FP00-01-06

LNG as a marine fuel

an introductory guide

Version 4.0

sgmf

the society for gas as a marine fuel

environmental

technical

safety

contractual

training & competence

Version 4.0, June 2021

ISBN number:
978-1-999669-6-5

While the advice given in **LNG as a marine fuel – an introductory guide** has been developed using the best currently available information, it is intended solely as guidance to be used at the owner's own risk.

The Society for Gas as a Marine Fuel (SGMF)

The Society for Gas as a Marine Fuel (SGMF) is a membership-based non-governmental organisation (NGO) established in 2013 to promote the safe and sustainable use of gas as a marine fuel. The Society has full consultative status at the IMO and is the recognised representative body for the gas-fuelled shipping industry.

About this Guide

As its name suggests, *LNG as a marine fuel – an introductory guide* sets out the key facts about LNG: what it is, how it is used, its environmental and safety profile, which countries have invested in it, LNG ship design and systems, bunkering facilities and process, how it is purchased, and how personnel involved in handling LNG should be trained and familiarised.

Although it is of necessity a high-level document, the Guide links to more technically rigorous SGMF guidelines, aimed at assisting the growing LNG-as-fuel industry to develop.

Marine fuels in context

The maritime transport industry is under mounting pressure to improve its environmental performance. The central aim is to reduce emissions from fuel: sulphur oxides (SOx), nitrogen oxides (NOx) and particulate matter (PM) which harm the atmosphere and human health, and carbon dioxide (CO_2) and other greenhouse gases (GHG) which contribute to climate change.

The International Maritime Organization (IMO), the industry's international regulatory body, has set targets to reduce SOx, NOx and CO_2 emissions, and the final stage of the sulphur emission rules (the 'global sulphur cap') was successfully introduced in 2020.

SOx emissions are fuel-related, and under the regulations, the maximum allowable sulphur levels in marine fuels have been reduced. Fuels exceeding the limits may only be used in combination with an approved exhaust gas cleaning system (EGCS).

NOx emissions are engine-related. Engine manufacturers have made improvements to their engine designs to reduce NOx emissions. In general, gas-fuelled engines have lower NOx emissions than oil-fuelled engines.

PM emissions are both fuel and engine-related and are regulated by IMO together with SOx.

The main focus of the shipping industry's attention has now moved to GHG reduction. CO_2 emissions are directly linked to the quantity and type of fuel used and these emissions may be reduced in two ways, firstly by increasing the vessel's fuel efficiency and thus reducing its fuel consumption, and secondly, by selecting a fuel with a relatively low carbon content.

Sustainably produced zero carbon/carbon-neutral fuels will be required to meet the emission reduction targets for the industry.

Introduction

The advantages of natural gas as a marine fuel

Liquefied Natural Gas (LNG) compares positively with traditional marine residual and distillate fuels as regards its impact on the environment:

- It emits up to 23% less CO_2 than marine fuel oil.
- It is less polluting than fuel oil, with reductions of 95% NOx, and at least 95% of SOx and PM.

LNG also has an excellent track record. It has been produced and transported efficiently and safely for over 50 years, it is compliant with existing regulations and its bunkering infrastructure is now reaching maturity.

That is why LNG is being increasingly adopted as primary energy source by the shipping industry, both for propulsion and for power generation on board. It is regarded as an essential transitional fuel until affordable zero carbon alternatives, including drop-in options liquefied bio gas (LBG) and liquefied synthetic methane (LSM), become available at scale.

What is LNG?

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 (-260°F). As the natural gas condenses, about 600 volumes of gas become one volume of liquid and 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 or power station. Alternatively, it is distributed to off-grid customers for industrial use or for use as transport fuel.

LNG is a mixture of hydrocarbons, predominantly 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.

Introduction

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. The water vapour in the air is condensed by the coldness of the warming natural gas and 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.

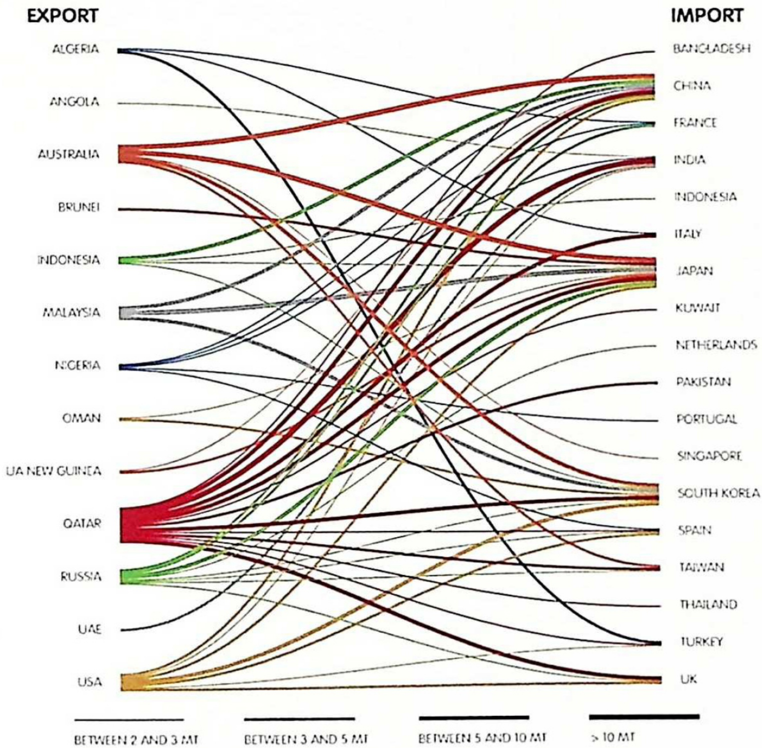
The scale and cryogenic temperatures involved make LNG production much more difficult than the underlying physics would suggest. Liquefaction plants are frequently valued in billions, or tens of billions, of US dollars. They require several hundred megawatts of electricity generation capacity (a megawatt (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 2021, 20 countries were producing LNG in bulk, with another nine producing smaller quantities for domestic consumption. According to the International Group of Liquefied Gas Importers (GIIGNL), the biggest producers in 2020 were Australia (77.77 million tonnes), Qatar (77.13 million tonnes) and USA (44.76 million tonnes).

LNG industry overview

Some 356.1 million tonnes of LNG were traded worldwide in 2020. Japan was the biggest importer (74.43 million tonnes), followed by China (68.91 million tonnes) and South Korea (40.81 million tonnes). Virtually all the LNG produced was used for electricity generation, industrial and commercial gas use, and by residential customers.

Well over 10 million tonnes per year of LNG are transported by road tanker from bulk import terminals and small LNG producers around the world. Road transport is most common in China, Spain, Turkey and the USA, and the quantity has more than doubled in recent years. Most of this LNG is consumed by large industrial users and power plants that do not have access to a gas pipeline network.



Bulk International LNG trade during 2020 indicating the major exporters and importers (Image courtesy of GIIGNL, Annual Report 2021)

Introduction

LNG as a fuel

Recently the use of LNG as a fuel has expanded significantly but volumes are still relatively small. For land transport it is mainly 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 Europe, and the number of LNG bunker supply vessels is increasing fast, with over 20 LNG bunker vessels in operation and as many again on order. Every sector of shipping has at least one gas-fuelled vessel in its fleet and significantly the container, tanker and bulker fleets are all now ordering and operating gas-fuelled ships. There are over 250 vessels in operation worldwide that comply with IMO's International Code of Safety for Ships Using Gases or Other Low Flash-point Fuels (the IGF Code).

Using LNG to fuel railway locomotives takes place 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.

Compressed natural gas (CNG)

Compressed natural gas has been used for many years as a road transport fuel, but its use in shipping is limited to some small domestic CNG-fuelled ferries in Brazil and in the Netherlands. LNG is a better option due to CNG's low energy density and complicated bunkering process.

Environmental

Fuel choice

The fuel choice for marine transport has traditionally been based on availability and economic considerations, though increasingly environmental performance is taken into consideration. When considering sustainably produced alternative fuels, the fuel choice is directly related to the selection of onboard technology, so the fuel's environmental profile becomes extremely strategically important.

Compliance with international regulations is and will remain a baseline for vessel operation. SOx and NOx regulations have been tightened and 2020 saw the introduction of the IMO global sulphur cap in which the maximum sulphur content in fuel was reduced to 0.5%.

Achieving this cap is relatively straightforward compared to the IMO's 2050 objective of reducing the industry's total carbon emissions by at least 50% in relation to 2008 levels. In the next 30 years the world population will increase and the amount of cargo moved by ship will rise in direct proportion. When taking this into consideration, the reduction of CO_2 emissions per transport work will amount to some 70% compared with 2008. The target cannot be met without the introduction of alternative zero-carbon fuels and carbon-neutral fuels produced from sustainable sources.

A discussion is going on as to which fuel(s) will be the best suited to take over from the currently available fossil fuels. Hydrogen and electric propulsion are likely to play a limited role because of their low energy density. For deep sea shipping, ammonia, methanol and methane produced from sustainably-produced sources (either from bio sources or as e-fuel) are expected to play significant roles in the future.

IMO regulations for reducing harmful and CO_2 emissions

The IMO, a United Nations body, controls and regulates many aspects of the global shipping business. It originally introduced the International Convention for the Prevention of Pollution from Ships (MARPOL) to address pollution of the oceans, but the protocol has since been expanded to encompass measures to reduce emissions such as sulphur oxides to the atmosphere.

MARPOL Annex VI also requires reductions in NOx emissions worldwide. The emission limits vary according to engine size, type and power. They are based on the tiered system which has seen ever tighter limits since 2011 and follow the direction taken by the land transport industry.

SOx and NOx maximum emission levels are stricter than the global standard levels in some specified geographic regions called Emission Control Areas (ECAs).

In addition, IMO adopted an initial strategy on the reduction of greenhouse gas (GHG) emissions from ships in 2018.

Local emissions and GHGs

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. SOx combines with water to form acid rain, which acidifies oceans and damages plant life. Sulphur dioxide affects the respiratory system, particularly lung function, and can irritate the eyes.

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 acid rain, and contributes to the formation of atmospheric ozone.

Particulate matter (PM)

Particulate matter consists of particles of soot (black carbon) or smoke resulting from incomplete combustion within the engine, and is considered a major health hazard. Particulates are the deadliest form of air pollution because they penetrate deep into the lungs and blood and are known to cause cancer.

Carbon dioxide (CO_2)

Carbon dioxide is a greenhouse gas, a contributor to climate change. Society, including the maritime transport industry, has to reduce CO_2 emissions in order to limit the warming of our planet. Emission reduction targets set by IMO in its initial strategy of 2018 lead the way in this development.

Methane (CH_4)

Methane is a GHG with a far higher 100-year global warming potential than CO_2. It is thought, however, that after a period of 12 years in the atmosphere, the GHG effect of methane is vastly reduced. Any quantity of methane that passes unburnt through the engine is called 'methane slip'.

Environmental

Emissions from ships

Sulphur

Sulphur oxides (SOx) depend on the amount of sulphur in the fuel. Since the global sulphur cap was introduced in 2020, the maximum percentage of sulphur in fuel has been set at 0.5%.

The most common fuel today is Very Low Sulphur Fuel Oil (VLSFO), a blended residual fuel with a sulphur content below this maximum percentage. VLSFO grades may vary to a considerable degree, and mixing of various grades may lead to fuel instability.

High Sulphur Fuel Oil (HSFO) has a sulphur content in excess of 0.5% and may only be used on vessels fitted with a certified exhaust gas cleaning system (EGCS), or scrubber.

Marine Gas Oil (MGO) is a more refined, higher price distillate fuel with its sulphur content reduced to around 0.1% during production.

The gas used for LNG production is cleaned before liquefaction. Typical sulphur specifications in LNG are less than 30 parts per million (ppm) of total sulphur, making them practically negligible, as they equate to only about 0.004% of sulphur by mass. SOx emissions are virtually eliminated when LNG is used as a ship fuel.

Nitrogen

NOx emissions are dependent on engine load and technology. NOx is produced during the combustion process in the engine, and the level of NOx increases with the combustion temperature. Maximising engine efficiency results in higher combustion pressures and temperatures and thus to higher NOx emission levels, so a balance has to be found between efficiency and NOx emission levels.

Oil-fuelled engines are not able to meet IMO Tier III limits unaided. These engines will need to be equipped with selective catalytic reduction (SCR) technology or exhaust gas recirculation (EGR) to reduce NOx emissions to acceptable levels. Whether an LNG-fuelled engine requires SCR/EGR to reach Tier III levels depends on the engine type. Most LNG-fuelled engines are NOx-compliant without after-treatment.

Particulate matter (PM)

PM emissions are all but eliminated with LNG-fuelled engines, while dual-fuel engines using LNG and pilot MGO will create marginal PM. Using LNG reduces PM emissions compared with HSFO engines by at least 95%.

Emission Control Areas (ECAs)

An ECA is an area, designated under MARPOL, in which the emission limits for SOx (sulphur oxides) and NOx (nitrogen oxides) are lower, to reduce their impact on health and the environment.

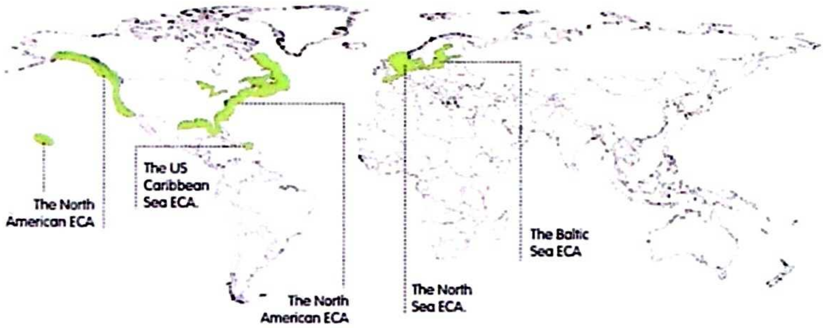
Ships operating outside an ECA may only use maximum 0.5%S content fuel, whereas within an ECA vessels are required to use maximum 0.1%S content fuel. Higher sulphur content fuel may be used in combination with an EGCS, which scrubs the exhaust gases to equivalent levels.

For NOx emissions, ships, engines and systems have to comply with Tier II levels for operation outside ECAs and Tier III inside ECAs. Tier III levels apply to vessels built after a specific date. This date (the actual keel laying date) is different for different ECAs.

The current ECAs are:

1. The Baltic Sea ECA.
   In this ECA NOx Tier III applies to vessels built since 2021.
2. The North Sea ECA.
   As with the Baltic ECA, the NOx Tier III applies to vessels built since 2021.
3. The North American (US/Canada Atlantic and Pacific Coasts, US Gulf Coast and Hawaii) ECA.
   In this ECA NOx Tier III applies to vessels built since 2016.
4. The US Caribbean Sea ECA.
   In this ECA NOx Tier III applies to vessels built since 2016.

Environmental



Map of Emission Control Areas

How are ECAs regulated?

Each signatory member state country implements the IMO rules under its own laws, nominally via port state control, and may further enforce the law through national procedures.

Are there alternative options?

Scrubbing

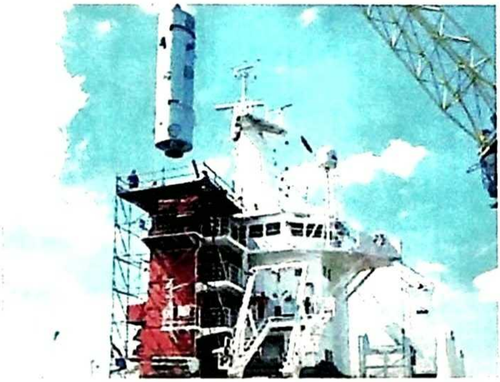
Ships may continue to burn HSFO in their engines if they then treat the exhaust gases to reduce SOx emissions to comply with the limits. Only ships fitted with a compliant EGCS may be permitted to carry fuel oil with a higher sulphur content than 0.5%.

A scrubber does not reduce NOx emissions. CO_2 emissions will increase slightly (estimated at 1-5%) because more fuel needs to be burnt to provide power to operate the EGCS.

Scrubbers are 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.

There are two types of scrubber: open loop where the wash water is pumped directly to sea, and closed loop where the wash water is recycled on board and the concentrated effluent periodically discharged ashore. Hybrid scrubbers can switch between these two modes. Open loop scrubbers are largely permitted in open sea but their use in coastal areas and ports is becoming increasingly prohibited because of their discharge.

Most EGCS in service have been retrofitted to existing ships so that they can continue benefiting from low cost HSFO, although some new vessels are also equipped with these systems.



Retrofitting scrubber on an existing ship
(Image courtesy of Spliethoff Group)

Today's fuel landscape

Shipowners can today choose from three types of oil fuel: HSFO, VLSFO and MGO. Reciprocating engines of most types are suitable for, or can be adapted to burn, all of these fuels.

The use of HSFO requires installation of an approved EGCS, and operating a vessel built on or after 1 January 2016 (or 2021, as appropriate) in an ECA requires Tier III NOx compliance, for which an EGR or ECR system is required.

Environmental

Shipowners can also opt for LNG. This requires an engine capable of operating on gas (dual-fuel engines are common) plus an LNG bunker station, storage tank and gas treatment plant. LNG complies with SOx emission limits, and most engine types are NOx Tier III compliant.

Shipowners may also opt for methanol, ethane or LPG (liquefied petroleum gas). Today, the application of these fuels is limited to methanol, ethane and LPG carriers. As with LNG, engines specifically suited to the relevant fuel will have to be installed.

Carbon-neutral biofuels have started making their way into the shipping industry. Limited amounts of liquid biofuel and LBG are available. These fuels form drop-in alternatives to MGO, VLSFO and LNG respectively.

The future fuel landscape

Decarbonisation of the shipping industry is the driver for developing sustainably produced fuels from renewable resources.

Production pathways for these fuels are diverse, but can be generally divided into two categories:

1. E-fuels, i.e. fuels produced from sustainably produced electricity (solar, wind, hydropower)
2. Biofuels, i.e. fuels produced from waste with a biological origin

Hydrogen is seen by many as the long-term fuel of the future. Hydrogen can be produced as e-fuel (by electrolysis) or by reforming natural gas whereby the by-product CO_2 is captured and stored (Carbon Capture and Storage (CCS)). Hydrogen can be used directly in fuel cells to generate electricity, which can then be used to contribute to the ship's energy demand.

The use of hydrogen in internal combustion engines is not yet a mature technology, however, and because of its low energy density, it does not play a significant role in deep-sea shipping. The use of hydrogen as a ship fuel presents significant safety, storage and infrastructure challenges.

Ammonia is also seen as a long-term fuel of the future. It is produced from hydrogen and used for a variety of applications such as fertiliser production. When replacing grey (produced from fossil resources) hydrogen with green (sustainably produced) hydrogen, this results in zero-carbon ammonia. Ammonia's main challenges today are its toxicity and the fact that marine engines running on ammonia are still in the development phase.

Methanol may become an alternative to ammonia. It is widely available as a petrochemical feedstock, although as a grey variant. Like ammonia, it may be produced as green methanol when produced from green hydrogen. Suitable engines are available, but methanol presents significant toxicity, structural and operational fire protection challenges when used on board a ship as a propulsion fuel.

Green hydrogen may also be used to produce liquefied synthetic methane (LSM), which is a carbon-neutral drop-in fuel to replace LNG.

Biofuels will play a role as well. Biofuel oil and LBG are available in limited amounts and are being used by some shipping companies.

Other gaseous fuels like LPG and ethane are not expected to play a role other than on board LPG and ethane carriers. Suitable engines for these fuels are available.

It is expected that the shipping industry will have a multi-fuel future, though, as yet, it is impossible to predict the share of the various candidate fuels. Competition for these sustainably produced fuels will be fierce, as other industry sectors such as land transport and power generation are all facing similar environment-related issues and are moving towards cleaner fuels and lower emissions.

The cost of marine fuels will increase when moving from fossil to sustainably-produced fuels, and carbon pricing is likely to play a role in this transition.

Environmental

Why an investment in an LNG-fuelled vessel is a sound decision

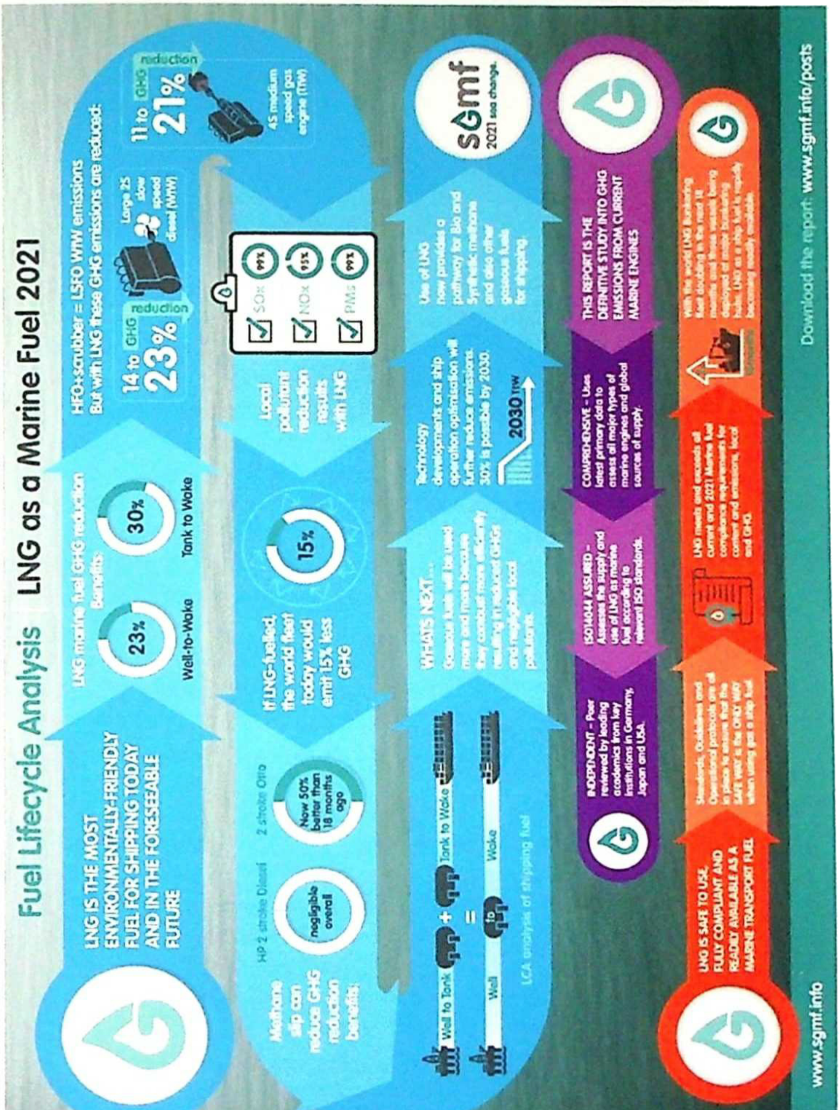
Contrary to other alternative fuels, LNG is widely available today. And it is a greener, more compliant alternative to conventional fuel oils: LNG-fuelled vessels emit less harmful emissions and GHGs than equivalent vessels using other available fuels.

A further benefit is that LNG can easily be replaced with carbon-neutral LBG or LSM when these alternatives become available, without requiring any conversion to the vessel's equipment.

LNG-fuelled vessels do however emit another GHG, i.e. methane which passes through the engine without combusting. Since methane is a powerful GHG, engine manufacturers have put a lot of effort into reducing this methane slip and continue to do so.

Sphera's *2nd Life Cycle GHG Emission Study on the Use of LNG as a Marine Fuel*, commissioned by SGMF and SEA-LNG, provides information on methane slip and concludes that GHG reductions of up to 23% are achievable now from LNG as a marine fuel, compared with current oil-based marine fuels over the entire lifecycle from well to wake.

The study is available via Sphera's website **www.sphera.com**


Fuel Lifecycle Analysis
LNG as a Marine Fuel 2021
LNG IS THE MOST ENVIRONMENTALLY-FRIENDLY FUEL FOR SHIPPING TODAY AND IN THE FORESEEABLE FUTURE
LNG marine fuel GHG reduction Benefits:
23%
Well-to-Wake
30%
Tank to Wake
HFO+scrubber = LSFO WtW emissions
But with LNG these GHG emissions are reduced:
14 to 23% GHG reduction
Large 2S slow speed diesel (WtW)
11 to 21% GHG reduction
4S medium speed gas engine (TtW)
Local pollutant reduction results with LNG
SOx 99%
NOx 95%
PMs 99%
If LNG-fuelled, the world fleet today would emit 15% less GHG
15%
Methane slip can reduce GHG reduction benefits:
HP 2 stroke Diesel
negligible overall
2 stroke Otto
Now 50% better than 18 months ago
Well to Tank
Tank to Wake
Well
to
Wake
LCA analysis of shipping fuel
WHATS NEXT...
Gaseous fuels will be used more and more because they combust more efficiently resulting in reduced GHGs and negligible local pollutants.
Technology developments and ship operation optimisation will further reduce emissions. 30% is possible by 2030.
2030 TtW
Use of LNG now provides a pathway for Bio and Synthetic methane and also other gaseous fuels for shipping.
sGmf
2021 sea change.
THIS REPORT IS THE DEFINITIVE STUDY INTO GHG EMISSIONS FROM CURRENT MARINE ENGINES
COMPREHENSIVE - Uses latest primary data to assess all major types of marine engines and global sources of supply.
ISO14044 ASSURED - Assesses the supply and use of LNG as marine fuel according to relevant ISO standards.
INDEPENDENT - Peer reviewed by leading academics from key institutions in Germany, Japan and USA.
LNG IS SAFE TO USE, FULLY COMPLIANT AND READILY AVAILABLE AS A MARINE TRANSPORT FUEL
Standards, Guidelines and Operational protocols are all in place to ensure that the SAFE WAY is the ONLY WAY when using gas a ship fuel.
LNG meets and exceeds all current and 2021 Marine fuel compliance requirements for content and emissions, local and GHG.
With the world LNG Bunkering fleet doubling in the next 18 months and these vessels being deployed at major bunkering hubs, LNG as a ship fuel is rapidly becoming readily available.
www.sgmf.info
Download the report: www.sgmf.info/posts

Technical

Who is doing it?

Interest in LNG as a bunker fuel is growing rapidly, not just for use 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 27 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 ECAs 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 early 2021 the Norwegian fleet had increased to 72 vessels. Elsewhere in Europe there are now 65 vessels operating in 13 countries with over 48 on order. The lead nations within the Europe are Sweden, France and Finland but other countries – including the Netherlands, Estonia, Belgium, Germany, Spain, Italy, Portugal and the UK – are also involved or have ordered vessels for their coastal or short-sea trades. The Netherlands has a CNG ferry in operation.

USA/Canada

In the Americas there are 24 LNG-fuelled vessels in operation with 15 in Canada and nine in the USA. Order books for both countries are healthy (a total of over 10 ships) so the business will continue to grow.

Far East

South Korea built the first LNG-fuelled vessel in Asia which is in service in Incheon harbour and now has three vessels in service. However, China is the leading player. It has five LNG-fuelled tugs in service with CNOOC, one of the Big Three national oil and gas companies, and has ordered several hundred inland waterway vessels. Japan's first LNG-fuelled vessel, a tug, has been delivered and operates in Tokyo Bay. It has now been joined by two other gas-fuelled vessels.

Southeast Asia

Singapore (five vessels) and Malaysia (four vessels) have started to invest significantly in gas-fuelled vessels.

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 ferry entered service in 2013. Brazil has CNG ferries in operation. Australia is now using LNG-fuelled offshore supply vessels (OSVs) and operates an LNG-fuelled ferry between Melbourne and Tasmania.

Most of these vessels operate in ECA zones.

LNG-fuelled fleet

Historically, car ferries and OSVs made up most of the LNG-fuelled fleet, accounting for about 30% and 14% 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 ship types now having a vessel in service and the remainder with vessels on order. Container ships and oil/chemical tankers are the most popular options, but 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 list.

Projections for the future

Over 200 gas fuelled vessels are on order for delivery before 2025. Oil/chemical tankers (69) dominate the order books followed by container ships (50 including 11 Ro-Ros) and cruise liners (29). There are also significant numbers of car ferries (21) and bulk carriers (17) in the mix.

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. These numbers have been interpreted in many ways to produce a range of forecasts.

Gas-fuelled ferry: BC Ferries Salish Eagle

Gas-fuelled container ship: CMA CGM Jacques Saade (Image courtesy of CMA CGM)

World's first electric hybrid polar exploration ship powered by LNG, delivery 2021 to PONANT

MSC Cruise World Class cruise ships launching in 2022 will be powered by LNG

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

Forecasts of ships have been about 1000 by 2020 (236 actually in service) rising to as high as 2000-3000 vessels by 2030. These forecasts now look too optimistic, at least in the short term. Probably a quarter to a third of that number will be built by 2030.

Currently there are under 236 ships globally using methane as fuel, representing 0.24% of the world fleet. The rate of gas-fuelled ship construction has accelerated year on year with 66 vessels delivered during 2020. Perhaps in 5-7 years this might reach 1500 though this would still only be 2% of the world fleet. To give a perspective, 20% of the world fleet fuelled by gas equates very roughly to the total consumption rate of a large industrial size country such as Korea or Germany.

One reason that take-up of gas as fuel has been slow is that 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. There is therefore little incentive to invest in new LNG fuelled ships in the short term and the number of 'LNG ready' ships ordered demonstrates this.

The IMO decision in 2019 to set a target for reducing carbon use by ships to 50% of its 2008 level by 2050 has led to the consideration of alternative carbon free fuels such as ammonia and hydrogen. However, neither of these fuels is commercially viable for deep sea shipping at the current time. The result of these discussions appears to be uncertainty and a drop off in LNG-fuelled ship orders.

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.

Technical

While industry commentators are not united 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 million tonnes per year (mtpa)) while others predict that about 20-30 mtpa will be required. This is equivalent to 4-6 baseload LNG trains or the whole output of number four LNG producer Malaysia. High end estimates indicate 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 about whether all these LNG plants can be designed, permitted, constructed and financed in the time period required.

The growth of LNG as a marine fuel is evidenced by the Port of Rotterdam releasing data on its sales of LNG which has seen a massive increase from 224 m^3 in 2016 to 210,334 m^3 in 2020. Similarly, Spain increased its LNG bunkering from 199 operations in 2019 to 741 occasions in 2020, transferring a total of 122,058 m^3 during the year.

What does an LNG-fuelled ship look like?

The fuel storage and use systems on an LNG-fuelled vessel differ to those on a conventional oil-fuelled ship. The requirements for an LNG-fuelled ship are covered by the IGF Code as part of the International Convention for the Safety of Life at Sea (SOLAS). They 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 from 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 posed by the use of gas as fuel
- Safety systems that provide a safe shutdown 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 Type A & B) and pressure vessels (Type C). Type C tanks are more robust and do not require vapour return systems but their cylindrical shape is 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 (BOG) 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.

Q-LNG 4000 which has Type C tanks (Image courtesy of Q-LNG)

Ship fuel systems

The IGF 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 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.

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 IGF Code covers main and auxiliary engines for propulsion and power generation on board all vessels over 500 GT, i.e. gas-only engines, dual-fuel gas and oil engines, multi-fuel engines using different fuels that are separate from each other, and gas turbines. (Regulations for the use of fuel cells are currently under discussion in IMO with interim guidelines projected to be approved in late 2021.) Redundancy is the key issue, with a vessel needing to continue to operate if one engine fails. 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 shutdown (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 in different countries/continents. Best practice guidance on this is published by SGMF and the International Standards Organization (ISO)

Hose connected to ship's bunkering manifold (Image courtesy of Harvey Gulf International Marine)

What does a bunkering system look like?

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

1. 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. Safety and commercial considerations will prevent large LNG terminals directly bunkering ships subject to the IGF Code, so they will use bunker vessels and road tankers to fulfil this role. 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 be by pressure differential or pumps.

2. 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.

3. 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.

4. 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.

Bunkering options

LNG Facility Port Fourchon
(Image courtesy of Harvey Gulf International Marine)

Bunker vessel - FuelNG Bellina
(Image courtesy of FuelNG)

Road tanker
(Image courtesy of Seaspan Ferries Corporation)

LNG Container

environmental technical safety contractual training & competence

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 in many in China, South Korea, Japan and Australia is therefore possible.

China, Denmark, Norway and the United States have developed small bunkering terminals. These terminals primarily serve dedicated vessel fleets such as ferries and OSVs or inland waterway vessels.

LNG transfer using bunkering vessels has seen a major growth over the last two years. The original vessel, 'Seagas' in Stockholm, has now undertaken more than one thousand bunkerings and has been joined by 24 other bunker vessels. In Europe, Norway has three vessels (Bergen and Risavika), two in Belgium (Antwerp and Zeebrugge), Netherlands has three vessels (two in Rotterdam, one in Amsterdam), two in Sweden (Gothenburg and Stockholm), three in Spain (Barcelona, Algeciras and Huelva) and one in Lithuania. Other vessels operate in western Europe including the Canary Islands and in the Baltic Sea. In the USA there are now tug propelled barges for Jacksonville in Florida (USA). China has multiple bunker vessels operating for use in inland waterways and one seagoing vessel. Both Malaysia and Singapore now have bunker vessels.

By the end of 2020, bunkering had taken place in 110 locations worldwide. Most of these were in Europe (88 sites including Belgium, Denmark, Estonia, Finland, Germany, Italy, Latvia, Lithuania, Netherlands, Poland, Portugal, Spain, Sweden, Turkey and the UK, and Norway with 11 locations being the most abundant). Eight ports in the Americas, three in the Middle East, eight in Asia and three in Australasia have provided LNG including Argentina, Canada, China, India, Japan, Panama, South Korea, UAE and the USA. A further 23 ports are in the advanced stages of developing bunkering infrastructure. 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 2025 and for inland ports by 2030.

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. Most of the tanks currently in service on gas-fuelled ships are Type C tanks. The largest tanks of this technology are about 1800 m^3 and many vessels have multiple tanks.

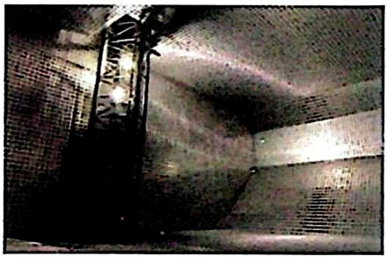
The iconic, free-standing, Moss Rosenberg spheres are extremely robust in terms of strength and operability but take up very large amounts of space. It is therefore difficult to envisage any LNG-fuelled ships adopting this tank technology. Self-supporting prismatic type B (SPB) tanks are effectively 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. Type B prismatic tanks are on order for container ships for 2021/2 delivery.

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 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. The first membrane type LNG fuel tanks entered service on CMA CGM's 23,000 Twenty-foot Equivalent Unit (TEU) container ships during 2020. Each of these tanks has a capacity of 18,600 m^3 of LNG.

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.

LNG tank systems

Type C tank
(Image courtesy of Gas and Heat SpA)



Membrane tank
(Image courtesy of CGM CMA)

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:

1. A hose made from an inner pipe of either stainless steel or multiple layers of LNG-proof fabric (composite hose), layers of insulation and an external armour.

2. 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 hose (Image courtesy of Technip Energies)

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 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.

Hard arm (Image courtesy of Gate Terminal)

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 shutdown 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
(Image courtesy of ARTA Group)

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 types.

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 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.

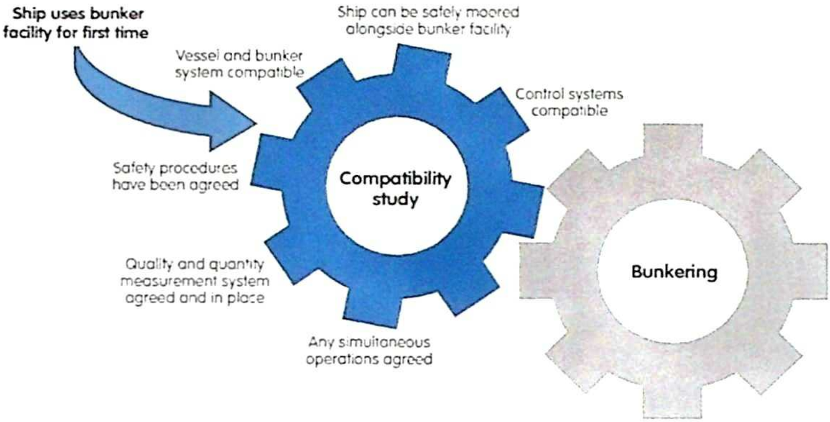
The choice of filling method will depend on many factors, including:

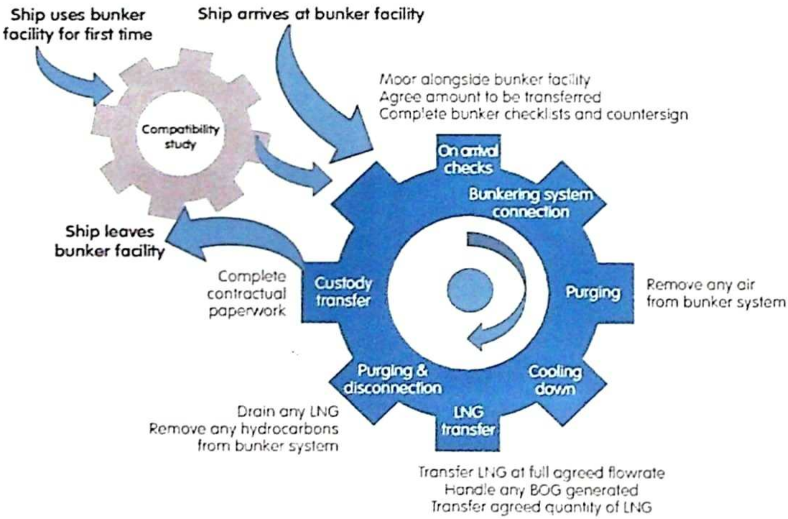
- the compositions of the LNG in the tank and the LNG fuel
- the temperatures of both LNG volumes
- the filling rate, and
- the pressure ratings of the LNG tanks

The bunkering process is summarised in the flow diagram below.

Technical

Flow diagram of a typical bunkering process





Safety

Is LNG safe?

The cryogenic nature of LNG introduces new hazards that differ to those of conventional oil-based marine fuels. However, the bulk LNG industry has a good safety record, having developed extremely rigorous design guidelines for both ships and shore facilities, as well as high standards of training and operational procedures.

LNG safety incidents

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.

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 may 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

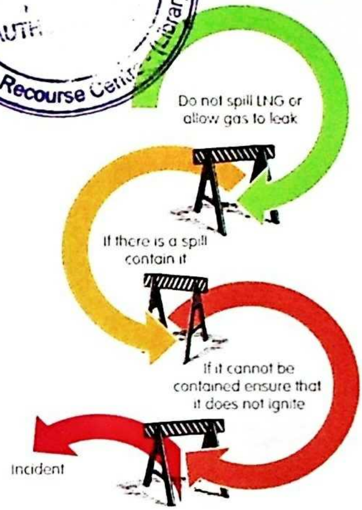
Dense white cloud formed by vaporising a liquefied gas (nitrogen in this case) spreading over water (image courtesy of Mann Teknik)

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 dependent on prevailing weather conditions. If the gas does not ignite, it should safely disperse in the atmosphere.

Fires and fire fighting

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.

Systems should be in place to detect leaks and trigger emergency shutdowns. If an LNG fire does start, however, it should be contained rapidly. It is best to isolate the fuel source and allow the fire to burn itself out. Alternatively, where available, dry powder will extinguish flames, while water is used to cool surrounding structures preventing escalation. Water should not be applied to the fire itself as this will make it bigger as the rate of vaporisation of the LNG increases.



Layers of protection principles

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.

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.

Safety distances and exclusion zones

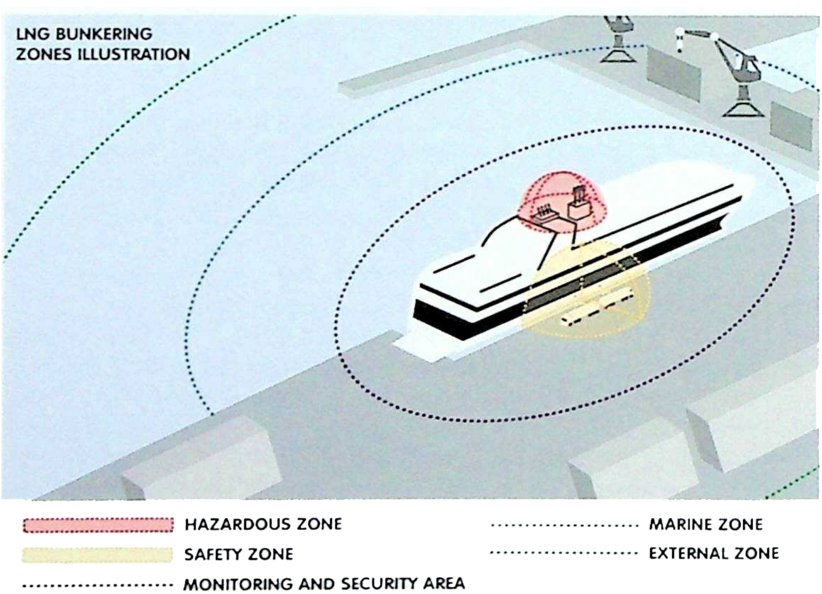
Safety distances are designed to keep ignition sources away from the LNG and any potential leaks, while simultaneously minimising the potential for scenarios such as collisions that could lead to damage.

To calculate the size of safety zones, quantitative risk assessments for a range of scenarios can be carried out using statistical software or computational fluid dynamics (CFD) modelling, or a deterministic approach can be taken, where the regulator provides a required distance.

Safety

SGMF have defined a series of safety zones to protect the bunkering vessel from 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 having a negative impact on the LNG bunkering
- external zone - in some jurisdictions a certain level of risk to the public needs to be considered



Notes

Truck to ship bunkering method shown as the example.

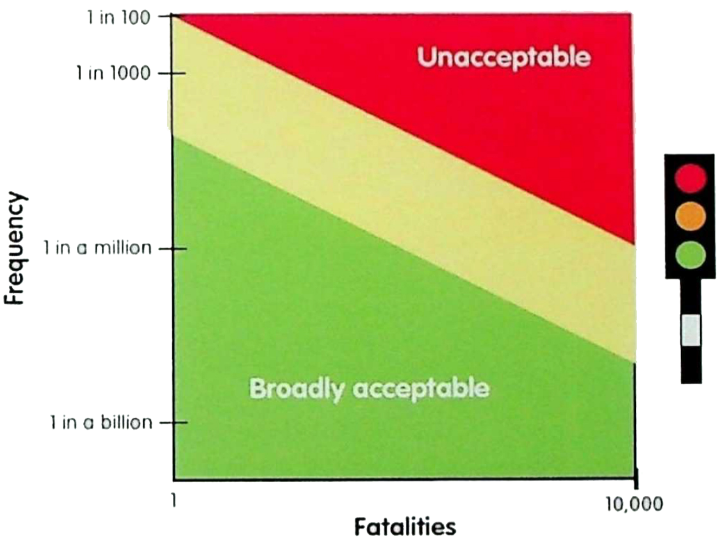
Hazardous zone around the ship/truck manifold(s) and truck relief valve not shown for clarity.

Relative sizes and distances are for illustration purposes only.

Guidance on the configuration and physical dimensions of these zones, based on a deterministic or group of credible release scenarios and local conditions, is available through SGMF's BASiL offering. 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.

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.



Probabilistic risk-based assessment

Safety

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 maloperations 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 (SIMOPs) be allowed?

Whether SIMOPs 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 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. 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.

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 the 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 the same purpose as fuel oils, varies in composition depending on where it is produced (see table on p.44 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.

Contractual

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 supply LNG to 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 on p.46). 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 MGO or (ultra) low sulphur heavy fuel oil, but potentially also the cost of running on HFO with scrubbers installed.

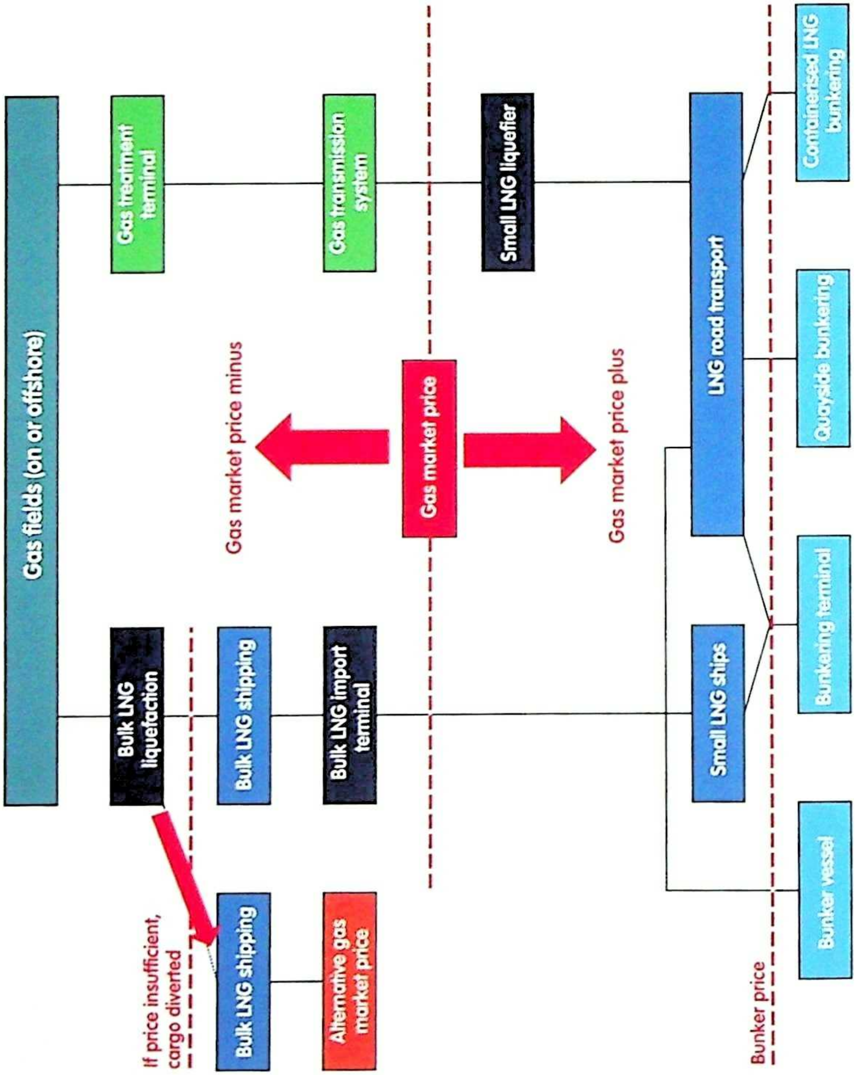
The actual price of the LNG sold will be somewhere between these maximum and minimum values. On the bulk LNG market, prices are normally based on internationally traded oil prices, for example, Brent (UK sector of the North Sea), WTI (West Texas Intermediate in the US) or JCC (Japanese Crude Cocktail 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.

Contractual

Bunker supply options



Impact on engine performance

Engine performance and emissions are affected in different ways by changes in gas composition (see p.49). Impacts are quantified through three variables:

- calorific value
- methane number
- Wobbe Number

The variables are 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 Net Calorific Value basis (no condensation). The difference between gross and net 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 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 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 them 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.

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. The industry is converging on two methods, MWM and Propane Knock Index (PKI), both of which have been fully published.

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, so 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.

Contractual

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+).

Ageing/Weathering

LNG differs from oils in that it is an evaporating liquid. Any heat ingress boils off some of the LNG to create 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 but it takes several weeks for significant changes in composition to occur. This is called 'ageing' 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, e.g. 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, which is the main one used in bunker vessels. The apparently laborious measurement and corrections are computerised and so require only occasional cross-checking and calibration.

The alternative method used in 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. Some bunker vessels have this technology available. Ultrasonic meters are also available and perform equally well.

BOG/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, so 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.

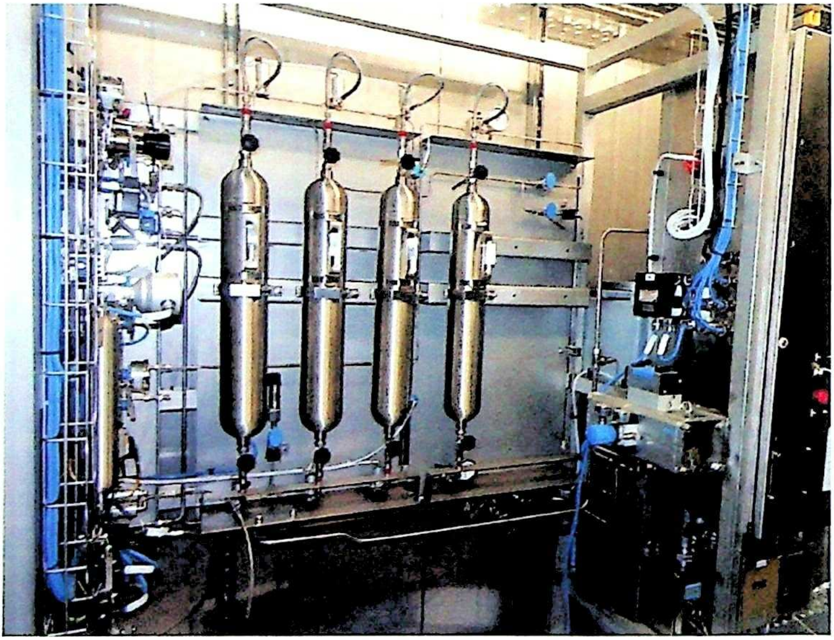
Mass Coriolis Meter in LNG Service

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 practice presents the highest risk of 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 may 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 ship bunkering may be some form of delivery contract to cover the costs incurred by third parties, for example road tanker 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 Notes (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 and Competence

Introduction

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 people 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, while 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 (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 comes under the IMO's Standards of Training, Certification and Watchkeeping (STCW) Convention. A four-level system is used:

- **Familiarisation of the crew** with the ship and equipment. This is expected to be the responsibility of ship owners and managers and is not covered by STCW.
- **Basic training of all crew** on an 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.

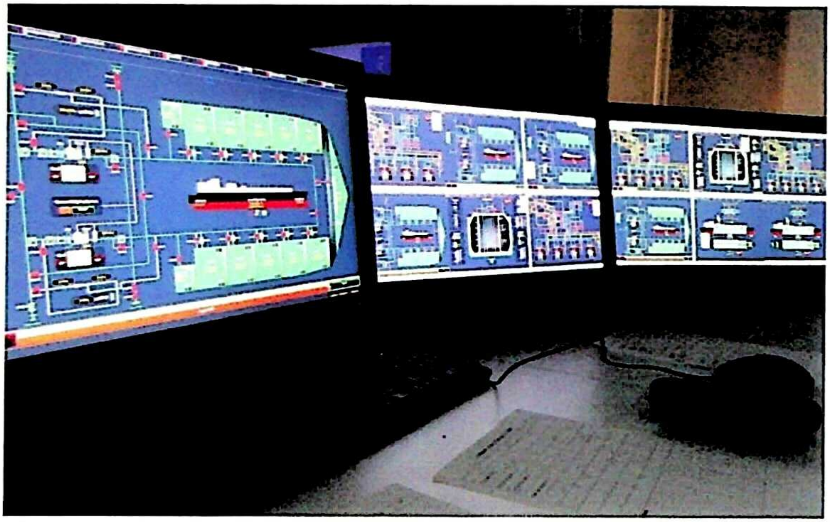
DNV has suggested an alternative approach for the advanced training that would involve separating out different learning requirements for deck and engineering staff, based on their actual roles within the gas/LNG storage, transfer and engine operation.

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 STCW training requirements under the International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (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.

Training and Competence



Maritime simulator training facility (Image courtesy of GTT Training)

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:

- classroom training to understand processes
- tanker-specific training as there are many different types of road tanker
- practical training, e.g. actually filling an LNG road tanker (to demonstrate competence)

SGMF's competence framework

SGMF has published recommended competence and assessment 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. The document is 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).

SGMF has also published recommended competence guidelines for the operation of the fuel gas storage and handling systems on gas-fuelled ships. 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

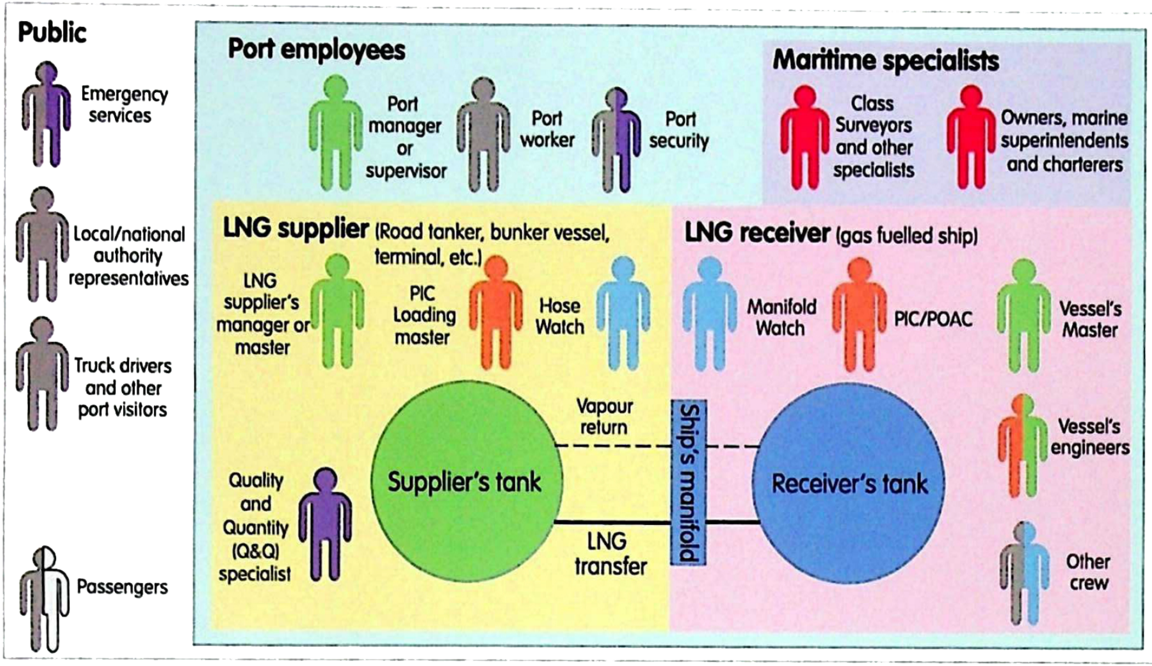
Specialist training may also be required for specialised activities. The modules also allow training plans to be assembled in a multitude of ways to cover bespoke industry needs.

SGMF's guidelines only cover the bunkering/transfer and fuel gas handling system 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; **RESPOND** = grey; **DO** = orange; **BESPOKE** = red; **MANAGE** = green; **SPECIALIST** = purple; No specific training = white

POAC = Person in Overall Advisory Control

Summary

LNG provides a clear pathway to fuels that will enable the maritime transport industry to meet the IMO's target of reducing GHG emissions by at least 50% by 2050, as well as providing a far cleaner energy source than marine fuel oils.

Green hydrogen, methanol and ammonia are several years away from commercial availability and LNG is an important first step, offering clear emission advantages today as well as potential for future GHG emission reductions, either by synthetic methane or bio-LNG, which can be used as drop-in fuels to gradually lower emissions, or to other cryogenic clean fuels.

While not available everywhere, LNG reserves and infrastructure are being developed all the time, presenting an attractive and cost-effective solution for ship owners to the challenge of finding a compliant energy source for shipping.

LNG's cryogenic nature introduces different hazards to handling compared with marine fuel oils. But multiple layers of protection mean that it can be safely used by trained and competent personnel.

SGMF provides guidance to shipowners on the many technical aspects of LNG purchasing, handling, safety and work practices.

Hello.

We are the Society for Gas as a Marine Fuel, helping you make the change to gas simple. There are six principal areas we focus on at SGMF.

we love **the environment**

By changing to gas, the maritime sector can really play its part in combatting climate change by significantly reducing emissions. Natural gas is the last fossil fuel available and without its extensive use it is unlikely the IMO 2050 targets can be met.

we are **technically tuned**

We are technical to our core, with a vast experience and wealth of knowledge that is available throughout the membership of SGMF. Join in to help us find safe, creative and innovative gas solutions for an industry that although slow to change is one that we all rely on.

you are **in safe hands**

Extraction, production, distribution and use of natural gas in all its forms is well understood and is completely safe, provided we really do think, plan, act and do with safety always first in mind.

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**

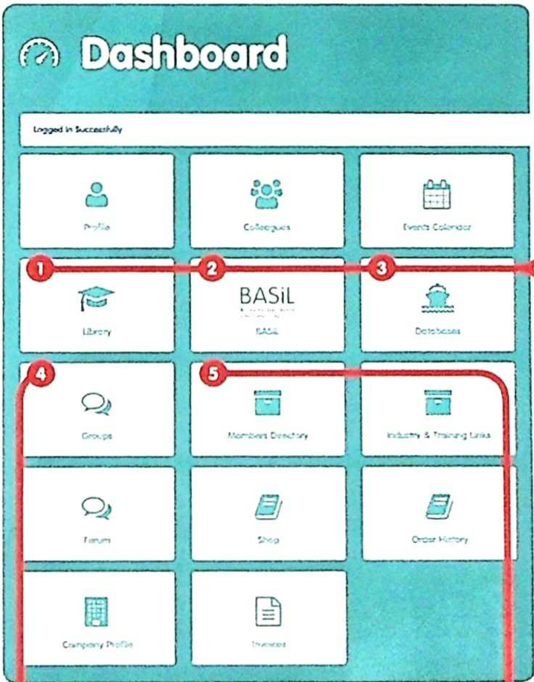
For everyone involved in the gas value chain, from the very source to the manifold itself, staff competence is absolutely vital for the safe transfer and use of gas as a marine fuel.

we **communicate**

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

Member Portal

SGMF Members have exclusive access to a portal with technical content as well as member-only resources. The portal can be accessed and used by any employee of an SGMF member company.



❶ **Library** – you can download formal publications, technical guidance notes and reference documents here. **Member Uploads** – you can upload relevant information (press releases, marketing information, images etc.) into the Member Uploads folder to share with your fellow members.

❷ **BASiL** – automated Bunkering Area Safety Information for LNG model. This can be used to manage bunkering risks through the definition of a safety zone. Available automatically to the Primary Contact, while other users need permission from the Primary Contact to have this enabled.

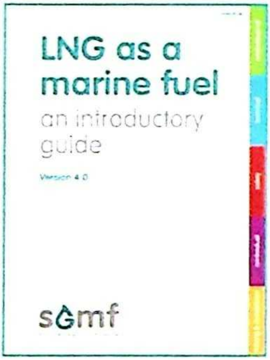
❸ **Databases** – Ships – Projects – Supply – Incidents, on various levels this is where you will find the up to date reference stats for the industry.

❹ **Groups** – you can view a list of the active workgroups and committees. Also, details of groups with open vacancies can be found here and you can apply for a vacancy directly from this section.
If you are involved in a group you can access documents and discussions through this area.

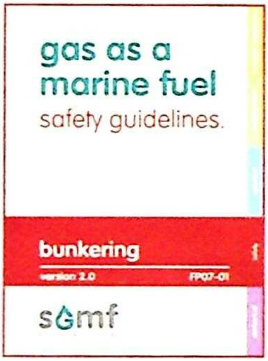
❺ **Members Directory** – go and meet your fellow members and connect! You will find contact details of all registered users that have not opted for a private profile.

www.sgmf.info

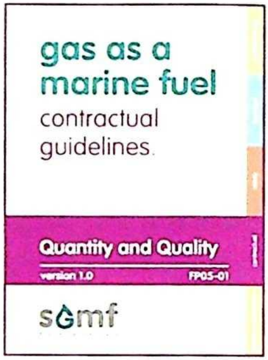
SGMF Publications



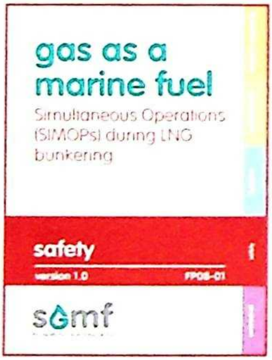
An Introductory guide
ISBN 978-1-9996669-6-5



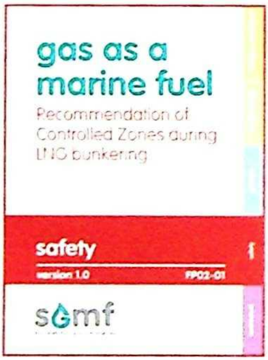
Safety Guidelines – Bunkering
ISBN 978-0-9933164-4-9



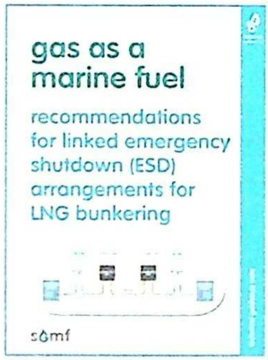
Contractual Guidelines – Quantity and Quality
ISBN 978-0-9933164-1-8



Simultaneous Operations (SIMOPs) during LNG Bunkering
ISBN 978-0-9933164-5-6



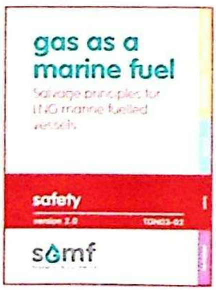
Recommendation of Controlled Zones during LNG bunkering
ISBN 978-0-9933164-8-7



Recommendations for linked emergency shutdown (ESD) arrangements for LNG bunkering
ISBN 978-1-9996669-1-0

SGMF Technical Guidance Notices

(Available to members only via the website)

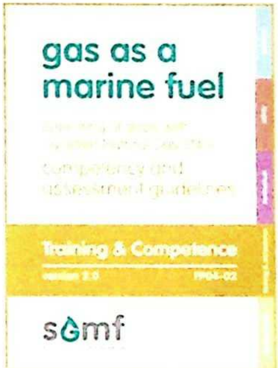


Manifold arrangements for gas-fuelled vessels

ISBN 978-1-9996669-0-3

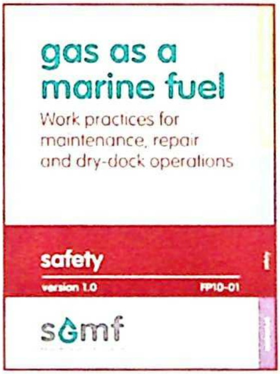
LNG bunkering with hose bunker systems considerations and recommendations

ISBN 978-1-9996669-2-7



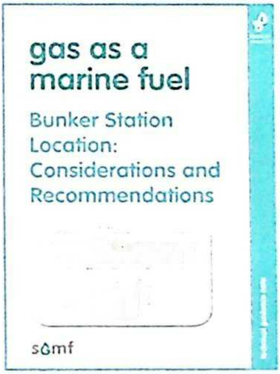
Bunkering of ships with Liquefied Natural Gas (LNG) - competency and assessment guidelines.

ISBN 978-0-9933164-5-6



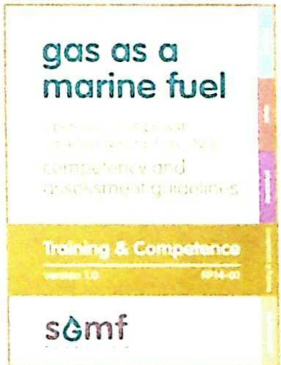
Work practices for maintenance, repair and dry-dock operations

ISBN: 978-1-9996669-3-4



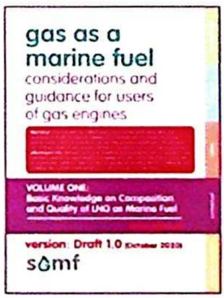
Bunker Station Location Considerations and Recommendations

ISBN 978-1-9996669-4-1



Operation of ships with Liquefied Natural Gas (LNG) - competency and assessment guidelines

ISBN 978-1-9996669-5-8



BASiL

sgmf gas dispersion distance tool

SAFETY DISTANCES MADE EASY

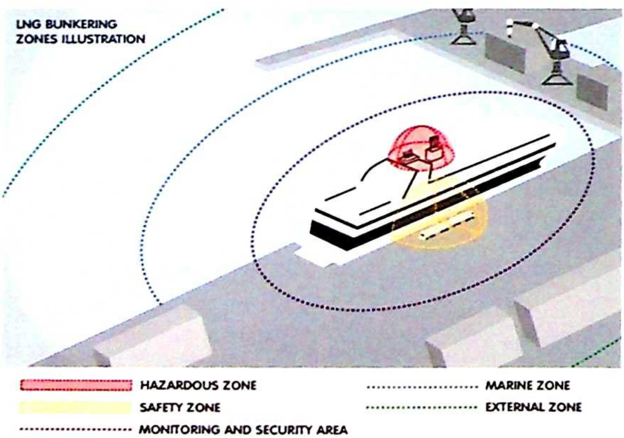
BASiL (Bunkering Area Safety information LNG) is SGMF's automated LNG gas dispersion tool. It can be used to manage bunkering risks on a consistent basis through the definition of a safety zone that depends on the type of bunkering operation being undertaken.

Features:

- Easy to use via the SGMF website.
- Available to everyone.
- Tested and proven, BASiL distances are proved within 5% of physical testing and gas dispersion modelling simulations.

Advantages of BASiL for your project:

- Based on representative scenarios.
- Quick.
- Covers all bunkering scenarios e.g. road tankers and bunker vessels.
- Simulates all bunkering parameters: volume, pressure, temperature, flow rate, locations etc.



- BASiL is robust and can quickly calculate a range of safety distances for different ships over a variety of climatic conditions worldwide, previously unavailable or expensive/bespoke.
- The value of BASiL as an assessment technique is in its fast assessment of three-dimensional zones, repeatability and on a conservative basis.

Access to BASiL: Free access for SGMF members.
Available at a small fee for non-members. For more information visit: www.sgmf.info

About SGMF

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. It has consultative status with the IMO and is the definitive information resource for the industry.

Governed by a representative board, the Society is driven by three principal Committees: Technical, Environmental and Asia Pacific. SGMF has several Working Groups at any one time solving issues and producing outputs such as guidelines, checklists, studies and factual, referenced best practice for the industry. The Society has produced many ISBN publications and has over 140 international members ranging from energy majors, port authorities, fuel suppliers through to equipment manufacturers and classification societies.

Contact us

Telephone: +44 (0) 20 3637 1455
Website: www.sgmf.info
Email: office@sgmf.info
LinkedIn: Society For Gas As A Marine Fuel

we sea change, do you?
sgmf