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LNG as a marine fuel

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The use of liquefied natural gas (LNG) as a marine fuel is expected to rise in the approach to the International Maritime Organisation (IMO) global sulphur cap in 2020.

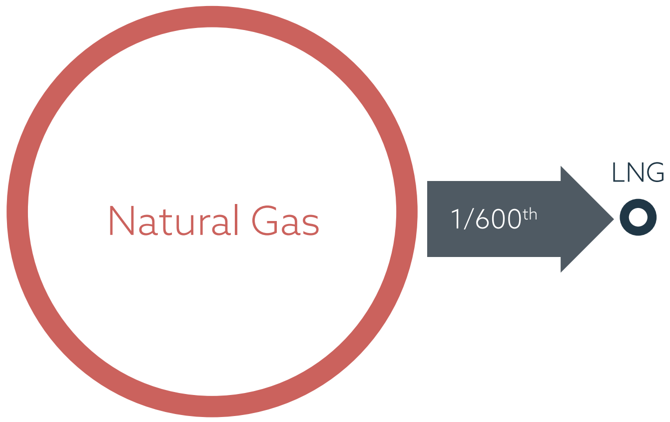
What is LNG Fuel?

LNG is colourless mixture of gases – mostly methane (typically 80-95%) – cooled to condense into a liquid.

LNG fuel is sourced from natural gas which is extracted from sub-surface gas fields. This is piped to liquefaction plants where it is cleaned and cooled to temperatures lower than -162c. In this liquid phase, the volume of the LNG is reduced by a factor of 600 and can be stored and transported at low temperatures.

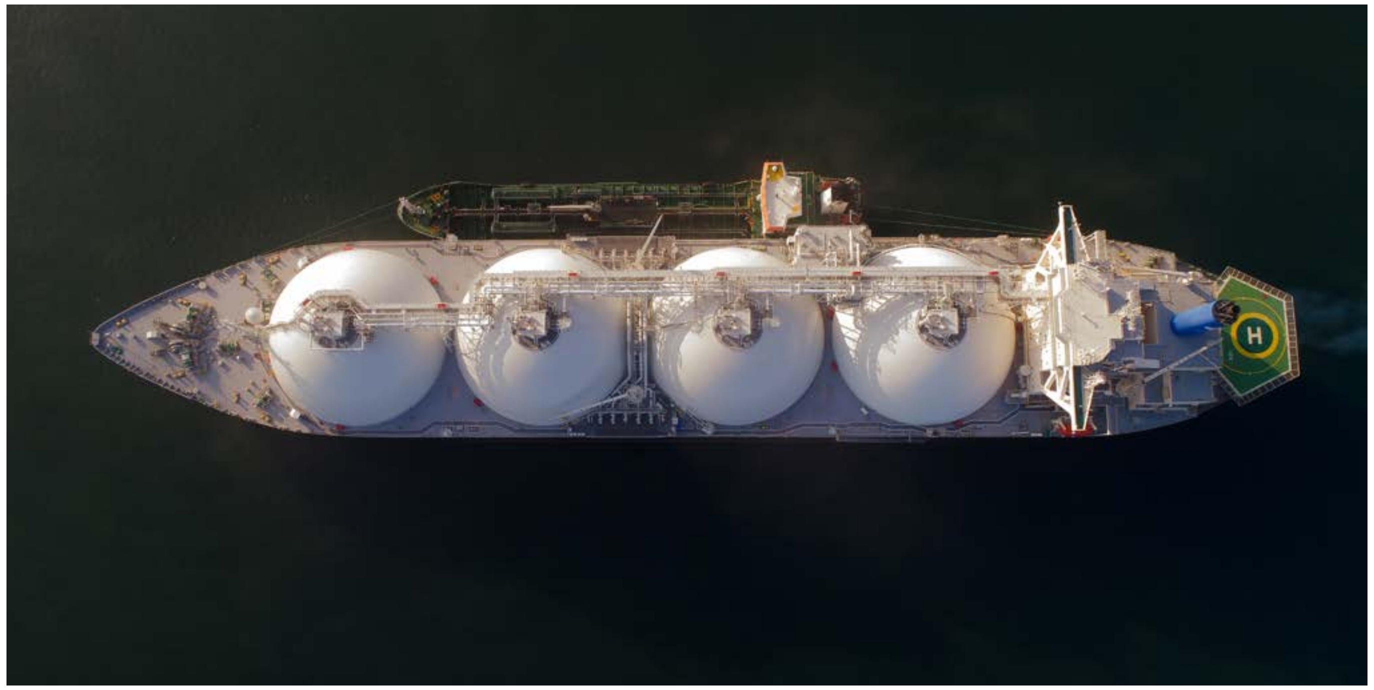
The use of LNG as a common marine fuel is still relatively undeveloped (in 2018). However, its use is likely to increase as a bunkering infrastructure develops and it becomes a recognised and viable alternative to traditional marine fuels, driven mainly by the need to comply with the forthcoming IMO global sulphur cap in 2020.

When natural gas is chilled it becomes a liquid, liquefied natural gas (LNG), that is 600 times smaller in volume



Characteristics

As it stands, there are no standard specifications for LNG as a marine fuel. ISO has appointed a working group – ISO/TC 28/SC 4/WG 17 'Specifications of liquefied natural gas for marine applications' – to investigate whether a standard for marine LNG fuel can be developed.

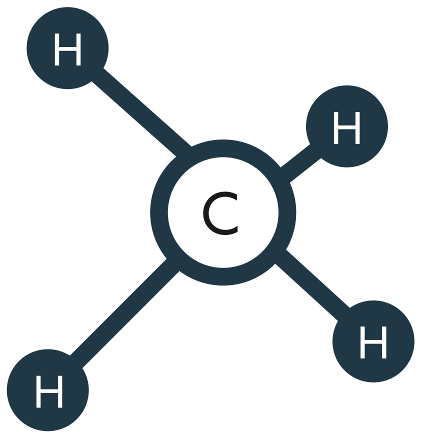


The characteristics of LNG do vary and buyers should receive a specification sheet and confirm its suitability before bunkering, paying particular regard to composition, density and its combustion properties. Countries that import LNG may source from multiple suppliers for the purposes of security of supply and are therefore not dependent on a single supplier. For example, suppliers in Europe source LNG from more than 10 different gas fields. This can result in variations over time in the composition of the LNG in the storage tanks.

Typical LNG quality characteristics that receiving vessels should be aware of are outlined in the following sections.

Methane (CH4)

Methane is the primary constituent of LNG. The quality of LNG can referred to as being 'lean' (methane >95%) or 'rich' (methane <95%). Lean LNG has a relatively low calorific value whereas rich LNG contains a greater proportion of heavier hydrocarbons which gives it a higher calorific value.



Methane number
In addition to the percentage composition of methane, LNG is also referenced by its methane number – an indicator of the ignition quality when vaporised. This is a scale of 0 to 100 based on the combustion characteristics of methane (100) and hydrogen (0).

The methane number is determined by the composition of the LNG and has direct relevance to its performance with Otto cycle gas engines, with particular regard to engine 'knock'. If the methane number of a fuel is too low, the engine performance can be adversely affected and can lead to damage.

Other hydrocarbons
Although LNG mostly consists of methane, other hydrocarbons are usually present in much smaller proportions. The amount and type of these hydrocarbon compounds depend on the source of the LNG and the requirements of the market it is destined for.

The main influence of these other hydrocarbons is on the calorific value of the LNG. Hydrocarbons with a greater number of carbon atoms provide more heat energy when compared with methane.

Typically found hydrocarbons include:

- Ethane (C_2H_6)
- Propane (C_3H_8)
- Butane (C_4H_{10})
- Pentane (C_5H_{12})
- Hexane (C_6H_{14})
- Heptane (C_7H_{16})

Calorific value

The calorific value is the amount of energy produced by the complete combustion of the fuel. It can be provided in either imperial units (BTU/scf) or metric units (MJ/m^3). It is therefore an important characteristic of LNG, so much that calorific value is used as the basis of buying and selling when in bulk.

Calorific value is given by either:

- **Higher heating value (HHV)** – also known as the gross calorific value
- **Lower heating value (LHV)** – also known as the nett calorific value.

The HHV and LHV are calculated differently. They both measure the heat recovered when a metered amount of gas is burnt and the combustion products cooled, but the HHV includes measuring latent heat whereas LHV does not.

Wobbe Index

The Wobbe index (or Wobbe number) is often referenced in LNG specifications and contracts. It is a function of the calorific value and the density of the LNG. This calculation provides a measure of the amount of calorific heat flowing through a burner nozzle of a specific size in a given time.

The index is used as an indicator of whether a burner will be able to run on an alternative fuel source without modification. If the Wobbe index is the same for two fuels, despite their different compositions, a burner will deliver the same amount of heat energy.

Density

Whilst density is a key piece of information, density alone has limited value as a characteristic of LNG, but it is required to calculate the Wobbe Index and the mass of fuel.

Trace components

Compounds that are damaging, toxic or corrosive should be restricted to trace levels.

Nitrogen (N_2)
Nitrogen contains no combustion energy and at high levels can cause storage and quality issues. Nitrogen boils at –196°C when at atmospheric pressure, so it is the most volatile component in LNG. This can lead to rapid mixing and vaporisation. As such, the nitrogen content in LNG should be limited to 1%.

Sulphur (S) and sulphur compounds
Typical sulphur levels in LNG are less than 0.004% of sulphur by mass. Sulphur compounds, which include hydrogen sulphide (H_2S), are removed during the production process to trace levels.

Water
LNG is stored at very low temperatures. Therefore any excess water has the potential to solidify and block pipework and equipment as the temperature is reduced to –162°C. A typical limit on water content for LNG fuel is 0.01 ppm.

Carbon dioxide (CO_2)
Like water, carbon dioxide has the potential to solidify and block pipework and equipment at the low temperatures required for LNG storage. A typical limit is 50 ppm.

Mercury (Hg)
Excessive levels of mercury in LNG will damage aluminium components in the system. It is typically limited to 10 ng/Nm^3.

BTEX
BTEX is an abbreviation used for four compounds found petroleum products. These are benzene, toluene, ethylbenzene and xylenes. They are considered pollutants and if released into the atmosphere can cause severe damage to human health. The total BTEX content in LNG fuel is typically limited to 10 ppm.

Purchase and Supply

Currently (in 2018), there are no internationally recognised purchase contracts or standard specifications for LNG as a marine fuel.

Therefore delivery contracts and charterparty clauses on LNG bunker quality cannot rely on referencing a recognised quality standard.

LNG bunker delivery contracts

Early adopters are entering into long-term delivery contacts with preferred partners. This is in contrast to the usual practice associated with conventional marine fuels, where there is no long-term relationship with a supplier or delivery provider. LNG fuelled vessels operating on short-sea or domestic routes will have LNG delivered at the same place by the same company. Vessels operating internationally or on a liner service may be engaged in a long-term supply contract with the LNG producer as well as the third party providing the delivery services.

Shipowners entering into long-term contracts should ensure there is a clear allocation of responsibilities. It may be prudent to consult the P&I club to ensure the terms are not too onerous on the shipowner, which may in turn impact P&I cover.

Shipowners can determine their requirements on the quality of LNG by consulting with the engine manufacturers, such as a minimum methane number (MN), lower heating value (LHV), the maximum amount of hydrocarbons other than methane, and limits on trace components. But as the composition of LNG varies quite significantly around the world, the scope of parameters on composition cannot be too narrow. These requirements can then form the basis of a fuel quality clause in a charterparty.

In addition to quality criteria, LNG bunker contracts will need to address quantity and how it is measured. Bulk LNG is sold on an energy basis, typically in British thermal units (Btu) or MJ/Nm^3, unlike LNG for road transport fuel which is sold either by mass or volume.

BIMCO's future work programme currently (2018) includes giving consideration to creating an LNG Bunker Purchase Contract.

Charterparties

The terms of a time charterparty may put an obligation on the charterer to provide suitable bunkers to the vessel.

The shipowner must be very clear on the LNG fuel requirements of the vessel, mirroring those for bunker delivery contracts. Both parties must also be aware of the limited infrastructure and availability of LNG as a marine fuel when determining trading areas.

In addition to the charterer's obligation to supply the vessel with the right fuel, there is a risk that LNG bunkering operations could affect cargo operations. Port authorities allowing LNG bunkering will only allow simultaneous operations (SIMOPS) to be conducted subject to a risk assessment.

Furthermore, some ports may only allow LNG bunkering to be carried out at certain berths or the delivery methods may be limited to trucks, which is much slower than a transfer from a bunker vessel. Any such restrictions could impact cargo operations and lead to delays. These factors should be considered when fixing both time and voyage charterparties.

The shipowner must be very clear on the LNG fuel requirements of the vessel, mirroring those for bunker delivery contracts.

Vessel performance

The composition of LNG fuel has a direct influence on the performance of the engine(s) consuming it. In turn, this affects the speed and consumption of the vessel on a voyage.

LNG with high methane content might have a lower calorific value than LNG with lower methane content. This means that more fuel must be consumed to achieve comparable power output. This potential for variations in performance must be taken into consideration when agreeing any vessel performance warranties in the charterparty.

The influence of calorific value must also be considered when planning a voyage. As is usual when passage planning, the expected fuel consumption must be determined and the master satisfied that sufficient reserves are on board. If the planning does not account for the higher consumption rates experienced by a fuel with a lower calorific value, and an incident results because of this, then the shipowner is open to allegations of failing to exercise due diligence to ensure seaworthiness at the commencement of the voyage.

Calorific value also has a direct relevance on contracts of carriage (bill of lading) where, under the Hague and Hague-Visby Rules, there is an explicit obligation on the carrier regarding seaworthiness. Furthermore, in the event of an incident that leads to the shipowner declaring general average, cargo interests may refuse contributions if they successfully prove this particular failure to exercise due diligence.

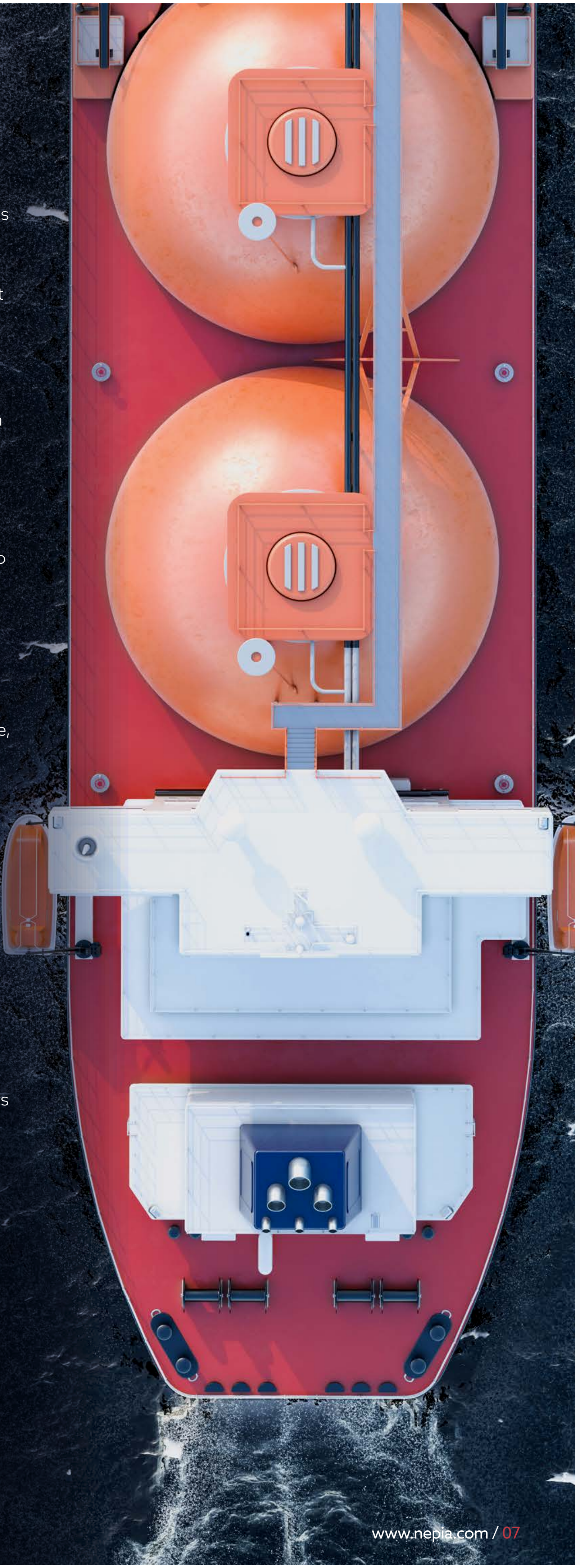
Determining the actual composition of the fuel in use is of course made much more challenging when the tank contains a mixture of previous bunkers with different characteristics.

Terminal's conditions of use

Vessels wishing to undertake LNG bunkering operations within a port, terminal or when engaging with a bunker provider may find themselves having to agree conditions of use.

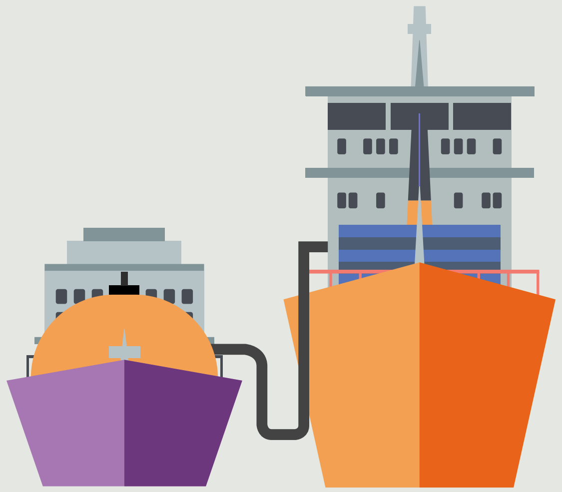
The conditions of use enforced by some terminals and providers are particularly onerous on the vessel, sometime imposing strict liability. This means the vessel is liable for costs and expenses incurred from an incident regardless of fault.

A shipowner presented with such conditions of use should consult its P&I club for further guidance to ensure cover remains unaffected.



Bunkering

Industry groups such as the Society for Gas as a Marine Fuel (SGMF) and the International Association of Ports and Harbors (IAPH) have published excellent guidance on LNG bunkering. Their guidance includes comprehensive LNG bunker checklists, with the IAPH issuing advice and checklists specific to each type of bunkering operation ('truck-to-ship', 'shore-to-ship' and 'ship-to-ship').



An international standard exists on LNG bunkering arrangements for vessels not covered by the IGC Code. ISO 20519:2017 Ships and marine technology -- Specification for bunkering of liquefied natural gas fuelled vessels provides standards on hardware, procedures, record-keeping and training.

However, some vessels have adopted a different approach to refuelling, particularly when short calls in port do not allow sufficient time to transfer LNG into its storage tanks. These vessels load and stow on deck ISO tank containers containing LNG and transfer the contents to the storage tanks while on passage. The spent tank containers are then discharged at a later port.

Safe bunkering

LNG presents very different risks to that of traditional marine fuels. It is cryogenic in nature, therefore the risks associated with extreme cold temperatures and heat transfer must be assessed and managed to ensure the integrity and safety of the vessel and its tanks.

The behaviour and flammability characteristics of LNG are also very different. Add the potential dangers introduced by 'rollover' – where different density layers change position – then it is clear that LNG transfers must be planned carefully and carried out by trained and competent people.

Cryogenic hazards

The low temperatures associated with LNG will cause standard steel to become brittle and at risk of fracture. Materials with superior cold temperature properties – such as 'cryogenic steel' – are therefore used where there is direct contact with LNG or where a spill could occur.

The transfer and storage temperature of LNG at –162°C is clearly hazardous to human health. If the skin comes into contact with LNG, the high rate of vaporisation will cause severe cold burns and frostbite.

Risk of fire and explosion

LNG burns when it vaporises into its gas phase, consisting mostly of methane vapour. The flammability range for methane is generally between 5 and 15% by volume in a mixture with air.

When gas clouds escape, ignition can occur at the edge of the cloud if an ignition source is present. Importantly, the minimum ignition energy for methane is almost 100 times lower than that of a marine distillate fuels such as MGO. This means only a tiny spark is needed to ignite methane – so small that the spark is not visible to the naked eye in daylight.

In very general terms, a methane gas fire can be considered to be one of the following: a flash fire, an explosion, a jet fire or a boiling liquid expanding vapour explosion (BLEVE).

A flash fire is when the gas cloud burns relatively slowly in an open area without generating any significant over-pressure. If a flammable mixture of methane and air ignites in a confined area, the initial combustion may lead to a much more severe over-pressure explosion. Jet fires result from pressurised releases, such as leaks from type C cylindrical tanks, and can be extremely destructive.

BLEVE is associated mostly with storage of LNG in pressurised containers such as type C tanks. It occurs when an external heat source is present – such as a fire surrounding a storage tank – and the tank contents expand. When the pressure is too great, the tank ruptures and the LNG vaporises at a very high rate and leads to a violent explosion.

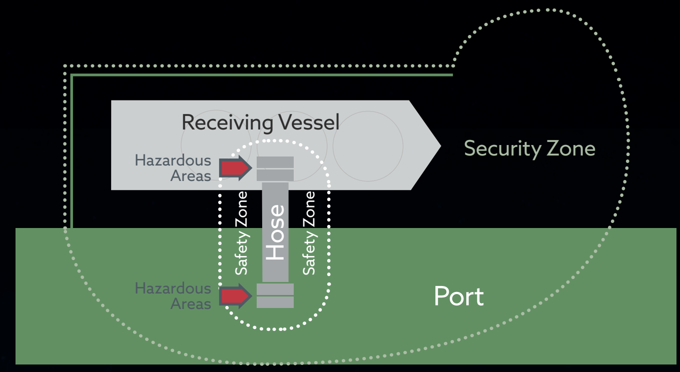
Although methane has a low flashpoint, its auto-ignition temperature is significantly higher than that of conventional marine fuel oils. This means that methane is not readily ignited when it comes into contact with hot surfaces, such as exposed exhaust pipes and manifolds. This is in contrast to marine fuel oils, which can ignite at such temperatures and result in severe and devastating engine room fires.

Safety and security zones

Prior to bunkering, a safety zone and a security zone should be established. These zones are usually determined and enforced by the port authority.

A safety zone is a designated area surrounding the receiving vessel's bunker station and the supplying vessel or installation. This is a restricted area where activities are limited, sources of ignition are eliminated and only trained persons can enter.

A security zone encompasses a larger area, and prevents other vessels or persons from coming into close proximity of the receiving vessel and the delivery vessel or installation during bunkering.



Typical arrangement of safety and security zones

The positions and magnitudes of both the safety and security zones are subject to a risk assessment and depend on the nature of the bunkering operation (truck-to-ship, ship-to-ship or shore-to-ship) and the location. Factors to consider when assessing the risk include the following.

- What external activities could affect safety, such as vessel movements and other traffic, and their proximity to the bunkering operation?
- Details of any simultaneous operations, either on board or ashore.
- If bunkering from another vessel, it should be positioned so its vent mast is not near any openings on the receiving vessel.
- Formation, size and the direction of travel of a gas cloud in the event of a credible leak.
- Details of the activities and necessary personnel required within the safety and security zones.
- Emergency response plans.
- Access to the vessel by emergency services.
- Port regulations.

Bunkering (cont.)

Compatibility assessment

Prior to bunkering, an assessment must be made to ensure compatibility between the supplying vessel or installation and the receiving vessel.

This verifies that each party's systems and equipment are compatible as well as their processes and procedures. Areas that are not compatible and present a potentially unsafe condition are identified and addressed as appropriate.

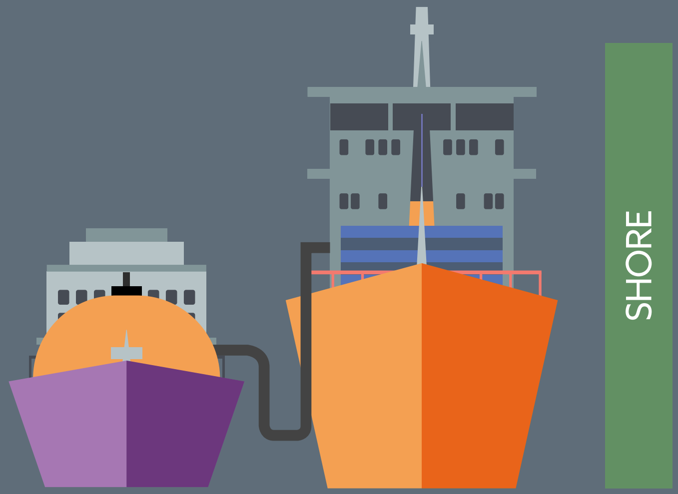
The International Society of Classification Societies (IACS) provides a minimum scope of items that should be checked for compatibility in its Recommendation No. 142 (www.iacs.org.uk/download/1962). Such items include communication systems, connections, emergency shutdown arrangements and mooring equipment.

Emergency response

The receiving vessel, supplying facility and the port or terminal will have an emergency response plan (ERP) for certain scenarios when bunkering LNG fuel. The ISM Code requires the receiving vessel to have an effective emergency response as part of its SMS.

The plans can be based on recognised industry guidance as well as the resulting control measures that are identified following risk assessments and compatibility assessments. Examples of situations to be covered by the ERP include:

- actual release of vapour from identified leakage points – taking into account how much gas could be lost and at what rate, based on what is reasonably foreseeable
- activation of a vapour leakage detection alarm
- actual report of fire in the safety zone
- actual report of fire in the security zone
- blackout – a loss of electrical power on receiving vessel or the supplying facility
- excessive movement between receiving vessel and supplying facility
- uncontrolled venting of vapour by the receiving vessel or the supplying facility



SIMOPS

Port authorities will only allow simultaneous operations (SIMOPS) to take place during bunkering if the risk has been suitably assessed and found to be acceptable.

The risk therefore depends on the nature of the operation. This may involve cargo loading or unloading operations, movement of dangerous goods, stores, passenger embarkation and disembarkation, and the bunkering of other fuels.

It also depends on the nature and size of any reasonably foreseeable releases of gas as well as the predicted direction of movement which may take it close to ignition sources. For example, when bunkering a container vessel, any vapour leakage could disperse towards the electrical components of a gantry crane.

Emergency shutdowns (ESD)

A link between the supply and the receiving vessel must be in place that shuts down the transfer in the event or threat of an emergency.

A typical emergency shutdown (ESD) will stop any transfer pumps upon activation. An ESD system might have a staged process in which the first alert – say, a tank high-level alarm – shuts down the transfer in a controlled manner. For example, it would stop the pump but leave the manifold valves on the supply and receiving vessel open to prevent any over-pressurisation in the hose. A second alert – for example when detecting a vapour release – may shut the manifold valves as well as the pump and could trigger an emergency de-coupling.

The transfer hose should be connected with a breakaway coupling (BRC). This is usually fitted at the receiving vessel's manifold. Upon activation of the emergency release system (ERS), either manually or automatically, a rapid disconnection of the coupling will occur. The BRC incorporates a self-closing valve at each end, resulting in minimal amounts of vapour escaping. Persons involved in the bunkering operation should be aware of the risk of backlash if the ERS is activated and avoid being in the vicinity of the hose during transfer.

It is therefore important to check that the ESD and ERS activation methods (sometimes referred to as emergency shutdown links) on the supplying vessel or installation and the receiving vessel are compatible and tested. Typical links use pneumatic, electric (SIGTTO 5 pin connector) and fibre-optic signals.

Bunkering checklists

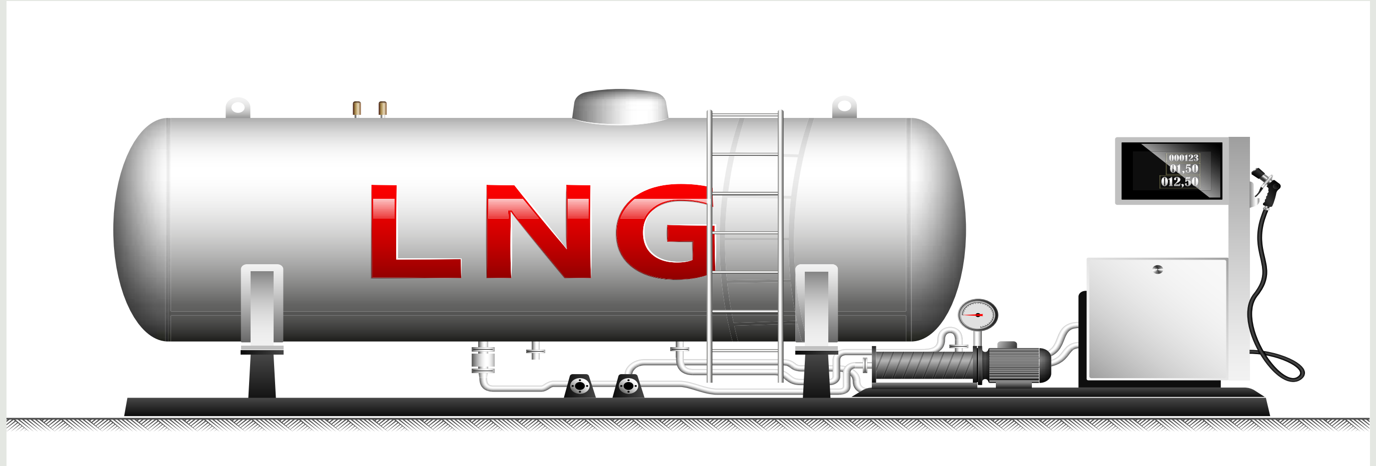
Harmonised checklists specific to the type of bunkering operation have been developed and issued by the International Association of Ports and Harbors (IAPH). These checklists, with accompanying guidance have been adopted by a number of ports around the world.

The IAPH checklists comprehensively cover three scenarios (truck-to-ship, ship-to-ship and shore-to-ship) and each encompasses planning, pre-transfer actions, simultaneous operations and completing the transfer. Each stage must be checked and signed by representatives of the receiving vessel, the bunker delivery company and the terminal.

Bunker delivery note

IMO and the European Sustainable Shipping Forum (ESSF) have defined a standard LNG BDN which can be used to document the LNG composition. This standard format BDN has been incorporated within the IGF Code.

Quantity Measurement



The means to measure the quantity of bunkered LNG are similar in principle to that of traditional marine fuel oils. Essentially this is quantity determination by:

- measuring the flow rate during transfer (mass or volume)
- measuring tank contents before and after transfer and then calculating the difference.

Measuring flow

The flow rate can be measured in terms of mass or volume:

Mass flow measurement
Typical mass flow measurement devices work on the Coriolis principle. This method is particularly attractive to LNG measurement as there are no moving parts that would otherwise be adversely affected by the cryogenic temperatures involved.

Volumetric flow measurement
Ultrasonic flowmeter units directly measure the velocity of the fluid passing the transfer pipeline. The measured velocity can be simply converted to volumetric flow rate by multiplying it with the cross-sectional area of the pipe.

The accuracy of flow measurement devices can be adversely affected if both phases are present, e.g. there is both liquid and vapour in the line.

Measuring tank contents

Similarly, the contents of a storage tank can be measured in terms of mass or volume. However, this can be difficult to measure accurately if LNG is being consumed from the nominated storage tank at the same time as bunkering. This also applies to a supplying vessel as that may be using the LNG intended for transfer as fuel for its own engines.

Mass measurement
When receiving bunkers from a road tanker, the total mass (weight) can be measured by means of a vehicle weighbridge before and after transfer. The difference will be the total mass transferred. Alternatively, storage tanks may be installed with load cells that directly measure its weight.

Volume measurement
The level of LNG in a storage tank is measured before and after transfer. The difference simply equates to the amount transferred.

Similar to the process for bunkering conventional fuel oils, the level measurements are corrected for ship list and trim before conversion to volume. However, there may also be a need to apply a correction factor for temperature to calculate the volume accurately. This is because the storage tank can physically contract when at the cryogenic temperatures needed for LNG.

Measuring vapour returns
LNG storage tanks are designated by type, namely membrane tanks or independent tanks termed type A, type B and type C.

Membrane tanks and types A and B tanks are designed to only withstand relatively low pressures. Therefore any vapour generated – known as boil-off gas – must be managed. When bunkering, this may mean that the vapour must be returned to the supplying vessel or installation where it is subsequently re-liquefied.

Receiving vessels fitted with cylindrical type C tanks will usually not need to return any vapour back to the supplier as they are constructed to withstand the pressures generated by the boil-off gas. This vapour remains in the storage tank and is compressed or liquefied by the incoming LNG.

Boil-off gas has a financial value and, if it is being returned to the supplier, it may need to be measured and quantified. This can be achieved by installing flowmeters in the receiving vessel's vapour return line or by measuring the volume of boil-off gas displaced during filling.

Fuel Sampling and Testing

There are currently no quality determination tests that can be carried out by a ship's crew on bunkered LNG fuel.

Due to the complexities involved in taking samples any samples taken are generally taken and held by the supplier. Detailed laboratory analysis of the composition of the samples will provide important measurements of density, calorific value and Wobbe index. This information should be provided prior to bunkering via a certificate of quality

On-board Storage & Treatment

The storage and management of LNG fuel on board a vessel is covered by the IMO International Code of Safety for Ships using Gases or other Low-flashpoint Fuels – known as the IGF Code. This has led to related amendments of other IMO conventions, namely SOLAS and STCW.

The IGF Code contains mandatory provisions for the arrangement, installation, control and monitoring of machinery, equipment and systems using low-flashpoint fuels, focusing initially on LNG.

Storage tank types

The types and sizes of on-board storage tanks will depend on the needs of the vessel and a detailed analysis of tank design is beyond the scope of this briefing. However, some of the unique aspects to be aware of regarding the on-board storage and handling of LNG bunkers are discussed in this section.

LNG tanks can be classed as follows.

- Non-pressurised – this includes membrane tanks and types A and B independent tanks that can withstand only low pressures, a typical maximum being around 0.7 bar.
- Pressurised – namely type C independent tanks and are typically designed to handle working pressures up to 10 bar.

The choice of tank type will be determined by the needs of the shipowner as well as the trade and size of the vessel. The tank choice may also determine if any arrangements to capture boil-off gas need to be installed.

Boil-off gas

As LNG warms, vapour will be generated – known as 'boil-off gas' – and this can result in a pressure increase within the storage tank.

Type C tanks are designed to withstand this pressure and as such, there is usually no need for the boil-off to be managed. But non-pressurised tanks may only be able to contain boil-off gas for several days, depending on the rate of heat ingress.

When the engines are running and consuming fuel, the generation of boil-off gas can usually be managed.

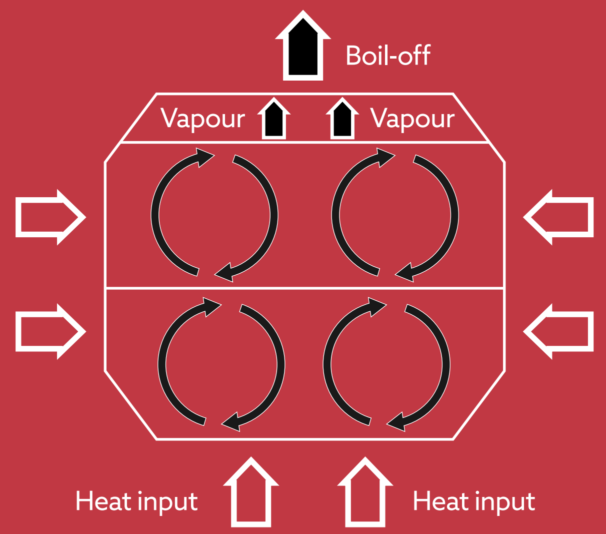
On-board Storage & Treatment (cont.)

However, if the vessel remains idle for periods of time and the engines are not running, different means of dealing with the potential pressure increase are required.

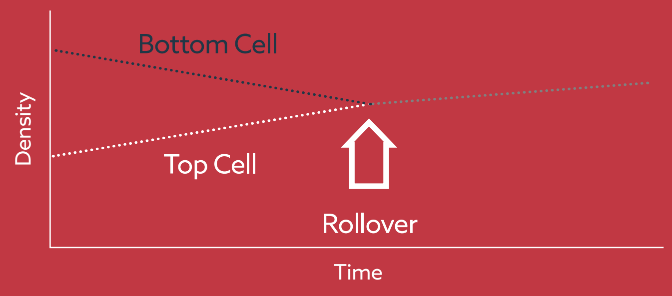
The most common means of handling boil-off, other than consumption by the ship's engines, is to re-liquefy the vapour and return it to the storage tank. Re-liquefaction plants are not expected to be widely used on board LNG fuelled vessels due to their high energy consumption and space requirements. As things stand, these plants are more likely to be found on the bunkering vessel. Therefore the expected boil-off rate should be a factor to consider when deciding on tank type during vessel build or modification.

During bunkering of LNG, there may be an option to return any generated boil-off gas back to the supplier's vessel or installation through a vapour return line.

Rollover



If LNG products with different densities are stored within the same tank, which is most likely to occur when bunkering, the LNG with the higher density will settle below the LNG with the lower density. This is known as stratification.



If there is limited movement or minimal sloshing of the storage tank, the temperature of the lower layer will rise. But the hydrostatic pressure of the LNG on top will prevent the lower layer from boiling off. The density of the lower layer will decrease and approach that of the upper layer.

As the densities of the two layers approach equilibrium, the potential for what is known as 'rollover' increases. Rollover is where the layers change position – effectively rolling over and hence the term. It can lead to rapid boil-off and generate large amounts of vapour which, in extreme cases, is relieved through the pressure relief valves.

Rollover can be avoided by the following.

- Preventing stratification by:
- top or bottom filling according LNG densities – top fill if the incoming LNG is heavier than the stored LNG and bottom fill for vice versa
- recirculation / mixing of the contents
- Avoid storing different compositions of LNG in the same tank
- Monitor LNG density and temperature over height of tank
- Monitor boil-off and heat balance to detect superheating
- Manage consumption to ensure old LNG is not stored for excessively long periods

Aging

LNG is volatile so it is usual for some of the fuel to vaporise into its gas phase. Over time this may result in a change to its composition which, in turn, could impact its quality. This phenomenon is known as aging or weathering.

The characteristics of LNG will change when left unused. As the temperature of the LNG increases, the lighter components will turn to vapour and leave behind the heavier liquid. This results in changes to the density, calorific value and consequently, the Wobbe Index of the LNG.

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