNG industry has developed techniques to capture a representative sample and vaporise it to allow standard gas industry composition measurement to be performed.

Sampling for quality measurement needs to take place close to the time of LNG bunkering, preferably at the same time, but otherwise within a few hours. Sampling is the largest inaccuracy in the whole LNG custody transfer measurement process. As with oil, a sample of LNG must be taken from the transfer pipe as close as possible to the manifold. Unlike oil, the sample must be vaporised to analyse the composition of the resulting gas in a chromatograph. Vaporisation must be very fast to prevent volatile components leaving prematurely and to ensure that no residual components are left as liquid. This analysis is used to calculate the density and the calorific vale of the LNG. As with oil, gas samples need to be kept in case of appeal by one party against another.

Typical Gas Sample Arrangement

Commercial agreements

There are two operations that need to happen for LNG bunkering to take place. Firstly, the bunkerer has to purchase LNG from a bulk importer or local liquefaction company. Secondly, the ship owner/operator has to purchase LNG fuel from the bunkerer. In between LNG supply and

Contractual

ship bunkering may be some form of delivery contract to cover the costs incurred by third parties, for example road tankers operators.

The LNG supply side is well covered by existing commercial practices. Many different models exist but companies and specialist energy lawyers should be confident of the continuation of these models with relatively minor modifications.

On the LNG delivery side there is no definite answer as yet. However, existing oil bunkering contracts – and Bunker Delivery Notices (BDNs) – are not dissimilar to the documentation used in the bulk transportation of LNG. A generic LNG BDN is provided in the IGF Code.

Training & Competence

Training & Competence

In many industries that routinely handle potentially hazardous cargoes or fuels, for example, the bulk LNG transport business, their main strength (or weakness) is the quality and experience of the staff involved and how these individuals perform, not just through routine operations but also how they react to unexpected or unusual events. Training is therefore essential to improving the knowledge, understanding and flexibility of the humans involved throughout the LNG industry, with the bunkering of LNG for use as a fuel being no exception.

Training is an activity that involves the teaching of a particular skill or way of doing something. Generally, it does not require the trainee to have a particularly high level of understanding of the activity.

Competency (i.e. the possession of competence) is often defined as being capable of undertaking a task and completing it successfully with confidence and understanding.

What competency is required?

Working together

Bunkering is a two-stage process – one party supplying the fuel and the other receiving it. The two crews need to work together so both must be trained. Competency is not therefore just about mariners but also needs to include all the shore side staff involved. It is probably not possible to train everyone in everything but the basic mental model between the two parties should be shared to enable understanding. Communication and co-ordination are key to successful and safe bunkering.

The main risks are thought to be associated with the ship being fuelled. The bunker vessel, terminal or road tanker staff would be bunkering every day and probably many times each day. The ship may bunker only infrequently (every several days). The quality of the receiving vessel and the competency of its crew are key to safe bunkering.

There is concern over "regulatory clash", the mismatch of onshore rules

Training & Competence

(frequently competence-based but with criteria set by operators and approved by regulators) with prescriptive shipping rules and IMO training systems.

Competence for mariners

Gas-as-fuel training for mariners will come under the International Maritime Organization's (IMO's) Standards of Training and Watchkeeping (STCW) Committee. A four-level system is anticipated:

- **Familiarisation of the crew** with the ship and equipment. This is expected to be the responsibility of ship owners and managers rather than the STCW.
- **Basic training of all crew** on a LNG-fuelled vessel about the safety issues of natural gas and how these should be dealt with on the vessel.
- **Advanced training for all officers and engineering crew** involved in the operation of the gas-fuelling system and the LNG-bunkering process.
- **Equipment-specific training,** probably from the vendors, for the actual systems used on the ship. This too would lie outside the STCW code.

DNV GL has suggested an alternative approach for the advanced training that would involve separating out different learning requirements for deck and engineering staff, based on their actual roles within the gas/LNG storage, transfer and engine operation.

A variety of training methods are proposed, including training courses, simulator training and experience on operating (or training) ships.

Training for bunker vessel staff

From a regulatory point of view, bunker vessels are considered to be LNG carriers as they transport LNG cargo in bulk. The existing training requirements of STCW under the IGC Code would therefore apply to bunker vessels, rather than any system proposed under IGF. Some elements of the IGF code training process may also apply.

Maritime simulator training facility

Training for terminal staff

It is normally a legal requirement for LNG import terminals and small liquefaction plants to provide training for their employees in the hazards of LNG and the company's operating and maintenance procedures.

Training for road tanker operators

All road tanker drivers need training – but there is no industry standard or commonality as to what the training should be. Good practice appears to be a one-day course, with the programme including: class-room training to understand processes; tanker-specific training as there are many different types of road tanker ("learning to think"); and practical training, such as actually filling an LNG road tanker (to demonstrate competence).

SGMF's Competency Framework

SGMF has published recommended competence guidelines for the supply and bunkering of LNG for marine vessels, and the environment (for example the port), in which these LNG transfers take place, together with the knowledge that underpins them. This document is

sgmf

Training & Competence

designed to be applicable to all the personnel who may be involved in carrying out the required tasks regardless of their background or location (ashore or afloat).

The competence framework is in four levels to cover distinct roles and is modularised to recognise prior learning and experience. The four levels are:

Manage – for individuals who plan, administer and are responsible for personnel performing the bunkering or the area that they work in

Do – for individuals who carry out the LNG transfer and who may supervise other personnel

Assist – for individuals who assist with LNG transfer under direct supervision

Respond – for individuals on the vessel or in the surrounding area who need to be familiar with the hazards associated with LNG and the actions to take in an emergency

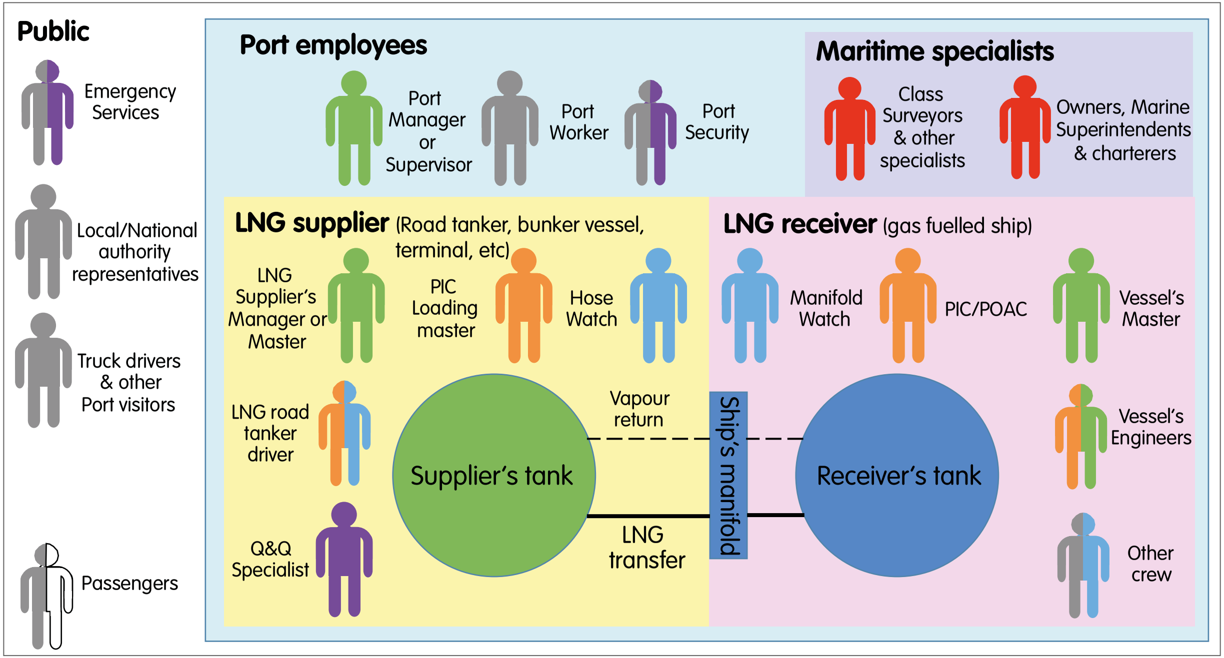
Specialist training may also be required for specialised activities. The modules also allow training plans to be assembled in a multitude of ways to cover bespoke industry needs.

SGMF's guidelines only cover the bunkering/transfer operation and are aimed to dovetail with and augment, rather than replace, other industry training schemes.

Assessment guidelines are available to assist with standard setting.

SGMF lists bunkering training courses on its web portal.

SGMF's suggested roles and competence levels



Key: **ASSIST** = blue **DO** = orange **MANAGE** = green
RESPOND = grey **BESPOKE** = red **SPECIALIST** = purple
No specific training = white.

Hello. We are the Society for Gas as a Marine Fuel, helping you make the change to gas, simple.

we love **the environment**

By changing to gas, the last fossil fuel available with the emerging sustainable source being biogas. Help maritime do its part to combat climate change and reduce emissions.

we are **technically tuned**

Our very language is technical, with a vast experience and wealth of knowledge that is available from the members of SGMF. Join in to help us find creative and innovative solutions for an industry that is slow to change and yet one that we all need and rely upon.

you are **in safe hands**

Natural gas in all its forms is well understood and is completely safe provided we always think, act and do....safety first.

There are six principle areas we focus on at SGMF.

we are **cost effective**

What price for change? Nothing will change without a clear financial case clearly evident and then also helping to enable the fuel transaction in a standard manner. Quality and Quantity are as important as ever yet perhaps easier to manage with Gas.

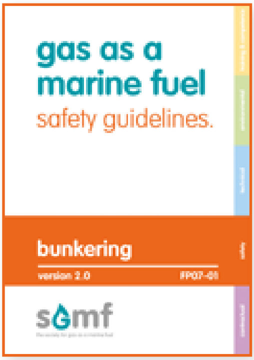
people **really do matter**

For everyone involved in the gas value chain, from the very source to the manifold itself, staff competence is absolutely vital for the safe transfer and use of gas as a marine fuel.

we **communicate**

Information is key to development of this industry and our website is the natural resource for members and the public.

SGMF Publications



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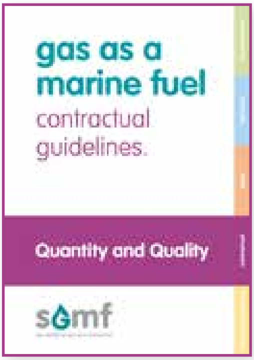

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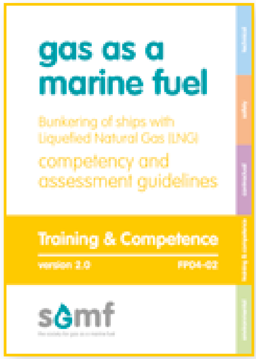

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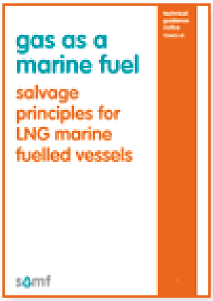

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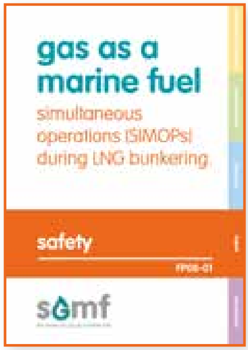

Simultaneous Operations (SIMOPs) during LNG Bunkering
ISBN 978-0-9933164-7-0

The Society for Gas as a Marine Fuel (SGMF) is a non-governmental organisation (NGO) established to promote safety and industry best practice in the use of gas as a marine fuel. Governed by a representative Board and driven by two principal Committees, SGMF has several working groups at any one time solving issues and producing outputs such as Guidelines and checklists for the industry. The Society has produced four ISBN publications in the past two years and has over 120 international members ranging from oil majors, port authorities, fuel suppliers through to equipment manufacturers and classification societies.

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