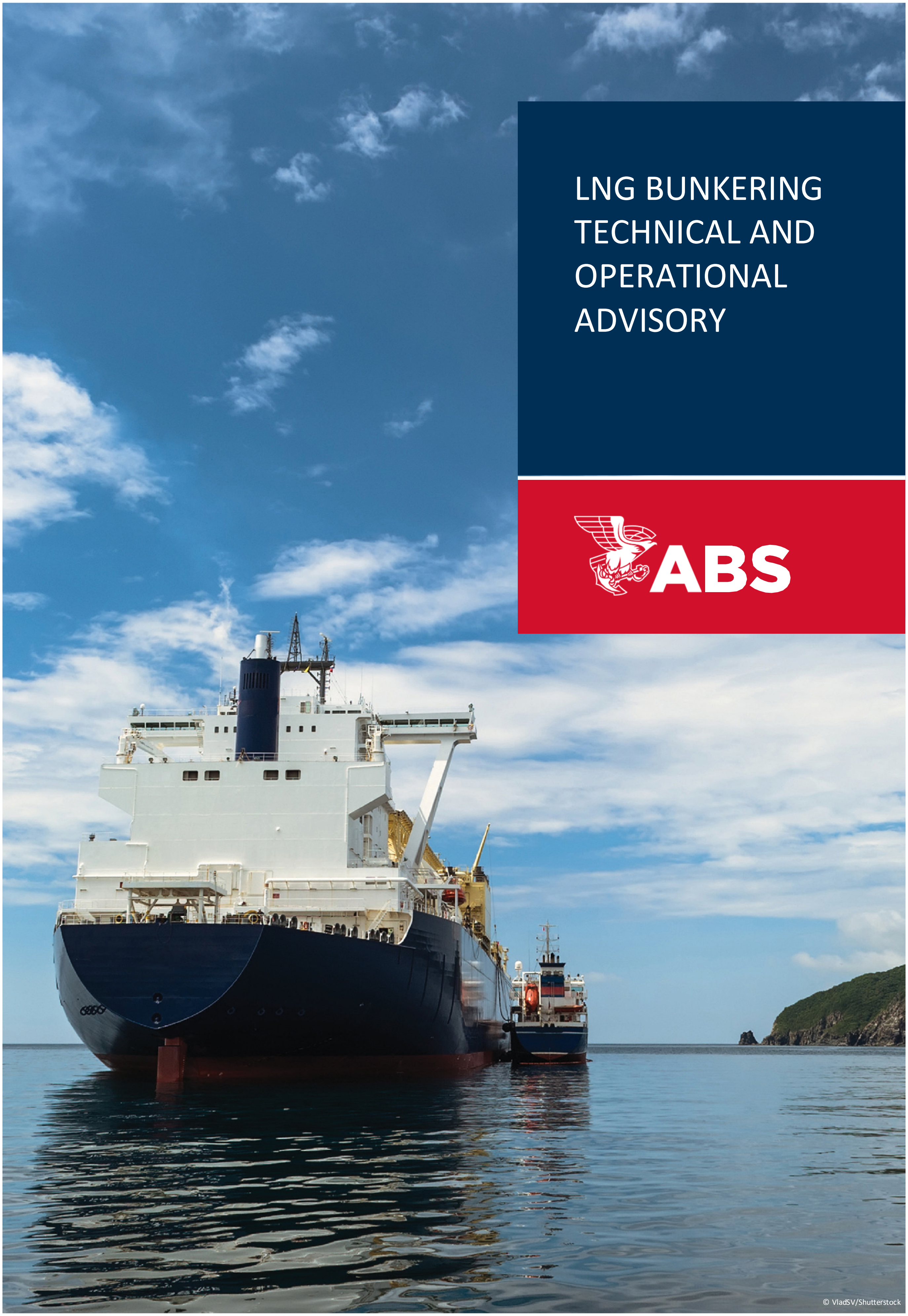
LNG BUNKERING TECHNICAL AND OPERATIONAL ADVISORY



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OUR MISSION

The mission of ABS is to serve the public interest as well as the needs of our members and clients by promoting the security of life and property and preserving the natural environment.

HEALTH, SAFETY, QUALITY & ENVIRONMENTAL POLICY

We will respond to the needs of our members and clients and the public by delivering quality service in support of our Mission that provides for the safety of life and property and the preservation of the marine environment.

We are committed to continually improving the effectiveness of our HSQE performance and management system with the goal of preventing injury, ill health and pollution.

We will comply with all applicable legal requirements as well as any additional requirements ABS subscribes to which relate to HSQE aspects, objectives and targets.

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1 INTRODUCTION

Owners, operators, designers and shipyards around the world are considering the advantages that operating on natural gas may provide. However, when considering any new or evolving technology, it is important to have a clear understanding of not only the benefits, but the challenges that may be involved. This Advisory has been developed in order to respond to the need for better understanding by members of the maritime industry of the issues involved with bunkering vessels with natural gas. It is intended to provide guidance on the technical and operational challenges of LNG bunkering operations both from the bunker vessel's perspective (or land-side source) and from the receiving vessel's perspective. Some of the key areas that are addressed in this Advisory are critical design issues, methods of analysis, and current thinking on possible solutions to the requirements of regulations and safe practice, as well as important areas of operational process, training and safeguards.

The regulatory framework is referenced, but this Advisory is not rule or region-specific. For further information and insight into the regulatory framework associated with LNG bunkering in North America, refer to the ABS report, Bunkering of Liquefied Natural Gas-fueled Marine Vessels in North America. This Advisory does, however, provide guidance on the ramifications of the various requirements on vessel design and operational issues, and how they impact the LNG bunkering process. This information can be useful to any owner, operator, designer or shipyard considering LNG fuel so that an informed decision can be made.

The following sections are included in the Advisory:

- Introduction
- General Information on LNG
- General Considerations for LNG Bunkering
- Key Characteristics of LNG and Tank Capacity for Bunkering
- Vessel Compatibility
- Operational Issues Aboard the Receiving Ship
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- LNG Storage Tanks and Systems for Monitoring and Control of Stored LNG
- Operational and Equipment Issues from the Supplier Side
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2 GENERAL INFORMATION ON LNG

Natural gas is one of the cleanest burning fuels available today with negligible sulfur or ash content. When burned in an engine or boiler, it can produce low levels of NOx (depending on engine type) and less CO_2 than petroleum based fuels.

Natural gas is a colorless mixture of several gases, but is principally composed of methane (CH_4) with a typical concentration of 70 to 99 percent by mass, depending on the origin of the gas. Other constituents commonly found in natural gas are ethane (C_2H_6), propane (C_3H_8), and butane (C_4H_{10}). Small amounts of other gases, such as nitrogen (N_2), may be present. When lowered to a temperature of about -162°C at atmospheric pressure, methane vapor becomes a liquid (LNG). At -162°C, the volume is reduced to about 1/600th of the volume needed for methane vapor. As a result, methane is typically transported as a cryogenic liquid. The density of LNG is less than half of water, which means LNG will float. Further, the methane vapor from LNG will at first be heavier than air. As such, a vapor release from a LNG tank will hover close to the water surface, ground or deck. When the vapor warms to above about -100°C, it will be lighter than air and begin to further dissipate.

LNG has roughly half of the density of traditional heavy fuel oil, but its calorific value is roughly 20 percent higher on a mass basis. Considering both its lower density and higher heating value, on a volumetric basis (m^3) roughly 1.8 times more LNG needs to be bunkered to achieve the same range compared to bunkering heavy fuel oil.

Due to heat leakage through the insulation of the fuel tanks, LNG in storage will be evaporating and giving off natural gas vapor constantly. If this natural boil-off gas is consumed in the engines or boilers of the ship, the temperature and pressure of the LNG in the fuel tanks will be maintained. If the boil- off gas is not consumed, the pressure and temperature in the fuel tanks will rise.

Natural gas, like other combustible liquids, is not flammable in the liquid phase and cannot ignite. However, in the vapor phase it is highly flammable and will readily burn when there is a 5 to 15 percent by volume mixture with air. Although methane is colorless, cold methane vapors cause the moisture in air to condense resulting in what appears to be a white cloud. A general guide is that within the visible cloud, the methane concentration is still within the flammable range. Therefore, it is critical that equipment and procedures are in place to prevent a flammable mixture from occurring, and that sources of ignition are nonexistent in and around areas where a flammable mixture is likely to occur.

More details on the characteristics of LNG are provided in the Appendix.

3 GENERAL CONSIDERATIONS FOR LNG BUNKERING

Loading LNG into fuel tanks is a different process from loading HFO due to some unique differences in the fuel's characteristics. One difference is that LNG is carried as a boiling liquid, which means temperature and pressure influence the behavior of the liquid. A second difference is that LNG is a cryogenic liquid at temperatures of about -162°C (-259°F), and consequently, it is hazardous to personnel and any conventional steel structures or piping with which it comes into contact. A third difference is that the vapor from typical petroleum bunkering is not considered to create a hazardous zone because the flash point is above 60°C (140°F), and is simply vented through flame screens to the atmosphere. In contrast, LNG vapor can form explosive clouds in confined spaces and is considered hazardous. This requires special handling of the vapor when bunkering.

Methods of filling LNG storage tanks have been developed wherein there is no vapor emitted from the tanks, or the vapor is returned to the bunkering vessel or terminal. The *International Code of Safety for Ships using Gases or other Low-Flashpoint Fuels* (IGF Code) mandates that no gas is discharged to atmosphere during the bunkering of LNG. Lines used for bunkering must at the completion of bunkering be drained of LNG and the remaining gas vapors removed using nitrogen. Any liquid remaining in the pipes that is trapped between closed valves will boil and expand to fill the space available. If that space is small, the pressure developed by the expanding vapor can increase to dangerous levels and cause the pipes to burst or valves to be damaged. Where there is a risk of natural gas pressure buildup, such as LNG storage tanks and piping systems, relief valves are required to safely allow the excess pressure to be released as a final safety measure. Relief valves should be properly located so the hazardous zone created by the release of vapor is not near any operational areas aboard the vessel. In general, relief valves should tie into a vent mast which directs the gas away from all critical areas. The outlet from the pressure relief valves shall normally be located at least 10 m from the nearest air intake, air outlet or opening to accommodation, service and control spaces, or other nonhazardous area and exhaust outlets from machinery installations.

LNG is bunkered at cryogenic temperatures so special equipment and procedures are required. Any contact of personnel with the fuel will cause severe frostbite. Spillage of even small amounts of LNG can cause structural problems as unprotected normal structural steel can become embrittled by the cold liquid, leading to fracture. Stainless steel drip trays, dry break-away couplings, and special hose connections that seal before uncoupling are often used to protect from spillage. Note that ISO 21593:2019, *Ships and marine technology — Technical requirements for dry-disconnect/connect couplings for bunkering liquefied natural gas*, specifies the design, minimum safety, functional and marking requirements, as well as the interface types and dimensions and testing procedures, for dry-disconnect/connect couplings for LNG hose bunkering systems intended for use on LNG bunkering ships, tank trucks and shore-based facilities and other bunkering infrastructures.

Communication between the receiving ship and the bunkering facility is always important, but it is even more critical when handling LNG. Because of the greater potential for hazardous situations with LNG bunkering, written operational procedures, including the fuel handling manual required by the IGF Code, should be followed and understood between the person- in-charge on the bunkering facility and receiving ship. Security and safety zones around the bunkering operation need to be set up to reduce the risk of damage to property and personnel from the LNG hazards, reduce the risk of outside interference with the LNG bunkering operation, and to limit the potential for expansion of a hazardous situation should LNG or natural gas release take place.

4 KEY CHARACTERISTICS AFFECTING TANK CAPACITY FOR BUNKERING LNG

Typical LNG characteristics, including chemical components and composition, heating value, methane number, liquid density, and methane vapor pressure (boiling pressure) are provided in the Appendix. The following characteristics represent key considerations for handling LNG and highlight its important differences from typical liquid fuel storage and bunkering.

Bunkering (Loading) Temperature: At atmospheric pressure, natural gas will liquefy at a temperature of about -162°C (-260°F). As LNG increases in temperature, its vapor pressure increases and its liquid density, decreases. These physical changes need to be considered because they may increase the required storage tank volume and pressure rating.

Filling Limit: The filling limit of an LNG tank is the maximum allowable liquid volume in the tank, expressed as a percentage of the total tank volume. The filling limit is not the same as the loading limit. The maximum filling limit for LNG cargo tanks, and IGF Code LNG fuel tanks, is 98 percent at the reference temperature.

Reference Temperature: The reference temperature is the temperature corresponding to the saturated vapor pressure of the LNG at the set pressure of the pressure relief valves (PRVs). For example, if the LNG tank has a pressure relief valve set pressure of 0.7 barg (10.15 psig), then the reference temperature is -154.7°C (-246.4°F), which is the temperature that natural gas will remain a liquid at 0.7 barg (10.15 psig).

Loading Limit: The loading limit is the maximum allowable liquid volume to which the tank may be loaded, expressed as a percentage of the total tank volume. This limit depends on the LNG densities at the loading temperature and reference temperature and is determined by the following formula:

$$LL = FL\left(\frac{\rho_R}{\rho_L}\right)$$

Where: LL = loading limit
FL = filling limit
ρ_R = LNG density @ reference temperature
ρ_L = LNG density @ loading temperature

Typical loading limits for gas fueled vessels are expected to range from 85 to 95 percent depending on tank type, pressure relief valve settings, and other vessel specific considerations. In cases where the tank insulation and tank location make the probability very small for the tank contents to be heated up due to external fire, special considerations may be made to allow a higher loading limit than calculated using the reference temperature, but never above 95% - see also IACS Unified Interpretation (UI) GF16.

Effect of Temperature and Pressure on Loading Limit: To understand the effect of temperature and pressure on the loading limit, it is helpful to consider an example where LNG and vapor are not being consumed from the tank. In this case, the LNG tank is a closed system and remains at a saturated condition, meaning the liquid and vapor are in equilibrium. Even though the tank is insulated, some heat will leak into the tank and cause an increase in the liquid and vapor temperatures while they remain in a saturated condition.

Liquid density decreases as temperature increases. If the tank is nearly full, the space available for vapor is relatively small, so the increase in liquid volume due to a lower density can significantly reduce the available vapor space volume. This decrease in available vapor volume as a result of the temperature changes will result in higher vapor pressure.

If the tank temperature is allowed to increase unchecked, the pressure in the tank will increase to the point where the pressure relief valves open. The temperature of the LNG at this point is the reference temperature. Because the density of the LNG at the reference temperature is lower than the density at the loading temperature, and given the formula for the loading limit, it is clear that the loading limit will always be lower than the filling limit.

As the pressure relief valve setting is increased, the reference temperature of the LNG also increases, which has the advantage of increasing the amount of time it takes for the tank to reach the pressure relief opening pressure. However, because the reference temperature is higher, the LNG density at the reference temperature will be lower, resulting in a greater difference between the LNG density at the loading and reference temperatures than in tanks with a low relief valve setting. This presents a tradeoff between initial loading capacity and the time it takes to reach the set pressure of the relief valve.

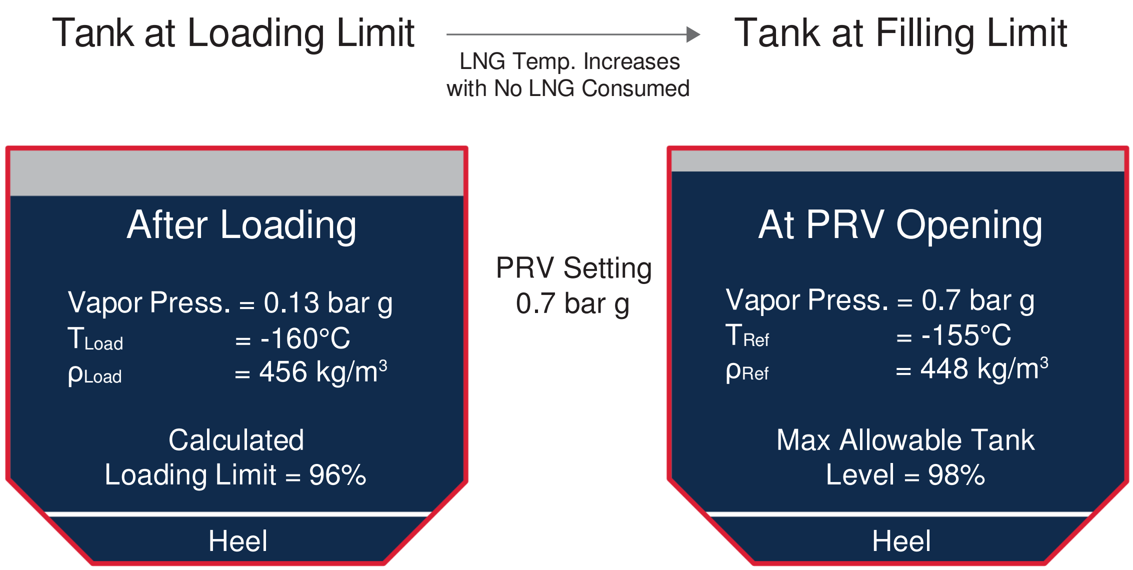


Figure 1. Typical Atmospheric Tank Loading Limit

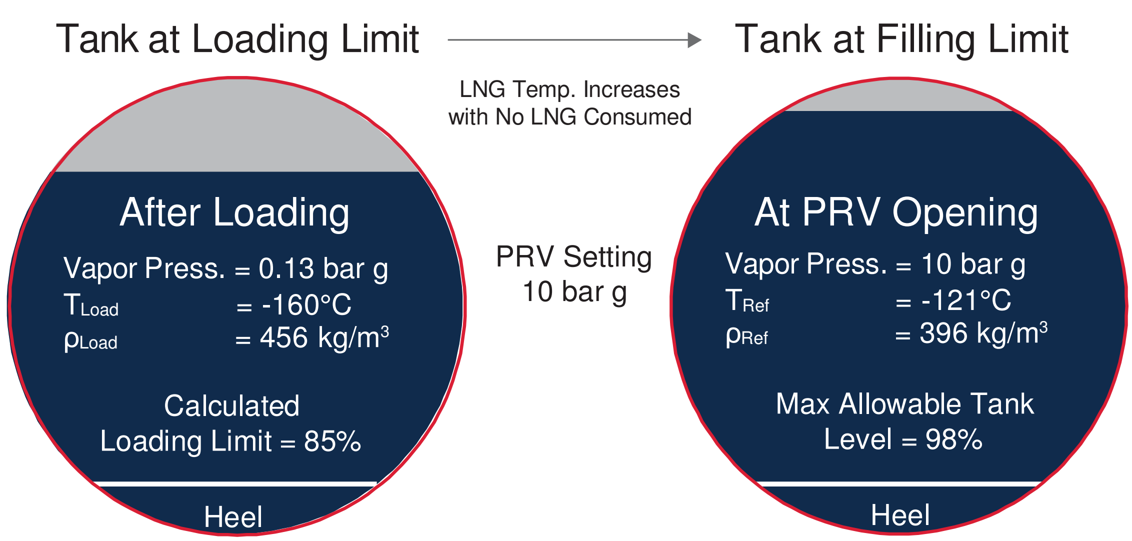


Figure 2. Typical Pressurized Tank Loading Limit

Figure 1 and Figure 2 show that pressurized tanks with higher pressure relief valve settings can allow the LNG to sit longer and warm up more than atmospheric tanks, but the tradeoff is that pressurized tanks have a significantly lower loading limit. Increased holding time is provided only with a lower loading limit.

Note: The reference temperatures in Figure 1 and Figure 2 are taken from the Appendix tables titled "Typical LNG Density".

Heel: The volume of LNG that is normally left in the tank before bunkering is called the tank heel. This small volume of LNG keeps the LNG tank cold before it is refilled during bunkering. The required tank heel should be calculated with the assistance of the tank designer and boil-off gas management/fuel gas supply system designer based on several variables such as tank size and shape, ship motions, heat inflow from external sources, gas consumption of the engines, and bunkering and voyage schedule. As a general rule of thumb, for initial design considerations a tank heel of 5 percent can be assumed.

Usable Capacity: In general, the usable capacity of the LNG tank is equal to the loading limit minus the heel, expressed as a percentage of the total tank volume. The usable capacity is the consumable volume of bunkered LNG in the tank.

5 VESSEL COMPATIBILITY

One of the key steps in safe LNG bunkering is verifying that the supplying vessel or facility and the receiving vessel are compatible. Compatibility covers a wide range of topics and because of the complexity of LNG bunkering, it is more important to confirm compatibility than for fuel oil bunkering. A vessel compatibility analysis/assessment should be carried out prior to LNG bunkering operations. Compatibility is normally agreed and confirmed in writing prior to the start of bunkering as part of the bunkering procedures. An easy way to do this is to fill out a checklist to confirm compatibility before each bunkering operation.

A compatibility review should address all shore-to-ship or ship-to-ship considerations, including:

1. Confirmation that the receiving vessel (and supply vessel, if applicable) can be safely moored and that adequate fendering or spacing is provided between the vessels or to the facility to prevent damage. Any restrictions on length should be noted. Moorings should be sufficient to keep the vessel(s) restrained for anticipated wind, tide and weather conditions, and any expected surges from passing vessels.
2. The relative freeboard of the vessel(s) or facility should allow hoses to reach from the bunker supply connection to the bunker receiving connection with sufficient slack to allow for any expected relative motion between the two. Any restrictions on freeboard should be noted.
3. The manifold arrangements, spill containment systems, and hose connections for the supply source and the receiving vessel should be confirmed. Capability for emergency release (hose breakaway) with minimal gas release should be provided. The means to prevent electrical arcing at the manifold is to be evaluated and addressed.
4. Confirmation that both the supply source and receiving vessel have compatible emergency shutdown connection, defined emergency procedures and safety systems.
5. Confirmation that the size and scope of the hazardous areas on both the supply source and the receiving vessel are compatible (i.e., that the size of one is not beyond the size of the other). The goal is to keep any sources of ignition from either the supplier or receiving vessel outside of the other's hazardous area.
6. Confirmation that the volume, pressure, and temperature of the supply source are compatible with the tanks on the receiving vessel.
7. If it is determined that the receiving vessel requires vapor return, then confirmation is needed that the supply source can accept returned vapor and that the vapor return systems are compatible.
8. Confirmation that inerting and purging capabilities exist at both the supply source and receiving vessel.
9. Confirmation that communications equipment is compatible, and the required connections and interfaces are provided so that both the bunker supplier and receiver can monitor the bunkering operation, and both can initiate an emergency shutdown of the complete transfer operation.
10. Confirmation of the provision and compatibility of the electrical isolation arrangements.

6 OPERATIONAL ISSUES ABOARD THE RECEIVING SHIP

6.1 DURING THE BUNKERING PROCESS

When receiving LNG bunkers, the receiving ship needs to implement several operational procedures that are unique to LNG. These procedures include special communications and monitoring, emergency shutdown, cryogenic material precautions, inerting and purging, firefighting and electrical isolation or bonding.

1. **Communications and Monitoring:** Communications between the receiving ship and bunker supplier are critical for carrying out the bunkering operation safely. Communications should be established before the bunker hoses are connected and can end after the hoses are disconnected. It is important for the supplier and receiver to both speak a common language and fully understand each other.

   Compatibility of all communication links between the receiving ship and bunker supplier must be confirmed and tested.

   Radio and communication equipment for involved persons should include the following considerations:

   - Radio equipment to be used in the safety zone during the operation should be designed for use in hazardous areas and should be intrinsically safe.
   - Any radio equipment, cell phones, or portable electronic equipment in the safety zone that are not intrinsically safe should be removed from the area.

   In addition to the communication system, a monitoring system with data link may be provided. The monitoring system allows both parties to monitor their own systems as well as critical aspects of the other's system. This data link may be an integral part of the emergency shutdown system or independent. The IGF Code suggests reference to ISO 28460 for the evaluation of a compatible ESD ship shore link (SSL). Integrated systems allow for automatic shutdown of the bunkering operation upon receiving an alarm, such as from the gas, fire, or smoke detection systems, or from manual activation. The typical technologies used for data and communication links in the LNG industry include electrical and fiberoptic cables, radio frequency and pneumatics. All of the listed technologies, except pneumatics, have the capacity to transfer additional information, such as communications or monitoring of other important, but non-LNG related systems. Pneumatic systems are simple and dependable, but generally only capable of sending one signal. They are typically used as the emergency shutdown.

2. **Emergency Shutdown (ESD):** Having a means to quickly and safely shut down the bunkering operation by closing the manifold valves, stopping pumps, and closing tank filling valves is essential to ensure safety. The ESD should be capable of activation from both the bunker receiving ship and the bunker supplier, and the signal should simultaneously activate the ESD on both sides of the transfer operation. No release of gas or liquid shall take place as a result of ESD activation. Typical reasons for activation of the ESD include the following:

   - Gas detection
   - Fire detection
   - Manual activation from either the supplier or receiver
   - Excessive ship movement
   - Power failure
   - High level in receiving tank
   - Abnormal pressure in transfer system
   - High tank pressure
   - Other causes as determined by system designers and regulatory organizations

3. **Special Precautions for LNG:** The issues associated with cryogenic substances such as LNG are extremely important to understand and respect. LNG cannot simply be handled as 'cold diesel'. It is in fact extremely cold and can cause serious burns to human flesh. Even insulated LNG pipes and equipment can become cold enough to cause serious injury to personnel. In addition, the cryogenic temperatures are cold enough to cause steel to become brittle and crack. Because of these issues, the piping system, material requirements, and safety issues are much different than for an oil fuel system. The hull or deck structures in areas where LNG spills, leaks or drips may occur must be either suitable for the cold temperatures or protected from the cold temperatures.

   Drip trays are commonly used to contain LNG leakage and prevent damage to the ship's structure. This includes the location below any flanged connection, which are typically fitted with spray shields, in the LNG piping system or where leakage may occur. Drip trays should be sized to contain the maximum amount of leakage expected and made from suitable material, such as stainless steel. Cryogenic pipes and equipment are typically thermally insulated from the ship's structure to prevent the extreme cold from being transferred via conduction. These requirements are especially important at the bunker station because this is where LNG leaks or spills are most likely to occur.

4. **Inerting and Purging:** Before bunkering, it is necessary to inert and purge the bunker hoses and other warm bunker lines. In order to prevent a flammable gas mixture, the inerting process includes displacing air from the bunker lines with inert gas, typically nitrogen, to ensure the oxygen content is less than or equal to 1 percent. Purging, also known as gassing up and gas filling, is the process of displacing the inert gas with warm natural gas. Purging can either be done with vapor purge lines, which force vapor from the tank through the bunker lines; or by slowly pumping small volumes of LNG through the bunker lines, which will quickly vaporize and purges the lines. After the bunker lines have been inerted and purged, the lines are slowly cooled to the temperature of LNG with the use of cold LNG vapor and/or LNG. This process prevents the risk of cold shock and damage that would occur if LNG was allowed to flow through the warm hoses and pipes at the normal flow rate. Once the bunker lines have been cooled, the transfer of LNG can begin.

   After bunkering, it is very important to drain the bunker lines so that LNG does not remain trapped in pipes or hoses. If LNG remains trapped in a sealed section of a pipe or hose, it will warm, vaporize and pressurize the pipe and may cause the pipe or hose to burst. One way to drain the bunker line is to allow the LNG to vaporize in the pipes while the valves leading to the ship's fuel tank are left open. This allows the LNG and natural gas vapor to flow to the tank. Purge connections also can be used after bunkering to force the remaining LNG into the ship's fuel tanks.

   When bunkering is complete and the lines have been drained of LNG, it is necessary to inert the LNG bunker lines to prevent a flammable gas mixture from accumulating in the pipes or hose. Inerting is to be completed prior to disconnecting the bunker lines. Typically, nitrogen is used to displace the warm natural gas from the bunker lines. The bunker facility and receiving ship should agree on the means to properly manage and dispose of the remaining natural gas and nitrogen so that the natural gas is not released into the atmosphere. This may be accomplished by pushing the natural gas and nitrogen mixture back into the bunkering facility tanks or by using gas combustion units or boilers. Furthermore, it should be confirmed with all agencies having jurisdiction over the bunkering operation that the proposed procedure is acceptable. Figure 3 shows a typical sequence for a simplified bunkering process including the inerting and purging of the bunker hose and associated piping.

Bunkering Hoses Connected
- Contents: Air
- Temperature: Ambient

Bunker Lines Inerted

↓

Inerting Complete
- Contents: Inert Gas (nitrogen)
- Temperature: Ambient

Purge Lines with LNG Vapor

↓

Purging and Cooldown Complete
- Contents: LNG Vapor
- Temperature: Same as LNG

Initiate Bunkering

↓

Bunkering Underway
- Contents: LNG Liquid
- Temperature: LNG

Complete Bunkering

↓

Bunkering Supply Stopped
- Contents: LNG Liquid
- Temperature: LNG

Drain Line

↓

LNG Liquid Removed from Lines
- Contents: LNG Vapor
- Temperature: LNG

Inert Lines

↓

Bunkering Hoses Inerted
- Contents: Inert Gas (nitrogen)
- Temperature: Ambient

Bunkering Hoses Disconnected

↓

Bunkering Complete
- Contents: Bunker Connection = Air
Ship's Bunker Lines = Inert Gas (nitrogen)
- Temperature: Ambient

Figure 3. Inerting and Purging Sequence of LNG Bunker Hose and Piping

5. **Fire Safety:** Section5C-13/11 of the ABS *Rules for Building and Classing Marine Vessels* (MVR) and SOLAS Chapter II-2 can be referenced for fire protection requirements for an LNG fueled vessel. A permanently installed dry chemical fire extinguishing system is required to be installed at the bunker station and drip trays. Manual release of the system should be easily possible from outside, but near, the bunker station. In addition, a portable dry chemical fire extinguisher is required to be located near the bunker station. For enclosed or semi-enclosed bunker stations, a fixed gas detecting system is also required.

   A water curtain is frequently fitted wherever large quantities of cold LNG can leak and damage critical structural components, such as the ship's side shell directly below the LNG bunker station and bunker hoses and above the waterline.

   Fighting LNG fires is not a simple task. Completely extinguishing an LNG fire could leave a pool of LNG which will continue to release gas that could reignite in a much more intensive fire. The most important first step is to cool any surrounding tanks or pipes that contain LNG, natural gas or other flammable substances, and to cool spaces that contain critical machinery and accommodations. This will help prevent the spread of the fire and reduce its consequential damage. Intensive heating of LNG tanks by an outside fire impinging on the tank can lead to excessive venting of the tanks. Spraying large quantities of water by a deluge system or from hoses or monitors is generally the recommended method of cooling. Medium or high-expansion foam sprayed on a liquid pool LNG fire also can reduce the intensity of the flames, reducing the potential for damage to surrounding areas, but will not stop the release of gas.

   Dry chemicals also will work to extinguish LNG fires, but with the caution that extinguishing the flame without cutting off the source of the gas can be dangerous. It is important to stop the spread of released gas into confined spaces and other parts of the vessel to prevent an explosion due to the confined space. Firefighting should be one of the major sections of the bunkering operation emergency response plans and personnel involved with bunkering should have training on what to do if a fire is encountered.

6. **Electrical Isolation:** Vessels transferring or receiving low flashpoint flammable liquids, such as LNG, need to take additional precautions against ignition resulting from electrical arcing. Two causes of arcing are static electricity buildup in the LNG bunker hose and differences in potential between the ship and bunker supplier's facility, including the quay or pier, trucks, bunker vessels, etc. It used to be common practice to connect a bonding cable between a ship carrying low flashpoint flammable liquids and the loading or offloading facility to physically ground the two objects together to equalize the difference in potential. It was noted that the bonding cable was not fully effective at equalizing the potential, if the cable accidentally broke or became detached, the chances of arcing would be greatly increased.

   An effective way of preventing arcing is to isolate the ship and the bunker supplier using an isolating (insulating) flange fitted at one end of the bunker hose only, in addition to an electrically continuous bunker hose. The Society of International Gas and Tanker Operators (SIGTTO) publication, *A Justification into the Use of Insulation Flanges (and Electrically Discontinuous Hoses) at the Ship/ Shore and Ship/Ship Interface* provides details and background for the use of an isolating (insulating) flange. The isolating flange, an example of which is shown in Figure 4, prevents arcs from passing between the ship and facility even if there is a difference in potential. Furthermore, because the hose is electrically continuous and one end is grounded to either the ship or the bunker supplier, static electricity will effectively be dissipated. An alternative method is to use one short section of insulating hose without any isolating flanges, but with the rest of the bunker hose string electrically continuous. To ensure that the ship is completely isolated from the supplier, it may be necessary to isolate mooring lines, gangways, cranes, and any other physical connections. This is typically done by using rope tails on mooring lines, insulating rubber feet on the end of gangways, and prohibiting the use of certain equipment that would otherwise pose an unacceptable risk of arcing.

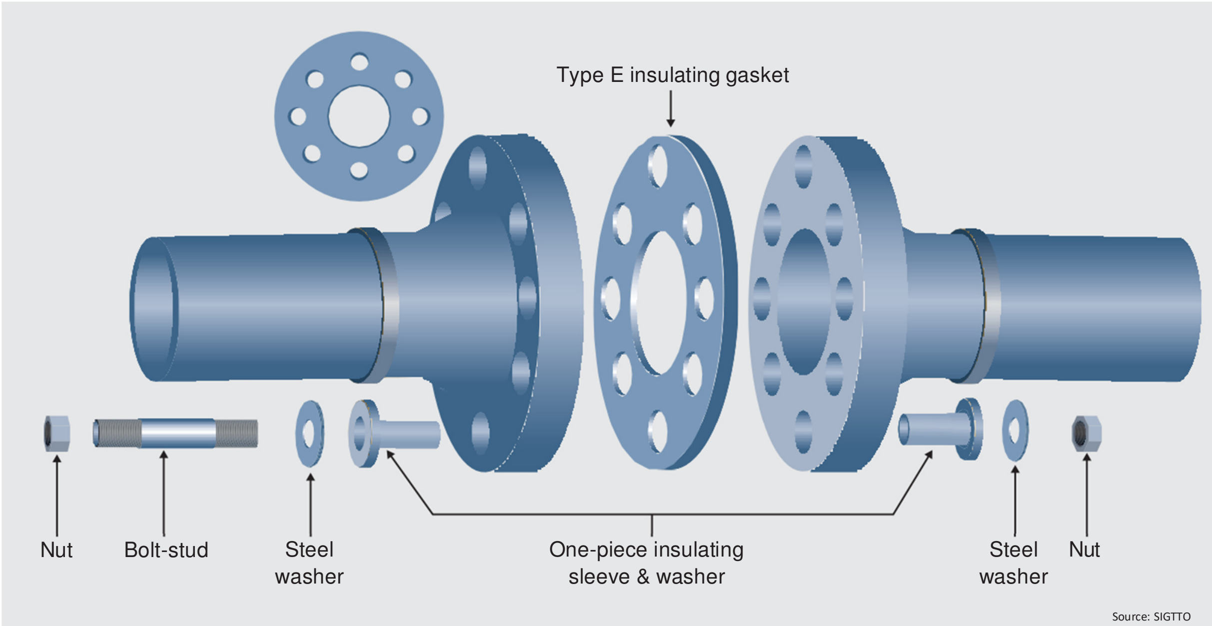


Figure 4. Typical Isolating Flange

6.2 OTHER OPERATIONAL PHASES RELATED TO LNG STORAGE

In addition to the actual bunkering process, there are several LNG handling and storage operations on board the receiving ship that are unique to cryogenic fuels. These involve managing the storage tank temperature and the mixing of LNG of different densities.

1. **Initial Gassing Up:** Before the initial filling of an LNG fuel tank or after it has been completely emptied and gas-freed, it will be full of air. Before LNG can be introduced to the tank, the air needs to be removed by inerting the tank (typically with nitrogen) to ensure an explosive mixture of gas and air is never present in the tank. Some ships might not be fitted with a nitrogen generator or nitrogen storage tank with sufficient capacity to inert the entire fuel tank or tanks. This task might be accomplished by the LNG bunker supplier or another source, such as a nitrogen tank truck or a fixed tank onshore. Even if the ship has a large enough nitrogen capacity, it should have proper connections to accept an outside source of nitrogen in case of system failure or emergencies.

   LNG bunkering can begin only after the LNG fuel tank has been properly inerted, purged and cooled down. The tank is inerted with nitrogen gas. After inerting the tank, the inert gas is typically displaced with warm natural gas. Displacing the inert gas with warm natural gas is known as purging, gassing up or gas filling. The inert gas is either returned to the shore facility or vented. Venting of the inert gas is stopped when the natural gas vapors are detected. It should be confirmed with all agencies having jurisdiction over the bunkering operation whether the inert gas can be released into the atmosphere; some agencies may require that the inert gas be captured and stored or processed since it could contain natural gas. The tank is then gradually cooled in stages to the temperature of the incoming LNG. The cooldown process can be accomplished using cold natural gas and/or LNG.

   This initial cooldown is typically done by spraying LNG into the fuel tank to slowly cool the piping, the tank and the gas in the tank. This is a slow process that uses a much lower flow rate than normal bunkering to ensure uniform cooling and minimize induced thermal stresses in the tank. The cooldown process may take several hours, typically 12 to 18 hours, depending on the size of the tank. The cooldown procedure is typically developed by the tank's manufacturer and includes directions for the use of the tanks spray nozzles and bottom filling. Once the tank is cooled to the specified temperature, continuous filling of the tank can continue to the desired level. Although the procedures and sequence of events will differ, the use of cold nitrogen gas and/or liquid nitrogen also is common for the cooldown process.

2. **Transit and Storage:** During transit, the ship's fuel tanks will normally contain some quantity of LNG. The volume of cold LNG in the tank, as a minimum, should be sufficient to maintain the cold temperature in the tank. Tank pressure during transit can be maintained within acceptable limits by consuming LNG or by using vapor control methods.

3. **Draining and Stripping:** The requirement to strip the LNG fuel tank prior to entry into a shipyard may vary worldwide depending on shipyard or port authority policies. Tank stripping can be accomplished by building up the tank pressure to force the LNG out of the ship's tank to another tank, or by using stripping pumps. Any liquid left in the tank after stripping can be removed by circulating warm methane vapor from the ship's vaporizer. After stripping, the tank will need to be inerted with nitrogen. If human entry and inspection is required, the tank has to be purged with fresh air to gas-free.

   As specified in 5C-13-6/3.11 and 3.12 of the ABS MVR, all LNG fueled ships also should have some means of emptying the fuel tanks with fuel piping systems and with the procedures for that to be available onboard. This capability would allow another vessel or shoreside facility to empty and strip the LNG fuel tank for scheduled events.

4. **Rollover:** When LNG from different sources with different densities are mixed (such as during a bunkering operation when new LNG is introduced into a tank), the LNG with the higher density (typically lower temperature) settles at the bottom with the lighter density on top. If the tank remains relatively stationary (no sloshing or mixing takes place) heating of the lower part of the tank will decrease its density and increase its vapor pressure, but the hydrostatic pressure of the LNG on top will keep gas from boiling off. If the density difference becomes too large or the tank is disturbed so rapid mixing occurs, the LNG with higher vapor pressure at the bottom will rise up and encounter the lower pressure at the top of the tank. This is called rollover and can lead to rapid boil-off and generation of large amounts of vapor in extreme cases. This could lead to a large gas release through the pressure relief valves.

   LNG density can vary significantly with change in temperature, but it also can vary depending on the physical composition of the LNG. As LNG warms, the lighter components boil off first and the remaining LNG has a different composition, with an increased density. According to the SIGTTO publication, *Guidance for the Prevention of Rollover in LNG Ships*, studies have shown that density differences as low as 1 kg/m^3 can lead to stratification if the LNG fill rate is very slow. This "rollover" hazard has occurred in shore terminals where there is no motion of the tank, and potentially is a hazard for ships which remain stationary for long periods and the LNG becomes stratified due to lack of sloshing or mixing. However, a vessel rolling at sea will have less of a tendency for this to occur because the sloshing of the LNG in the tank will cause mixing. It is unlikely for bunkered LNG to have the same temperature and density as the LNG remaining in the fuel tank, so it is important for the LNG to be thoroughly mixed during bunkering.

   A typical way to minimize the risk of stratification is to use the top or bottom fill lines to mix the incoming LNG with the retained heel in the tank. If the bunkered LNG is lighter (lower density) than the heel, the bottom filling connection should be used. This will cause the bunkered LNG to rise to the top of the denser heel, mixing in the process. Conversely, if the bunkered LNG is heavier (higher density) then the top filling connection should be used. Mixing jet nozzles fitted to the fill line in the bottom of the tank can be used to increase movement within the tank and help to mix the bunkered LNG with the existing contents of the tank. Once the vessel goes to sea and rolling commences, mixing will tend to happen naturally, reducing the risk of rollover. Figure 5 shows the stages of a rollover in an LNG tank.

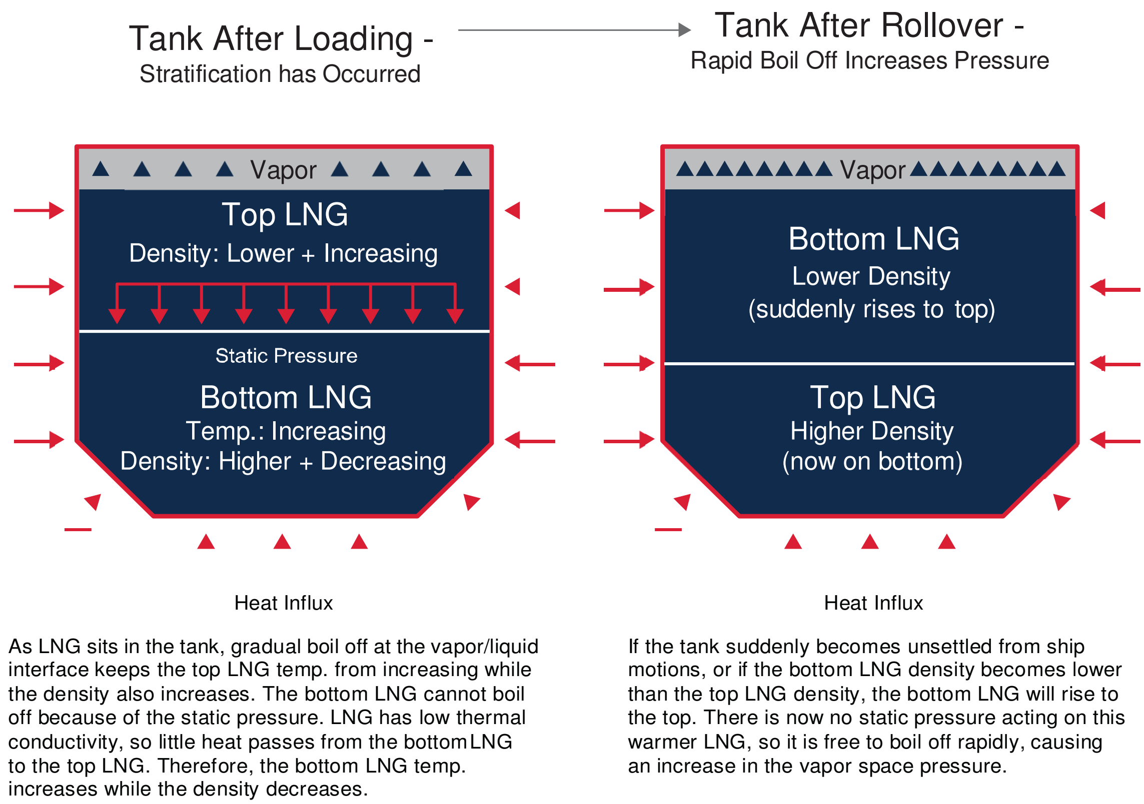


Figure 5. Rollover After Stratification

6.3 SIMULTANEOUS CARGO OPERATIONS

Commercially, it may be necessary for the ship operator and terminal to perform simultaneous cargo operations while bunkering. For this Advisory, the term simultaneous operations (SIMOPS) refers to the transfer of cargo on vessels while bunkering. For passenger vessels, SIMOPS refers to bunkering with passengers on board or while embarking and/or disembarking. However, simultaneous operations may include other general operations conducted on board the bunkered vessel, such as bunkering conventional fuel oil, taking on stores, maintenance work, etc.

1. **Key Issues with Cargo Operations During Bunkering:** During normal bunkering operations, a flammable gas mixture should not be present provided all equipment is operating properly and appropriate procedures are being followed. However, in certain situations, natural gas vapor may inadvertently be released into the atmosphere resulting in a flammable mixture. Sources of ignition are not allowed in hazardous areas, so that even in the case of inadvertent release of gas the possibility of ignition is reduced. The risk of ignition increases substantially when uncontrolled sources of ignition are in the vicinity of the bunkering operation.

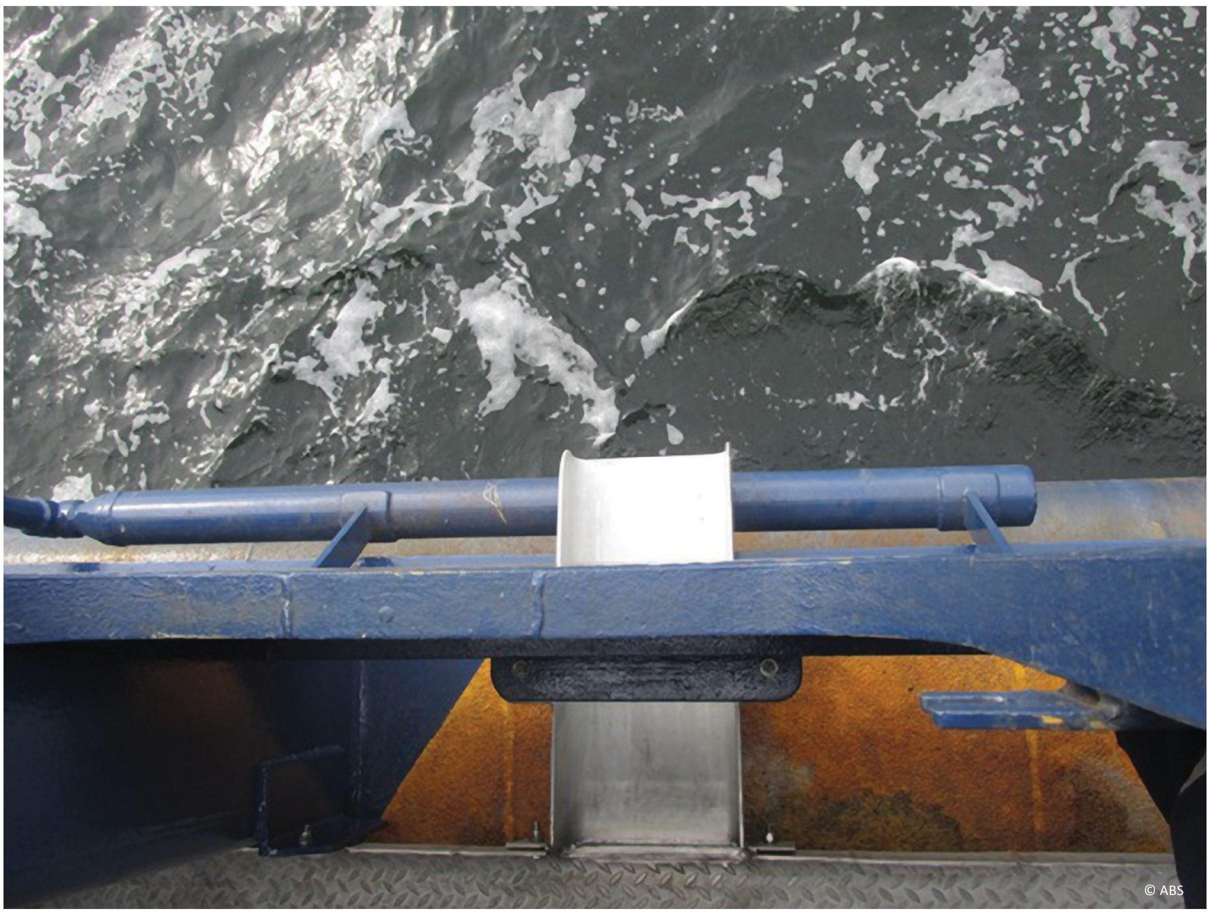
   Cargo operations can increase the potential for uncontrolled sources of ignition. This is particularly of concern for cargo operations located near to or in the gas hazardous areas. Certain cargo operations present a greater chance for sources of ignition than others. For example, loading containers in a container bay adjacent to the ship's bunker station can provide a greater risk of producing sparks, which can be a source of ignition, than does loading passengers onto a ferry using a gangway on the opposite side of the ship from the bunker station.

   However, the presence of passengers approaching the vessel during the bunker operation presents much greater risk of personnel injury from a hazardous event than simple cargo operations with a limited number of trained personnel in the vicinity of the vessel.

   Accordingly, potential simultaneous operations (SIMOPS) need to be evaluated on their own merits, and their risk levels determined as part of the bunkering operations risk assessment process.

2. **Receiving Approval for Cargo Operations During Bunkering:** Prior to conducting SIMOPS, it is expected that the flag States and port authorities will require the operation be thoroughly evaluated and supported by a risk assessment which would identify the associated risks, safeguards and acceptance criteria. Flag States and port authorities will develop their own standards and permitting process. Although the approval process may differ worldwide, some may use published standards as the basis. For example, USCG Policy Letter 01-15 dated 19 February 2015, *Guidelines for Liquefied Natural Gas Fuel Transfer Operations and Training of Personnel on Vessels Using Natural Gas as Fuel*, states that a formal operations risk assessment may be conducted to help determine whether the SIMOPS may be conducted safely. The USCG policy letter refers to the technical specification from the International Organization for Standardization (ISO), ISO/TS 18683:2015, *Guidelines for Systems and Installations for Supply of LNG as Fuel to Ships*, as a guide for the risk assessment process. USCG CG-OES Policy Letter 01-17 dated 8 June 2017 provides additional guidance for evaluating SIMOPS.

   It should be expected that a rigorous analysis of the hazards and risks, and countermeasures put in place to reduce them, will be required by reviewing organizations for the SIMOPS study. It should not be assumed beforehand that simultaneous cargo operations will be approved. Structural risk reduction methods, rather than procedural risk reduction methods, such as large security zones to isolate the bunkering from cargo operations, having the bunkering take place on the opposite side and end of the vessel from piers and cargo operations, and barriers to keep all non-essential personnel away are typical methods employed to reduce the risks of simultaneous cargo operations and increase the likelihood they will be approved.



7 SPECIAL EQUIPMENT REQUIREMENTS ABOARD THE RECEIVING SHIP

The equipment required to support the bunkering operation on the receiving vessel includes bunker stations, bunker piping and storage tanks. While these are familiar elements, they have unique requirements when used with LNG.

7.1 BUNKER STATIONS

Much like oil fueled ships, LNG fueled ships will have bunker stations allowing the ship to refuel through hoses from either a shoreside facility, truck or a small LNG bunker vessel or barge. The bunker station provides connections to the ship's fuel gas system and fuel tanks to allow loading of LNG fuel and, in some cases, return of displaced vapor from the fuel tanks. Due to the additional hazards present with LNG, the requirements and capabilities of bunker stations on LNG fueled ships are more complex than for oil fueled ships. The following describes the primary considerations for LNG bunker stations. Refer also to the requirements under Section 5C-13-8 of the MVR .

1. **Location:** Bunker stations present risks for allowing LNG and vapor to escape into the atmosphere, potentially creating a flammable mixture with air. The location of the bunker station is a critical factor for determining the level of risk associated with the ship's bunkering operation and arrangement. The location will be considered a hazardous area.

2. **Outfitting:** Depending on the location of bunker stations, certain additional outfitting requirements may exist. For example, on certain types of ships bunker stations are located below the weather deck. These normally require a suitable watertight door in the side shell, which prevents waves and weather from entering the space, but can be opened to allow the ends of the bunker hoses to enter the bunker station. Furthermore, for such enclosed bunker stations an air lock will be required to separate the bunker station from adjacent non-hazardous areas.

3. **Ventilation:** Proper ventilation of bunker stations is necessary to remove any vapors released during bunkering operations. For bunker stations located within the ship's hull or elsewhere that is not an open deck, a forced ventilation system will be required.

4. **Gas Detection:** Permanently installed gas detectors are provided for enclosed or semi-enclosed bunker stations in order to detect the release of methane vapors.

5. **Controls:** The controls for bunkering operations may be remotely located from the manifold area.

7.2 BUNKER PIPING SYSTEMS

The bunker piping system consists of LNG transfer pipes and, in some cases, vapor return pipes between the bunker station and the fuel tank. The following describes the main considerations for LNG bunker piping.

1. **Flow Rates:** Bunker pipes are sized according to the design flow rates through the system. The design flow rate is based on the LNG fuel tank capacity, pressure, temperature and other factors, such as vapor return capability, flow velocity limits and bunkering time window. The flow rate is also dependent on the achievable bunkering rate from the bunker vessel or shore facility.

   Some vessels may require a shorter bunker time than others depending on their operating profile. Depending on the size of the fuel tanks and frequency of bunkering, owners may wish to maximize the bunker rate. A vapor return from the receiving tank back to the supplier's tank may help achieve a higher flow rate. Pre-cooling the LNG fuel tank before bunkering and other methods discussed in detail later in this Advisory can help to achieve the highest flow rate possible.

2. **Pipe Materials, Fitting Joints, Deck and Bulkhead Penetrations:** All LNG system pipe components that could come in contact with LNG must be suitable for cryogenic temperatures. This includes all pipes, valves, fittings, penetrations, etc. It is important to minimize the number of pipe joints in order to minimize the potential for leaks. This is achieved by using welded connections wherever possible. For all joints located in areas where leaking LNG can cause damage to the ship's structure, drip trays and spray protection should be provided with suitable containment capacity and constructed of a material that is suitable for LNG, typically stainless steel.

   Pipes, valves, and other fittings used for handling LNG should have a minimum design temperature of -165°C (-265°F). Typically, these pipes are stainless steel and have to pass an impact test at a colder temperature than the design temperature.

   To protect the crew from exposure to extreme cold, and to minimize heat influx and subsequent warming of the LNG leading to potential boil-off while bunkering, the bunker lines are typically insulated. Rigid foam or other types of insulating materials may be used, or the pipes can be vacuum insulated. Note ASTM F3319-20, *Standard Specification for Selection and Application of Field-Installed Cryogenic Pipe and Equipment Insulation Systems on Liquefied Natural Gas (LNG)-Fueled Ships*, provides requirements for the design of thermal insulation systems for cryogenic piping and equipment for LNG fueled ship applications.

3. **Bunker Hose Fittings:** Presentation flanges at the bunker manifold are not yet standardized for gas fueled ships, but LNG connections will be significantly different than those for other service, such as potable water, diesel fuel oil, oily waste, etc., so that it is impossible to connect hose fittings for other services to the LNG and vapor connections. ISO 21593:2019 indicates bunkering systems are to be designed to connect to a standard ASME B16.5 flange and also provides informative annexes on the presentation flange and dry-disconnect coupling geometry. Note also ASTM F3312-18, *Standard Practice for Liquefied Natural Gas (LNG) Bunkering Hose Transfer Assembly*. This practice provides guidance on the minimum requirements for the design, manufacture, installation, and operation of bunker hose transfer assemblies for cryogenic service pertaining to bunkering of LNG fueled vessels. The bunker hose transfer assemblies addressed by this practice are for connections between the LNG fueled vessel bunker manifold presentation flange connections and the LNG supplier bunkering manifold presentation flange connections.

4. **Pipe Routing:** According to classification and regulatory requirements, LNG and vapor piping may not pass through accommodation spaces, service spaces, or control stations, but they can pass through certain enclosed spaces, such as machinery spaces, if the pipes are protected by a secondary enclosure, either double walled or installed in a ventilated pipe or duct.

   In the case of double-walled piping, the arrangements consist of two concentric pipes with the inner pipe used for LNG or vapor transfer. The space between the concentric pipes is pressurized with inert gas at a higher pressure than the maximum pressure in the inner pipe. A monitoring system with alarms is fitted to detect a loss of inert gas pressure, thus indicating a leak in either of the concentric pipes.

The typical ventilated pipe or duct method consists of the LNG or vapor pipe(s) located inside of a larger pipe or duct. The air space between this outer pipe or duct and the LNG/ vapor pipe(s) is provided with mechanical exhaust ventilation with a capacity of at least 30 air changes per hour. The volume of one air change is equivalent to the total volume of the air space for the full length of the pipe or duct. The ventilation system maintains the air space pressure below atmospheric pressure so that a leak in the inner pipe, outer pipe or duct, or both will not allow natural gas to enter the non-hazardous space. A monitoring system with alarms is fitted to detect natural gas in the air space between the inner and outer pipes, thus indicating a leak.

5. **Emergency Shutdown System (ESD):** The ESD system is critical to the safety of the vessel and is typically a hardwired system. The ESD system is to be fitted to stop bunker flow in the event of an emergency. Generally, the ESD system is activated by manual and automatic inputs as indicated in Section 5C-13-15/Table 1 of the ABS MVR. The ESD system is to be tested prior to each bunker operation.

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8 LNG STORAGE TANKS AND SYSTEMS FOR MONITORING AND CONTROL OF STORED LNG

1. **Overview of Tank Types:** There are several different types of LNG fuel storage tanks. LNG tanks can be independent tanks, which include Type A, B and C tanks. LNG tanks also can be non-independent tanks, which include the membrane and semi-membrane types.

   a) *Independent Tanks (Types A, B and C):* The *International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk* (IGC Code) defines three categories for independent LNG tanks, which are self-supporting tanks that do not rely on the ship's structure for strength.

   Type A tanks are designed primarily using recognized standards of classical ship structural analysis and constructed of a plane surface and are prismatic in shape. The Code limits this type of tank to a vapor pressure of less than 0.7 bar, and where minimum design temperature is below -10°C (14°F), requires a complete secondary barrier capable of containing the cargo for a period of 15 days in the event of a ruptured or leaking tank.

   Type B independent tanks are defined as "designed using model tests, refined analytical tools and analysis methods to determine stress levels, fatigue life and crack propagation characteristics." Type B independent tanks can be spherical or prismatic shaped tanks. One of the key characteristics for Type B designation is compliance with the "leak before failure" concept, under which crack propagation analysis by fracture mechanics techniques must demonstrate that if a crack in the system should develop, its growth will not be rapid enough to allow excessive leakage into the cargo hold. A partial secondary barrier, which can consist of a spray shield and drip pans, is required for independent Type B tanks with minimum design temperatures below -10°C (14°F).

   Type C independent tanks are designed to pressure vessel codes and are typically cylindrical or spherical in shape, or more volume efficient, but more complex, constructions such as bi-lobe or tri-lobe. Type C tanks can be designed for much higher vapor space pressures than Type A and Type B tanks. A secondary barrier is not required for Type C tanks.

   b) *Non-independent Tanks (Membrane):* Membrane tanks are non-self-supporting tanks which consist of a thin layer (membrane) supported through insulation by the adjacent hull structure. The membrane is designed in such a way that thermal and other expansion or contraction is compensated for without undue stressing of the membrane. This containment system includes a complete secondary barrier capable of containing the cargo for a 15-day period. Ship design and construction standards limit this type of tank to a vapor pressure of less than 0.7 bar.

2. **Top and Bottom Fill Methods:** LNG fuel tanks can be fitted with separate top or bottom fill connections or both. These connections can allow bunkered LNG to be directed to either the top of the tank, usually by spray nozzles, or the bottom of the tank. The top spray connection allows LNG to enter the tank and cool the vapor in the tank, thereby reducing pressure and temperature in the tank. The top spray connection also can be used for initial tank cooldown purposes. Having a separate top and bottom fill also provides a way to ensure proper mixing of incoming LNG with the remaining heel in the fuel tank.

3. **Pressure Monitoring and Relief:** Since LNG is a boiling liquid, the fuel tank pressure is to be controlled during transit, in port, and during bunkering in order to prevent the pressure in the tank from exceeding the tank design pressure. To monitor the pressure, pressure indicators are fitted in the vapor space of the tank. In addition, the tank must be fitted with two pressure relief valves that lead to a vent mast.

4. **Temperature:** The temperature inside the LNG fuel tanks can vary significantly at the time of bunkering depending on tank type, LNG temperature control systems and how the LNG was consumed. There are two primary reasons for temperature change in the tanks. One is that although the LNG fuel tanks are insulated, there will still be some heat transferred through the tank walls causing the LNG in the tanks to heat over time. A second possible reason for heating of the contents is linked to tank type, with some LNG fuel systems depending on pressure in the tank to supply the fuel directly to the engines and intentionally provide an external heating vaporizer as part of a PBU (Pressure Build Up) system, to heat the LNG and return to the tank vapor space to achieve the desired tank pressure.

Counteracting the heating is the cooling effect of evaporation as LNG boils off. The gas boils off to fill the lost volume of LNG or vapor in the tank, maintaining the LNG liquid and vapor in equilibrium at the cooler saturated temperature and pressure. Therefore, slow or no removal of LNG from a tank can cause the tank temperature and vapor pressure to increase from the heat flux into the tank, while fast removal without forced generation of boil-off gas can cause the LNG tank temperature to decrease. It is important to know the temperature in the LNG fuel tanks compared to the temperature of the LNG being bunkered because the temperature difference can have a significant effect on the vapor control process, as discussed in the next section.

5. **Vapor Control During Bunkering:** The differences in properties between the bunkered LNG and the LNG in the receiving tank can cause issues that require careful control of the vapor. In most cases, the bunkering operation will consist of filling colder LNG into a tank containing relatively warmer LNG. The temperature difference between the two liquids can be significant, and thus the saturated vapor pressures also will be different. If the vapor spaces of the supplier's colder tanks and the receiver's warmer tanks are interconnected directly prior to the start of LNG transfer, the receiver's tank is likely to depressurize rapidly from condensation of vapor.

Similarly, if cold LNG is pumped into a warm tank, a considerable amount of flash gas might be generated as the cold LNG is warmed by the contents of the tank. Vapor control during bunkering is critical and can be handled in several different ways depending on the supplying and receiving system capabilities and LNG conditions in the tanks. The following discusses typical bunkering methods for each combination of LNG temperatures in the tanks. Figure 6 shows a typical arrangement of piping and connections between the two tanks.

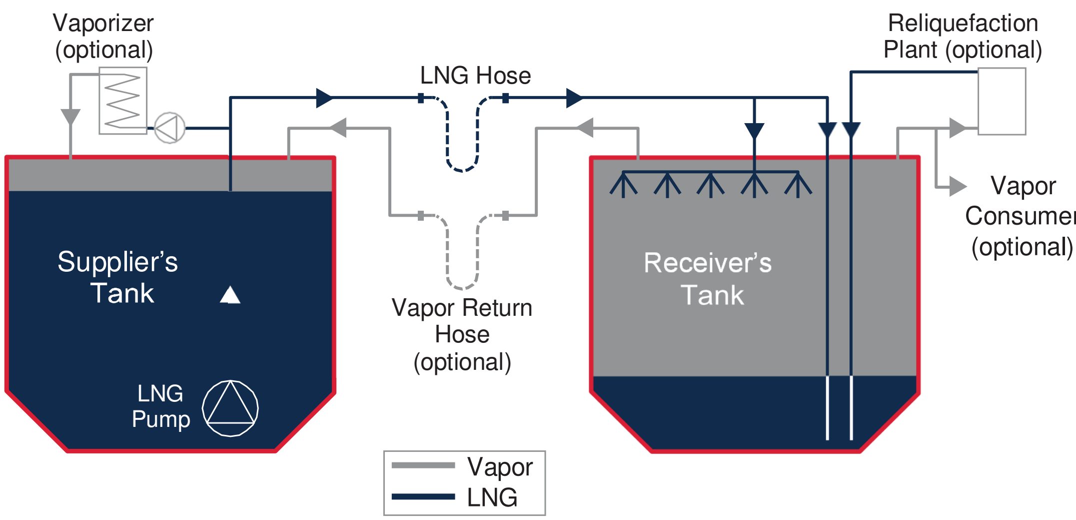


Figure 6. Typical Arrangement of Bunker Piping and Connections

a) LNG at similar temperatures in both tanks: If the LNG in both tanks is at similar temperature, then there are several options which can be used for bunkering. As the receiving ship's fuel tank is filled with LNG, the LNG displaces an equal volume of vapor already in the tank. The vapor needs to be condensed to liquid or removed from the receiving tank to prevent excessive pressure buildup. Similarly, as LNG is pumped out of the supplier's tank, the lost LNG volume needs to be replaced with an equal volume of vapor to prevent a vacuum. Vapor control in the two tanks can be accomplished by a vapor return line allowing the vapor displaced from the receiving tank to be returned to the supplier's tank. This will only be possible if the two tanks are at the same pressure, or if there is a way to control the pressure between the two tanks. Another option is to top spray in the receiver's tank or reliquefy or consume the displaced vapor from the receiving tank, while separately vaporizing LNG in the supplier's tank to maintain its positive pressure.

b) *Supplier's LNG is colder than receiver's LNG:* If the LNG in the supplier's tank is appreciably colder than the remaining LNG in the receiver's tank, the two tanks will likely be at different pressures and using the vapor return line is generally to be avoided, unless pressure control is provided on the vapor return line. Instead, filling of the receiver's tank can be done using the top spray line to cool and condense the vapor to control the pressure. The bottom fill line can be used as necessary to prevent too much vapor from being condensed. Depending on the amount of LNG being bunkered and the conditions in the tank, it might still be necessary to reliquefy or consume some of the vapor from the receiving tank to control pressure. Similarly, it might be necessary to vaporize some LNG in the supplier's tank to maintain pressure.

c) *Supplier's LNG is warmer than receiver's LNG:* If the LNG in the supplier's tank is appreciably warmer than the remaining LNG in the receiver's tank, the introduction of this warm LNG can cause rapid vaporization of the remaining LNG in the receiving tank and can result in a significant increase in tank pressure. Unless the receiving tank can handle this additional pressure or has some way of removing this sudden increase in vapor, it may not be possible to receive this warm LNG. This scenario is highly dependent on the condition of the LNG in both tanks, the capability of the supplier and receiver's LNG systems, and the amount of LNG being bunkered. Thus, contracts for the delivery of LNG bunkers should specify maximum LNG temperature at delivery.

6. **Level Monitoring:** The maximum allowable loading limit should be calculated based on the densities of the LNG remaining in the fuel tank and being bunkered. The level indicator should indicate the tank level throughout the operating range of the tank. A high liquid level alarm is to be fitted that is independent of the level indicator. A second independent high liquid level sensor should be provided that is capable of automatically initiating an emergency shutdown of the bunkering process.

7. **Fuel Supply During Bunkering:** It is important to note that depending on the fuel tank arrangement and gas consumption requirements during bunkering, it may be necessary to supply fuel at a specified minimum vapor pressure from the same fuel tank as being bunkered. If the fuel tank being bunkered must be maintained at a high pressure to maintain the fuel supply to an engine, the fuel supply pressure required at the bunkering flange can be quite high. The bunkering procedure manual kept on the ship should clearly indicate any such requirements or restrictions.

9 OPERATIONAL AND EQUIPMENT ISSUES FROM THE SUPPLIER SIDE

LNG supply can be from shore-based LNG facility or quay or from bunker vessels, typically a barge or a small ship. Which LNG supply method will be developed in a port depends on whether the source of LNG is local to the port or must come from some distance. Also, safety considerations, such as simultaneous cargo operations and other activities and hazards that occur on the pier or quay during bunkering, affect whether the LNG bunkering supply is from shore or from a bunker vessel located on the offshore side of the receiving vessel or alongside it at anchorage. Figure 7 illustrates some of the common types of bunker supply methods.

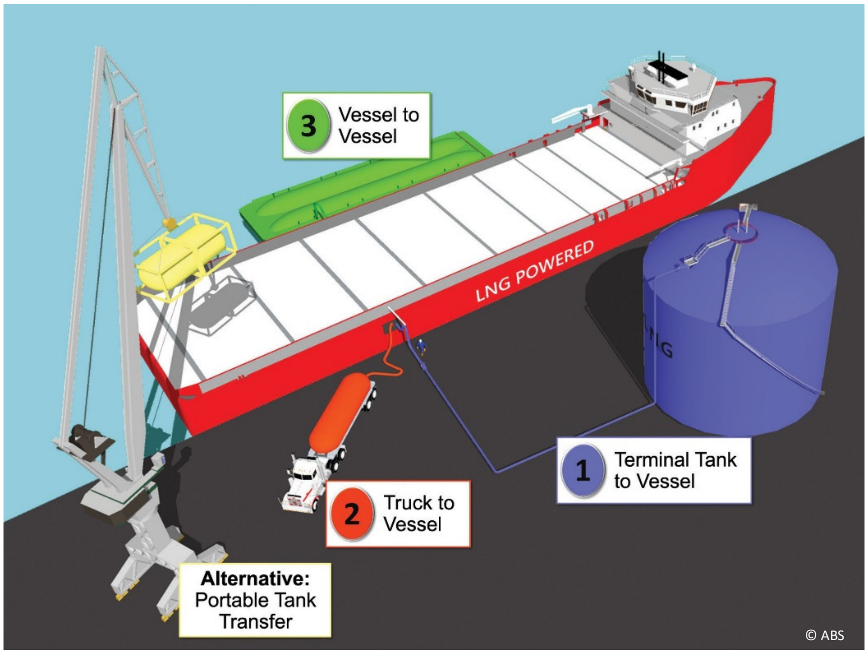


Figure 7. Typical Methods of Bunkering a Gas Fueled Ship

9.1 BUNKERING FROM ONSHORE FACILITY

The total LNG supply network from the gas source to the ship might involve multiple methods of transport. The following discussion will focus only on the supply from the onshore facility directly to the ship.

1. **Fixed Installation Ashore**: Fixed installations provide a bunker supply connection directly at the quay or pier of the LNG fueled ship. LNG is supplied from a storage tank located in or near the port. The LNG is transferred from the bunker supply connection to the ship through hoses or a moveable arm.

2. **Mobile Tanks Ashore:** Mobile LNG supply tanks can allow LNG fueled ships to refuel at a quay or pier if the port is not outfitted with a fixed LNG supply infrastructure. The mobile tanks can be brought to the quay or pier of the LNG fueled ship for bunkering through hoses.

   Another alternative could be to use portable LNG tanks (e.g., ISO tank containers) as the ship's fuel tanks. The fuel tanks, when empty, would be replaced by preloaded tanks. The preloaded tanks could be brought to the ship by truck or rail, and the empty tanks taken away to be refilled. This could shorten the overall bunkering duration. Refer also to ASTM F3285-18, *Standard Guide for Installation and Application of Type C Portable Tanks for Marine LNG Service*. This guide is intended to define and identify best practices for minimum requirements for the design, installation, and application of Type C portable tanks for marine service on LNG fueled vessels for service as a LNG fuel tank. These best practices provide added detail to the requirements in 6.5 of the IGF Code (5C-13-6/5 of MVR) to facilitate consistent and practical implementation of those requirements.

9.2 BUNKER VESSELS

The following sections highlight the characteristics of bunker vessels and how they relate to gas fueled ships. An advantage of using an LNG bunker vessel moored on the offshore side of the receiving ship or at anchorage is that this isolates the bunkering operation from the pier area, which should reduce LNG bunkering's impact on cargo operations and can reduce the consequences of an LNG incident.

1. **Bunker Barge:** LNG barges are expected to operate in a similar manner to oil fuel bunker barges. They can be pushed or towed by a tugboat and brought up alongside the LNG fueled ship for bunkering. The barge hull could vary greatly in design. It could be a simple deck barge with LNG storage tanks fitted on the deck or it could have one or more storage tanks fitted in the hull and likely protruding through the deck. It could be a traditional barge or an articulated tug barge (ATB) with the tug semi-rigidly connected to the barge. Larger bunker barges might be fitted with a hose handling crane that could be used to lift one end of the bunker supply hose to the receiving ship. In some instances, smaller bunker barges might rely on a davit fitted on the receiving ship to lift the hose end to the ship's bunker connection.

2. **Bunker Ship:** Typically LNG bunker ships will be small, manned, self-propelled vessels. These ships could have a greater LNG delivery range and a larger capacity than barges making them more suitable for bunkering larger LNG fueled ships or ships in remote ports located far away from natural gas sources. LNG bunker ships are typically designed, constructed, and operated in accordance with the IGC Code and class requirements for LNG carriers.

3. **Bunker Vessel Regulatory Requirements and Challenges:** In general, LNG bunker ships are considered gas carriers, and the vessels are to meet the requirements of the IGC Code and applicable class requirements. The IGC Code is mandated by SOLAS and applicable to internationally traded vessels. The regulatory challenge is for ships that will operate only in restricted or domestic services, in which case compliance with the IGC Code may not be required by the flag Administration or port authorities. The IGC Code is not directly applicable to barges so flag Administration, port authorities, and class requirements would apply, such as Section 5-2-5 of the ABS *Rules for Building and Classing Steel Barges* (SBR). Therefore, for certain operating profiles and types of bunker vessels, early communications with the flag Administration, port authorities and class are recommended.

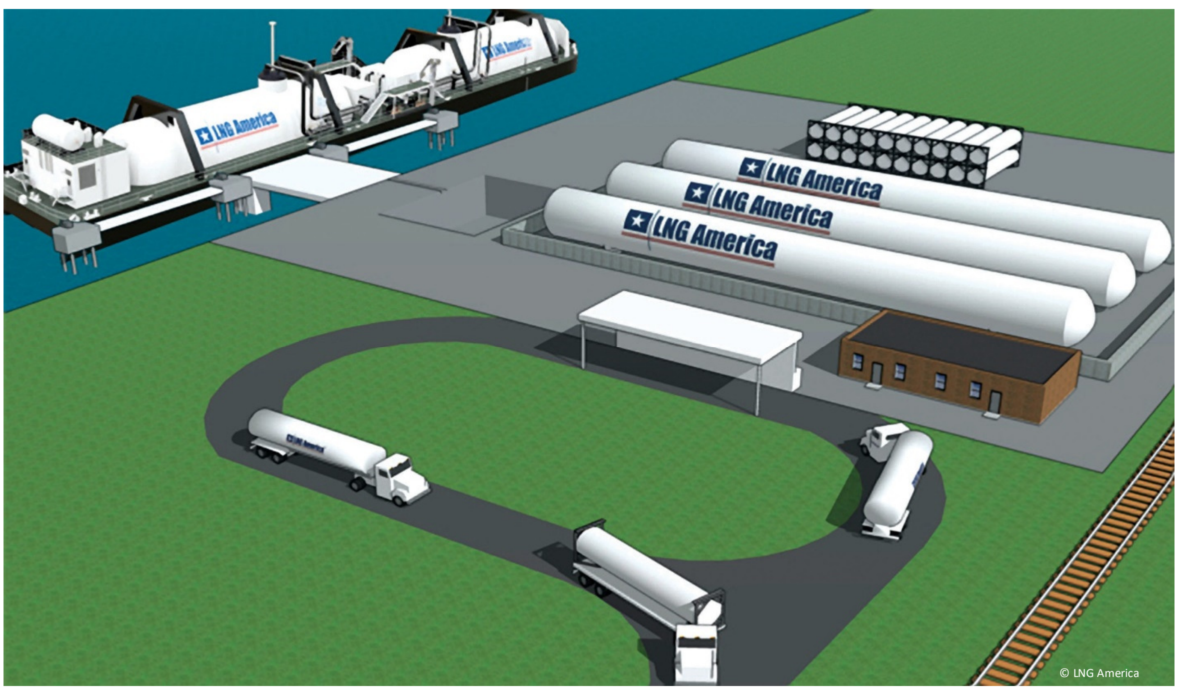


Figure 8. Marine Terminals for Loading LNG Bunker Barges, Trucks, ISO Containers and Third-party Vehicles

9.3 SUPPLIER'S TANK TYPES

Fixed tanks, installed onshore, can be either pressurized or atmospheric tanks. Large tanks (e.g., Type A, B, and Membrane) are more commonly atmospheric and have equipment to provide vapor control. Small, fixed tanks and mobile tanks (e.g., Type C) can be pressurized, which allows greater ability to match the pressure of the receiving tank.

Bunker vessels can be fitted with the same tank options as previously discussed for ship's fuel tanks. The requirements for LNG temperature and tank vapor control will vary greatly, depending on storage tank type and bunker vessel operational profile. For example, a bunker vessel that only sails within a single port and delivers LNG within a day or two of filling up may be able to use a pressurized LNG storage tank without the need for reliquefaction units or gas combustion units to control its LNG temperature and tank vapor pressure. However, most bunker vessels will incorporate additional means for BOG management and LNG temperature control to cover operational requirements, which may involve traveling long distances and/or spending many days between loading and delivering LNG. Ambient temperature also impacts boil-off rate and will affect tank and vapor control requirements along with the operational profile.

9.4 SUPPLIER'S TANK PRESSURE AND TEMPERATURE

The pressure and temperature inside the supplier's LNG storage tank is important to the receiving ship. Unlike fuel oil, LNG has a natural tendency to change properties after being loaded. As it warms, its vapor pressure increases, necessitating a higher tank pressure rating or a constant means of removing the vapor from the tank. Receiving ships will prefer to receive the coldest LNG possible. This allows the LNG to remain in the ship's fuel tank for a longer period of time.

9.5 EQUIPMENT AND OPERATIONAL ISSUES

1. **Fendering, Vessel Separation and Cryogenic Spill Protection:** Where required, a fender system should be provided to maintain separation and prevent damage to the receiving ship or the supplier's facility. Bunker vessel's mooring lines and fenders should be insulated such that an arc cannot pass between the two vessels. If an arc is allowed to occur, it could ignite any LNG vapor that escaped or was vented while bunkering. The supplier should be equipped with drip trays and water curtains as necessary to prevent damage occurring from cryogenic liquid spills. The supplier's facility also should be designed such that leaks or spills will not be directed onto the receiving ship's structure.

2. **Bunker Hose and Fittings:** Typically, the bunker hose is expected to be provided by the supplier. It should be suitably long and flexible, such that the hose can remain connected to both the supplier's manifold and the receiving ship's manifold during normal relative movements expected from wind, waves, draft changes, current, and surges from passing vessels. Typically, bunker hoses are constructed of composite materials and are flexible to allow for relative movements. The supplier should provide a bunker connection at the hose end that will match the receiving ship's connection. Refer to the ISO 20519:2017 and ISO/TS 18683:2015 standards for further requirements for hoses and bunkering connections and ISO 21593:2019 for the technical requirements for dry-disconnect/couplings.

   Additionally, the hose should be capable of releasing without damage or significant spills if the relative position or movement of the receiving ship exceeds the limits. LNG bunker hoses are typically fitted with connections that are of the quick connect type and remain sealed until the connection (drip-free type) is made. The receiver's end of the hose also will usually be fitted with an emergency release system (ERS), such as a drip-free, breakaway coupling that gives way before excessive pull causes the hose to break or other damage to occur. This type of coupling uses spring loaded shutoff valves to seal the break and stop any LNG or vapor release. Quick connect and break- away couplings are readily available in the market and minimize the possibility of LNG leakage and gas escape. Section 5C 8-5/11.7 of the ABS MVR can be referenced for more specific requirements pertaining to bunker (cargo) hoses.

3. **Hose Handling:** The LNG and vapor hoses are typically supplied and handled by the bunker vessel or shoreside bunkering facility with the assistance of the receiving ship's crew. The bunker vessel or facility may have a hose handling crane or boom which can lift the end of the hoses to the receiving ship's bunker station. For ships with bunker stations located unusually high above the waterline, it may be necessary for the ship to be fitted with a davit or crane which can be used to raise the end of the bunker hoses to the bunker station.

4. **Bunker Loading Arms:** Instead of bunker hoses, loading arms may be used for transferring LNG to the receiving ship. Loading arms generally consist of a rigid structure with swivel joints to allow for articulation of the LNG connection and relative movements between the receiving ship and the supplier, and may include a powered emergency release system. LNG fluid can pass through either a flexible hose supported within the arm or solid pipes with swivel joints. Loading arms will typically be more mechanically automated and eliminate some of the handling issues that are present with hoses, but loading arms can induce higher reaction forces on the bunker manifold that need to be considered in the design of the bunker station.

5. **Monitoring and Control:** Typically both the supplier and the receiving ship will have an emergency shutdown system. A complete emergency shutdown should be possible to initiate from either the receiving ship or the supplier. The supplier's and receiver's tanks will both have separate monitoring systems, but constant communication via radio or other methods should be available at all times.

6. **Fire Protection:** The bunker supplier should have an appropriate firefighting system or equipment as required by governing regulations. Typical systems include portable and fixed dry chemical systems and/or fixed water spray systems. Different regulations for these systems will apply depending if the supplier is a manned vessel, unmanned barge, tank truck, fixed installation onshore, etc., and may be dependent on the bunkering arrangement.

7. **Inerting and Purging Requirements for Hoses and Pipes:** Before bunkering begins, the hoses and associated pipe should be inerted with nitrogen gas and then purged with LNG vapor. After each bunkering, the hoses and associated pipes should be purged with LNG vapor and then inerted with nitrogen. Depending on the arrangement and capabilities of the receiving ship and the supplier, this can be done separately or while the bunker hose is connected to both manifolds. The requirements for inerting and purging should be determined before the bunker hoses are connected.

8. **Ignition Sources, Safety Zones and Vent Mast Locations:** All sources of ignition in the vicinity of the bunkering operation need to be eliminated before bunkering. To ensure this, a safety zone is established around the bunkering operation. Access near the bunker station and other high risk areas should be blocked to all passengers and non-essential crew before, during, and after bunkering, as necessary. Cargo operations should be suspended until bunkering is completed unless permitted by the SIMOPS arrangements. During bunkering, the bunker vessel should be positioned such that its vent mast is not near any openings on the receiving ship, or if mobile tanks are used they should be positioned such that any leaks will vent away from critical locations or openings on the receiving ship. If this is unavoidable due to the arrangements of the receiving ship, then these openings should be secured while the bunker vessel is alongside the receiving ship.

9. **Lighting, Platforms and Other Outfit:** The supplier should arrange adequate lighting to create a safe working environment. If adequate lighting cannot be provided at night or during inclement weather, bunkering should be postponed until suitable daylight exists. On bunker vessels, platforms and ladders should be placed to allow easy access to all required bunker connections, valves, and controls. Both the supplier and the receiving ship should have all necessary safety equipment and other gear available and ready for use before beginning the bunkering procedure.

10. **Personal Protective Equipment:** All personnel involved directly with LNG handling operations should wear personal protective equipment (PPE) including gloves, face protection and other suitable clothing to protect against LNG drips, spray, spills, and leaks. PPE is also required to protect against skin damage caused by contact with the cold pipes, hoses, or equipment. Although no standard exists for required PPE during bunkering procedures, guidance is provided by SIGTTO and others. Material Safety Data Sheets (MSDS) identify LNG health hazards and provide guidance for PPE, LNG handling, first aid, firefighting measures and firefighting equipment.

10 BUNKER OPERATIONS

It is important to note that LNG bunker procedures may vary greatly between projects, ships, and bunker facilities. The use of standardized procedures and checklists from existing projects may be helpful as guidance. However, vessel-specific procedures for the bunkering operation should be developed to include any characteristics or features that are unique to the particular bunkering facility and receiving vessel or location.

10.1 SEQUENCE

The following is a simplified bunker operation sequence. Actual sequences will vary depending on the supplier's and receiver's equipment and capabilities. More detailed sequences are currently available online from some ports, such as the Port of Rotterdam.

10.1.1 BEFORE TRANSFER:

1. Notify port authorities of intent to bunker, when required to do so.
2. Compatibility confirmed between the supplier and receiver regarding equipment, procedures and protocols.
3. Receiving ship moors alongside the quay or pier, or bunker vessel moors alongside receiving ship.
4. Security and safety zones are established.
5. Any pre-bunkering checklist, procedures, and communication protocols are completed and agreed between the supplier and receiver. Persons-in-charge are designated.
6. Communications, monitoring and ESD links have been established. ESD is to be tested.
7. Supplier evaluates tank pressure and temperature (depends on tank types and bunker procedure).
8. Firefighting equipment is readied for immediate use.
9. All safety systems, such as gas detection and alarms, are operational and have been tested.
10. Sufficient lighting is established.
11. All involved personnel put on required PPE.
12. Weather and sea conditions are deemed to be within established limits.
13. Electrical isolation or bonding connections, as applicable, are confirmed.
14. Water spray curtains and drip trays, as applicable, are in place.
15. Supplier's bunker hoses or transfer arms are connected between the supplier's and receiving ship's manifolds.
16. Supplier and/or receiver should inert and then gas up and cool down all required bunker lines and equipment that will be utilized.
17. LNG transfer starts.

10.1.2 DURING TRANSFER:

1. Monitor tank levels.
2. Monitor tank pressures and temperatures.
3. Monitor pump transfer rates.
4. Adjust pump flow rates as necessary.
5. Adjust top spray and bottom fill rates as necessary to control tank pressure.
6. Adjust mooring lines and bunker hoses and arms as necessary.
7. Monitor that the integrity of security and safety zones is maintained. Monitor that weather and sea conditions remain within limits.

10.1.3 AFTER TRANSFER:

1. LNG transfer stops.
2. LNG in lines is allowed to vaporize and displace the remaining liquid back to the tanks.
3. Supplier and receiver inert all bunker lines and bunker hoses utilized during the bunker operations.
4. Supplier's bunker hoses, communications, monitoring, ESD and electrical isolation or bonding connections are disconnected from the receiving ship's manifold.
5. Receiving ship unmoors from the quay or pier, or bunker vessel unmoors from the receiving ship and notifies port authority.

10.2 EMERGENCY PROCEDURES

Emergency response planning and preparedness are critical to protect personnel, the environment, the public and assets during an incident. In addition to the typically required emergency response plans aboard the ship, specific plans relevant to an emergency involving the LNG system and bunkering operations also should be developed and implemented. The IGF Code requires that such emergency procedures are to be provided and that drills and emergency exercises shall be conducted on board at regular intervals - see IGF Code sections 17 and 18.2.4 (MVR 5C-13-17 and 5C-13-18/2.4).

Emergency procedures can be classed as 'higher level' and 'lower level'. Higher level procedures are intended to provide general instruction to all relevant personnel, while lower level procedures are more specific to certain incidents, areas aboard the vessel, or equipment. The emergency procedures are intended to provide guidance and direction on how to carry out an organized and effective response to an incident, which may include LNG spill and/or gas release, fire, or other hazardous situation. Some possible incidents that directly affect bunkering are loss of power by the supplier or receiver, non-LNG related fire near the bunkering, unexpected breakaway of one of the vessels, etc. Emergency procedures also should exist for other external incidents not directly related to the bunkering, such as a fire or gas release on a quay, pier or bunker vessel. Other emergency procedures should handle incidents relating to injury sustained by personnel involved in bunkering, such as frostbite induced by contact with extremely cold LNG or equipment.

It is important that personnel from both the supplier and the receiving ship are familiar with and trained in the emergency procedures and have access to them at all times. The training, drills, and exercises should ensure that all involved personnel understand the procedures, their role and responsibilities, and the use of the emergency response equipment available at the supplier and aboard the receivingship.

The emergency procedures can be updated to reflect lessons learned from previous incidents or exercises or to reflect any modifications made by the supplier or receiving ship. SIGTTO and other agencies have developed numerous publications specifically related to the hazards of LNG which can be referenced when developing emergency response procedures.

10.3 RESPONSIBILITIES

A designated person-in-charge (PIC) should be present for every LNG bunkering operation from both the receiving ship and the supplier's side. Aboard the receiving ship, this person-in-charge is normally an officer permanently assigned to the ship who has the proper training and experience with all relevant characteristics of the ship for the purposes of LNG bunkering. This includes the LNG bunkering systems and procedures, monitoring and control systems, shipboard emergency equipment and procedures, and pollution reporting procedures. The supplier also should have a person-in-charge who is familiar and experienced with all aspects of the supplier's bunkering equipment and procedures. Both persons-in-charge should coordinate the bunkering operation and have an adequate understanding of the other party's bunkering capabilities and responsibilities before starting the operation. Both persons should have complete responsibility for their side of the bunkering operation and should be present for the entire duration. Refer also to IGF Code 18.4.1 (MVR 5C-13-18/4.1) for the PIC bunkering operation responsibilities.

10.4 MANNING

Well-designed bunker facilities and LNG fueled ships may only require one or two people each during a typical bunkering operation, but additional crew will be necessary for normal vessel operations and should be available in case of emergency or other circumstances. The number of bunker supplier personnel depends on the method of supply (e.g., truck, barge, ship or fixed facility). Actual manning requirements will be dependent on the bunker procedure, facilities, and regulatory requirements. All personnel involved in the bunkering operation should have the necessary training and certification.

10.5 PROCEDURES AND MANUALS

Port state regulatory requirements will typically require operational procedures and manuals for bunkering gas-fueled ships such as:

- *LNG Fuel Transfer Systems Operation Manual*
- *Emergency Manual*
- *Maintenance Manual*

The manuals and procedures should be readily available during bunker operations. Before beginning any bunker operations, both the supplier and the receiver should ensure that the receiving ship's procedure is compatible with the supplier's transfer procedure and the procedure to be followed is agreed by both parties.

10.6 CHECKLISTS

Part of the LNG bunker operation includes the completion of checklists before and after bunkering by the persons-in-charge. The checklists serve to ensure that all requirements for bunkering have been completed in the correct order. Checklists should be specifically developed for each receiving vessel in accordance with the regulations and circumstances applicable to that vessel and the expected type of bunker supply and bunker location. The following lists items that are typically included in LNG bunker operation checklists. It is for illustration purposes and for actual bunkering a more detailed list may be required. There are also many sample checklists available from industry organizations, published standards and guidance documents, for example those published by IAPH (International Association of Ports and Harbors), ISO/TS 18683:2015, ISO 20519:2017 and SGMF's bunkering safety guidelines.

10.6.1 BEFORE BUNKERING:

1. Verify all required notifications were issued and permissions received from port authorities.
2. Confirm that the bunker operation security and safety areas have been established and only required personnel are present within their boundaries. Confirm all required separation distances to at risk locations are in place.
3. Confirm that all accessible portions of the bunker piping system and equipment to be used have been inspected and worn or inoperable parts replaced.
4. Review and agree with the supplier's person-in-charge as to:
    a. The sequence of transfer operations
    b. The transfer rate and transfer quantity, plus which tanks are to be filled
    c. Compatibility of the hazardous zones between the supplier and receiver
    d. The duties, location and watches of each person assigned for transfer operations
    e. Methods of inerting and purging bunker lines and handling of any nitrogen used in the inerting process
    f. Method of handling vapor in the receiving tanks
    g. Emergency procedures
    h. Pressure, temperature, and volume of supplier's tanks and confirmation they are safe for transfer to the receiving ship's tanks
5. Confirm that the transfer connections (hose or arm) can allow the ship to move to the limits of its moorings without placing strain on the manifolds.
6. Confirm proper fit up of bunkering connection.
7. Confirm that all vessels are properly moored and that adequate measures are in place to account for changes in tides, winds, and currents, and for any surges.
8. Confirm that weather and wind are within allowed criteria and that the forecast over the bunker time period confirms they will remain so.
9. Confirm proper lighting of the bunkering operation, including all bunker lines, is in place to allow visual checks.
10. Confirm that all ignition sources in the bunker operations areas and any other hazardous areas (e.g., around tank vents) have been eliminated.
11. Confirm all openings to non-safe interior spaces are closed.
12. Confirm that drip trays and water curtains are in place and operable.

13. Confirm all required personnel are in place according to the LNG fuel transfer system operations manual. All personnel are wearing any required PPE.
14. Confirm language fluency.
15. Confirm firefighting equipment is ready for use.
16. Confirm electrical isolation or bonding is in place.
17. Confirm the following systems have been tested and operate properly in accordance with the operating procedures:
    a. Sensing and alarm systems
    b. Emergency shutdown (ESD) system
    c. Communication systems
18. Confirm the receiving vessel bridge has been informed that the bunkering operation is about to commence.

10.6.2 DURING BUNKERING:

1. Continuous communication is possible with the supplier's person-in-charge.
2. Inspect all accessible portions of the bunker piping system and equipment for leaks, defects and other issues at regular intervals.
3. Monitor that level and pressure gauges in the receiving tanks continue to function and that levels and pressures remain within allowed values.
4. Monitor that the integrity of the safety and security zones is maintained.
5. Ensure bunkering is stopped and hoses properly disconnected upon notification or detection of electrical storms, high winds, or other contingencies identified in the emergency manual.

10.6.3 AFTER BUNKERING:

1. Confirm tank levels are within the allowable loading limit and the custody transfer is agreed.
2. Confirm bunker hoses, manifold, and piping are properly drained and free of residual LNG.
3. Confirm bunker hose is properly inerted prior to disconnecting.
4. Confirm all communications, monitoring, ESD, electrical isolation or bonding connections are safely disconnected and secured.
5. Confirm bunker manifold connections are securely blanked.
6. Confirm port authority has been notified of bunkering completion.

10.7 CREW TRAINING AND CERTIFICATION

Proper crew training is essential to promote safe LNG bunkering practices. Those involved with bunkering should receive comprehensive, formal training, including emergency response training to deal with conditions of leakage, spillage, or fire and first aid training specific to LNG. The courses will generally cover basic training for all ship's crew and more advanced training for the ship's crew responsible for handling LNG and operations associated with LNG. Crew training courses for LNG handling typically could take three to five days. The courses should cover LNG fundamentals, hazards, safety, fire prevention and firefighting and person-in-charge responsibilities and procedures.

Any ship-specific training procedures should be reviewed and approved by a governing regulatory agency. However, training courses are still under development. Part D of the IGF Code details the training requirements for seafarers' onboard ships subject to the IGF Code which use gases or other low-flashpoint fuels. This requires that operators shall ensure relevant training has been completed, taking into account the IMO International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (the STCW Convention and Code). These IMO instruments were amended at the same time as the adoption of the IGF Code by MSC.396(95) and MSC.397(95) to cover the range of potential new fuels. The STCW contains requirements in Section A/V3 tables A-V/3-1 and A-V/3-2 for a minimum standard of competence in basic and advanced training, respectively, for ships subject to the IGF Code. The basic training for seafarers is required for those with "… *designated safety duties associated with the care, use or in emergency response to the fuel* …" and advanced training is required for "… *Masters, engineer officers and all personnel with immediate responsibility for the care and use of fuels and fuel systems on ships subject to the IGF Code* …". Vessels under the jurisdiction of flag Administrations signatory to SOLAS should ensure that seafarers should have the specified certificates of proficiency and the Administration shall approve courses and issue endorsements indicating completion of the qualification.

11. COMMERCIAL ISSUES AND CUSTODY TRANSFER

11.1 PRICING BASIS

The basis of pricing for LNG is normally related to the energy content of the fuel. LNG is often priced in terms of energy with units of $/kJ or $/MMBTU, while the energy content often has units of kJ/kg or BTU/lb. However, quantities of LNG must physically be measured either by volume or by mass. Selling LNG based on volumetric readings is only accurate if the energy content is corrected for density at the time of bunkering, most likely by measuring the temperature of the fuel. Measuring by mass is less complicated because corrections do not need to be made for density. However, the chemical composition will vary depending on the initial gas source, and also can change, along with density, as the LNG vapor is allowed to boil off. Therefore, the energy content can vary significantly between ports, between suppliers in a port, from day to day for the same supplier, and even from the beginning to the end of the bunkering operation. Therefore, it is essential to obtain an accurate energy content at the time of bunkering for accurate pricing. The transaction between the LNG supplier and receiver to determine the amount and price of fuel delivered is called the custody transfer.

11.2 CUSTODY TRANSFER

Proper custody transfer involves measurement of both energy content and quantity of LNG transferred. In order to obtain an accurate quantity of bunkered LNG, an accurate determination of either the total volume or total mass of transferred LNG is required. Typically, the LNG supplier will be better equipped to measure the volume of LNG transferred and the properties of the fuel than the receiving ship.

For the simplest bunkering scenarios, LNG volume measurements in the tanks can be taken before and after bunkering to determine the total volume transferred. For smaller tanks, such as those on truck trailers or railcars, it may be possible to weigh the tanks to determine the total mass transferred.

Another custody transfer option is to use continuous metering which can be performed using Coriolis (mass) flow meters or ultrasonic (volumetric) flow meters installed in the LNG supply line. Flow meters can be accurate to ± 0.25 percent, but the accuracy of continuous metering relies heavily on proper calibration of the equipment.

Some issues with the different custody transfer methods need to be considered. If the supplier's tank is very large and used for the LNG transfer measurements (as opposed to the ship's tanks) any inaccuracies in the measuring equipment will be magnified due to the size of the tank. If the supplier consumes LNG during bunkering to operate its own gas fueled engines, the consumed volume also should be considered so that it is not counted toward the total quantity of bunkered fuel. Similarly, if the supplier bunkers more than one ship at a time from the same LNG supply tank, measurements will have to be taken from the ship's tank, or the liquid will have to be continuously metered during bunkering to determine the quantity transferred.

If the properties of the LNG change significantly during the bunkering process, it might be necessary to determine the energy content before, during, and after bunkering in order to determine an accurate price basis. This can be done by measuring the temperature or density of the fuel at intervals and correcting the energy content accordingly. A more accurate method would be to use a gas chromatograph to analyze the chemical composition of the fuel.

11.3 FUEL SPECIFICATIONS AND QUALITY

Much like oil fuel, the LNG fuel specifications will need to be agreed upon between the supplier and receiver for the purposes of custody transfer and to ensure compatibility of the fuel with the receiver's gas fueled engines.

A standard format Bunker Delivery Note (BDN) has been incorporated within the IGF Code, and which includes sufficient parameters to define the LNG properties, composition and delivered quantities. ISO has also published the ISO 23306:2020 standard, *Specification of liquefied natural gas as a fuel for marine applications*.

Aging: The characteristics of LNG fuel change as it sits in a tank without being consumed. This is referred to as 'aging' and may be undesirable. As the LNG warms, the lighter more volatile components will typically vaporize first, leaving behind the heavier components still in liquid form. This not only increases the density of the LNG, but also can change calorific values and quality. For ship's utilizing vapor return during bunkering, a similar effect will occur as the lighter vapor is removed from the tank leaving behind the denser LNG. It is important to account for these changes to ensure that the LNG present in the tanks will be suitable at all times for consumption in the ship's engines.

Wobbe Index: Significant variations in gas composition can cause changes to the gas fueled engine's combustion efficiency and energy content. Therefore, the energy content should be understood. The Wobbe Index (I_W) is used to compare the combustion energy of different gases, and is typically measured at nominal temperature (0°C, 32°F) and pressure (1 atm, 14.695 psia). The Wobbe Index is calculated as follows:

$$I_W = \frac{V_C}{\sqrt{G_S}}$$

where V_C is either the higher or lower calorific value with units of MJ/Nm^3 or BTU/scf and G_S is the specific gravity compared to air.

It is important to be consistent with the calorific values (i.e., higher or lower value for both gases being compared) used when comparing the Wobbe Index of different gases. Wobbe Index variations of up to 5 percent between gas sources are typically not noticeable to the consumer.

Methane Number: The LNG composition will determine the methane number, which is an indicator of the vaporized LNG ignition quality for internal combustion engines and is of relevance to Ottocycle gas engines and the onset of engine knocking. If the methane number of the fuel is too low, the engine can be damaged by excessive knocking, or a significant loss in performance and efficiency can result if engine operation must be adjusted to avoid knocking. Gas fueled engine manufacturers typically specify a minimum required methane number to indicate the quality of LNG fuel that can be burned in the engine without issue. The method used to calculate methane number might vary slightly between engine manufacturers, so it is important to utilize the correct calculation method for the actual engine installed. A number of online methane number calculation tools are available from the engine designers, however the IGF Code sample BDN makes reference to the calculation method in the DIN EN 16726 standard. The International Council on Combustion Engines (CIMAC) provides further information on the impacts of gas quality on gas engine performance and other relevant position papers, together with software for calculating methane number in accordance with the Euromot MWM tool.

As a reference, pure methane has a high knock resistance and is given a methane number of 100. Hydrogen has a low knock resistance, compared to methane, and is given a methane number of 0. A gas that is composed of 80 percent methane and 20 percent hydrogen has a methane number of 80. Typically dual fuel engines (Otto cycle gas mode) require a minimum methane number of 80, whereas gas only engines require a minimum methane number of 70.

Unlike the Wobbe Index, the methane number cannot be used to determine the energy content of the fuel. This is because the fuel can be composed of a large percentage of inert gas, such as nitrogen. This inert gas does not affect the methane number, but it does affect the higher calorific value of the gas, which will affect the Wobbe Index and indicate a difference in energy content. Depending on the fuel gas system used, the gas composition supplied to the engines can be very different from the composition of the LNG. For example, the nitrogen content in LNG is small, typically under 1 percent, but if the fuel gas is supplied from the vapor phase in the fuel tank (boil-off gas) the nitrogen content could be as high as 20 percent. If vaporized LNG is used as the fuel source, the methane number of the LNG will decrease over time as part of the aging process. Accordingly, LNG bunkered ‘on-spec’ could become ‘off-spec’ over time.

12.0 REGULATORY FRAMEWORK

12.1 REGULATORY ORGANIZATIONS AND REQUIRED APPROVALS

Bunkering with LNG is a process that presents a number of unique risks and hazards not seen with oil fuel bunkering. For that reason, most regulatory organizations having jurisdiction over vessel design, operation, and bunkering are focusing their attention on it. Many new regulations and requirements are being developed and implemented, so keeping abreast of the regulatory framework is important to anyone involved with LNG bunkering.

The primary organizations that will be involved with reviewing LNG bunkering system designs and arrangements, as well as possibly the fueling procedures, are as follows.

12.1.1 CLASSIFICATION SOCIETIES

Classification societies, such as ABS, will have a major role in reviewing the design and construction of LNG bunkering systems on board gas fueled vessels (receiving ships) and any LNG bunker vessels. Besides reviewing the design and surveying construction according to its own Rules and standards, class societies may be the reviewing organization for compliance with national and international regulations on behalf of the flag Administration and some port States.

ABS has prepared classification requirements for vessels that will adopt LNG as fuel, and which are included in Chapter 5C-13 (IGF Code) of the ABS *Rules for Building and Classing Marine Vessels* and are available for download from the ABS website (www.eagle.org). These requirements address the arrangements required at the bunkering station of a gas fueled vessel. Chapter 5C-8 (IGC Code) of the ABS *Rules for Building and Classing Marine Vessels* is also available for download from the ABS website and addresses LNG cargo vessels that would supply LNG as a bunker fuel.

ABS developed a report, *Bunkering of Liquefied Natural Gas-fueled Marine Vessels in North America*, that can be used as a reference for understanding the regulatory framework. The detailed report provides an overview of LNG supply in North America and the regulations and requirements that apply to bunkering operations in both the United States and Canada. The report is available for download from the ABS website (www.eagle.org) and is a useful supplement to this Advisory.

12.1.2 FLAG ADMINISTRATIONS

Flag Administrations, such as the USCG, the UK Maritime and Coastguard Agency (UK MCA), and other national maritime agencies, have primary responsibility for enforcing international and national regulations related to the bunkering systems, processes, and procedures. International regulations are primarily those issued by IMO. National regulations apply to vessels registered in that country. Most of the nations where LNG fueled vessels will be actively operating have developed, or are in the process of developing, national regulations. National regulations can be more restrictive than class Rules or international regulations. Some flag Administrations may delegate all or part of their review and approval process to classification societies (acting as Recognized Organizations), while others will carry out the review and approvals themselves.

12.1.3 PORT STATES

Port States are actively involved in the LNG bunkering process because they are the locations where the actual bunkering process will take place and, thus, any of the risks to life, environment, and property will be borne in their waters. The port State will have primary jurisdiction over any land-based facilities that may be part of the LNG bunkering process. Port State regulations will likely cover more parts of the bunkering process than either class Rules or flag Administration regulations. For example, port States could include requirements on the actual bunker procedure, locations where bunkering is permitted, restrictions on bunkering times and weather conditions, simultaneous cargo operations, bunkering supply facility, training, required documentation, acceptability of risk assessments, permits, etc. Since port States (and local jurisdictions within the port State, such as port authorities, harbor masters, and local and regional governments) can have a broad authority over the bunkering process it is important to determine early on which ones will be involved, particularly at the local or port level.

12.1.4 REQUIRED APPROVALS

Classification societies, flag Administrations and port States will likely each require review and approval of some aspects of the receiving gas fueled vessel and/or the bunker supplier. The flag Administration and port States are also likely to require the review and approval of the LNG bunkering procedures. The approval process has the potential to be far more extensive than for oil fuel bunkering because of the additional complexity and hazards encountered with LNG. In order to reduce the risks for major design changes and delays, it is critical that the approval process be initiated early on in the development of a project involving an LNG fueled vessel or an LNG bunkering supply facility or vessel. Design details and operating procedures may be specific to a variety of different bunkering scenarios, bunkering vessel types and bunkering locations, so the preparations for the approval process may need to be quite comprehensive. Detailed consultation and collaboration with the classification society and the regulatory organizations are recommended. All parties involved in the project development should be prepared to submit detailed designs, reports, analyses and procedures to the multiple reviewing organizations.

Approvals may need to be revisited or applied for anew because regulations are in the process of being finalized and, thus, there may be a need to re-apply when final regulations are issued. As bunkering scenarios and bunker suppliers change overtime, new approvals also will likely be required.

12.2 OVERVIEW OF REGULATIONS

There are a wide variety of regulations and requirements applicable to an LNG bunkering operation because of the multiple organizations with jurisdiction over it. This section will highlight some of the major ones.

12.2.1 INTERNATIONAL MARITIME ORGANIZATION (IMO)

The IMO has the primary responsibility for the development of requirements for ships involved in international voyages. There are specific references that apply to LNG fueled vessels in the two primary IMO regulations applicable to vessels – SOLAS and MARPOL. But the primary regulations addressing vessels that have LNG on board are found in the IMO Codes as follows.

IGC Code: The *International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk* (IGC Code) is the primary code for LNG carriers. The IGC Code is applicable to any internationally trading bunker supply vessel to which SOLAS is applicable or when required to be applied by class, national or port regulations. It is not applicable to vessels that carry LNG as engine fuel only. However, it provides criteria for LNG carriers using LNG cargo boil-off as fuel and has been used as guidance in the development of rules and regulations intended to be applied to LNG fueled vessels. The IGC Code has been in effect for many years and reflects the knowledge gained from years of safe and reliable LNG transport across the oceans.

IGF Code: The *International Code of Safety for Ships using Gas or Other Low Flashpoint Fuels* (IGF Code) is the mandatory code for all ships (other than those falling under the scope of the IGC Code) burning gases or other low-flashpoint fuels and was adopted by IMO resolution MSC.391(95) in June 2015 with an entry into force date of 1 January 2017. SOLAS has historically prohibited the use of low-flashpoint fuel oils less than 60˚C, therefore at the same time IMO adopted the IGF Code, the amendments to SOLAS making the IGF Code mandatory (by including a new Part G to SOLAS II-1) were also adopted by IMO Resolution MSC.392(95). The IGF Code is applicable to all new ships, and ship conversions, over 500GT using low flashpoint fuels for which the building contract is placed on or after 1 January 2017. In the absence of a building contract, the IGF Code is applicable to those ships with a keel laid on or after 1 July 2017, or the delivery of which is on or after the 1 January 2021.

The adopted IGF Code includes detailed prescriptive requirements for natural gas under Part A-1. The IGF Code also includes requirements for risk assessment, but for natural gas this need only be applied to the specific sections of Part A-1 of the IGF Code referenced by 4.2.2 of the IGF Code.

Other low flashpoint fuels may also be used as marine fuels, provided they meet the intent of the goals and functional requirements of the IGF Code and provide an equivalent level of safety. The approval process for this is by application of the 'Alternative design' criteria under 2.3 of the IGF Code and equivalency shall be demonstrated as specified in SOLAS II-1/55. The adopting SOLAS amendments for the IGF Code included amendments to capture these additional low flashpoint fuel references under SOLAS II-1 Part F Regulation 55, the IMO Alternative design and arrangements regulation.

12.2.2 INDUSTRY STANDARDS

ISO/TS 18683:2015: An ISO technical specification titled *Guidelines for Systems and Installations for Supply of LNG as Fuel to Ships* was released in January 2015. It describes the properties of LNG, the safety hazards, the risk assessment process, and the functional requirements for LNG bunkering systems. While ISO/TS 18683:2015 is not specifically a standard or regulation, it is expected to be cited in many national and local regulations. Under the ISO procedures this technical specification would subsequently either be further updated, converted to a full standard or be withdrawn if replaced by a different standard; it is currently indicated by ISO as to be replaced.

ISO 20519:2017: This standard titled *Ships and marine technology – Specification for bunkering of liquefied natural gas fuelled vessels* sets requirements for LNG bunkering transfer systems and equipment used to bunker LNG fueled vessels, which are not covered by the IGC Code. This document includes the following five elements:

1) hardware: liquid and vapor transfer systems;
2) operational procedures;
3) requirement for the LNG provider to provide an LNG bunker delivery note;
4) training and qualifications of personnel involved;
5) requirements for LNG facilities to meet applicable ISO standards and local codes.

ISO 21593:2019: This standard titled *Ships and marine technology — Technical requirements for dry-disconnect/connect couplings for bunkering liquefied natural gas* specifies the design, minimum safety, functional and marking requirements, as well as the interface types and dimensions and testing procedures for dry-disconnect/connect couplings for LNG hose bunkering systems intended for use on LNG bunkering ships, tank trucks and shore-based facilities and other bunkering infrastructures.

12.2.3 NATIONAL REGULATIONS

Some nations are in the process of issuing their own regulations covering the LNG bunkering process. Some of the key regulations are as follows.

United States: In the USA, the USCG is the lead agency with oversight over LNG fueled vessels and LNG bunkering. It has issued several documents pertinent to LNG bunkering:

1. Policy Letter CG-521 01-12: Equivalency Determination – Design Criteria for Natural Gas Systems. This document supplements the recommendations contained in the IMO resolution MSC.285(86) with USCG interpretations and supplementary requirements.
2. Policy Letter CG-521 01-12, Ch-1: Equivalency Determination – Design Criteria for Natural Gas Systems. This document supersedes previous Policy Letter 01-12 and supplements the recommendations contained in the International Code of Safety for Ships Using Gases or Other Low-Flashpoint Fuels (IGF Code) with USCG interpretations and supplementary requirements. It is applicable to US flag LNG fueled vessels, and is relevant to LNG bunkering by covering the bunkering equipment and systems on the receiving vessel.
3. Policy Letter CG-OES 01-15: Guidelines for Liquefied Natural Gas Transfer Operations and Training of Personnel on Vessels using Natural Gas as Fuel. This policy letter provides USCG guidelines for LNG transfer operations and training of personnel working on US and foreign flagged vessels. It includes guidance on the required manuals, equipment and systems, as well as crew responsibilities and training.
4. Policy Letter CG-OES 02-15: Guidance Related to Vessels and Waterfront Facilities Conducting Liquefied Natural Gas (LNG) Marine Fuel Transfer (Bunkering) Operations. This policy letter focuses on the safety aspects of the LNG transfer (bunkering) operation and provides safety and security recommendations for the supplier. It covers transfer operations that are from vessel to vessel, from mobile tank to vessel, and from waterfront facility to vessel that occur in the USA.
5. USCG CG-OES Policy Letter No. 01-17 - Guidance for Evaluating Simultaneous Operations (SIMOPS) during Liquefied Natural Gas (LNG) Fuel Transfer Operations. This policy letter provides guidance to Coast Guard Captains of the Port (COTPs) considering safety issues associated with SIMOPS which are planned to occur at facilities regulated pursuant to 33 Code of Federal Regulations (CFR) Part 127 – Waterfront Facilities Handling LNG.
6. LGC NCOE Field Notice 01-2017 – 14-Aug-17 - Recommended Process for Analysing Risk Of Simultaneous Operations (SIMOPS) During Liquefied Natural Gas (LNG) Bunkering. This field notice provides recommendations for the marine industry and USCG COTPs to follow when considering the risks of LNG SIMOPS. It includes guidance on an optional, formal operational risk assessment, if the vessel operator chooses to conduct one.

These policy documents serve as guidance for USCG Headquarters and Sector reviews of proposed gas fueled vessels, bunkering facilities and bunkering operations until the final regulations are developed and approved.

Any LNG bunkering operation that is planned for US waters will need to be approved by the local USCG COTP. This will involve providing documentary evidence, procedures, and any safety assessments required by the COTP to demonstrate that the bunkering process is safe, sufficient safety and security zones are provided, trained personnel will manage the bunkering operation, and that it follows the regulations. For waterfront facilities where LNG bunkering will take place, additional regulations and safety assessments are applied in order to obtain approval from the COTP for bunkering operations.

Canada: Transport Canada has issued TIER I - POLICY (RDIMS: 11153519) – *Requirements For Vessels Using Natural Gas As Fuel*.

This policy letter primarily addresses ships which use LNG as a marine fuel as regulated by the IGF Code. The Policy letter also addresses the evaluation of associated bunking operations. This policy applies to all Canadian vessels of 24 meters or more in length, which intend to use a type of fuel covered by the IGF Code. This policy will apply to new buildings constructed under the SOLAS regime, and existing buildings built under SOLAS or the Canadian regime, which are being converted to use low flash point fuels, such as LNG or CNG.

In order to meet the requirements for natural-gas fuelled vessels, the Authorized Representative (AR) of the Canadian flag vessel in question must:

a. Apply for a Marine Technical Review Board (MTRB) equivalency;

b. Apply the requirements of the IGF Code;

c. Apply the Canadian modifications, as set out in the Annex to this policy; and

d. Apply the Ship Classification Rules of a Canadian Recognized Organization applicable to the type of vessel, including the provisions for the use of natural gas as a fuel.

Regarding LNG bunker vessels or bunker facilities, currently there are no Canadian regulations directly applicable to them. There are a number of resources currently available that may be applied to develop the Canadian regulatory framework for bunkering facilities. The existing international regulations, codes (such as IGC for a bunker vessel), standards and guidelines most relevant to LNG bunkering and an LNG facility should be referred to when developing a regulatory framework for obtaining approval of a bunker vessel or facility in Canada. A similar review process as described above for a LNG fueled vessel can be expected for the LNG supply vessel or facility.

Canadian provinces are developing a number of provincial regulations, depending on the facility's characteristics and location. Similar to the national regulatory framework, provincial regulations are not yet developed to explicitly address LNG bunkering; however, there are existing regulations that may be applied. Examples include:

- British Columbia: Oil and Gas Activities Act (SBC 2008, Chapter 36)
- Nova Scotia: Gas Plant Facility Regulations (Section 29 of the Energy Resources Conservation Act)

There are additional provincial government agencies that will cover various aspects of LNG bunkering operations and facilities, including energy, natural resources, transportation, and environmental protection. Agencies will vary from province to province and should be identified, and their requirements addressed as part of the development process.

Owners and operators of Canadian LNG bunker vessels should take into account the existing Marine Personnel Regulations established by Transport Canada under the Canadian Shipping Act of 2001. In addition, mariners responsible for the supervision of LNG cargo transfer, including LNG being transferred to a gas-fueled vessel, are required to have a specialized certificate as Supervisor of a Liquefied Gas Transfer Operation.

Europe: The use of LNG as vessel fuel in non-LNG carriers was developed first in Europe, particularly in Norway. Regulations and requirements for LNG bunkering in the early projects in Norway were developed on a case by case basis. Reference was made to the guidelines and standards for LNG cargo transfer and to risk assessments for the planned bunkering operation. Currently, in some places in Northern Europe LNG bunkering is a daily occurrence, including bunkering taking place with simultaneous cargo and passenger operations, and in these instances an appropriate safety and regulatory framework was developed for that particular port, but it is well recognized in the European Union (EU) and countries outside the EU, such as Norway, that a more comprehensive regulatory framework is needed.

In anticipation of the growing use of LNG as a fuel in Europe, the European Maritime Safety Agency (EMSA), national governments, port authorities and regional planning groups have carried out studies on what regulations and standards are currently applicable to LNG fuel use and bunkering and what gaps exist that should be filled by new regulations and standards. One key study issued in 2012 was a final report based on an EMSA commissioned study on standards and rules for bunkering gas fueled ships. It provides a comprehensive overview and gap analysis of the regulatory framework for LNG bunkering in Europe.

The EMSA study identified many gaps that existed in the regulations for LNG bunkering at that time. It advised that many of the existing regulations and best practices for LNG cargo transfer from ship-to-shore and from ship-to-ship, such as ISO 28460, *Installation and Equipment for Liquefied Natural Gas – Ship-to-shore Interface and Port Operations* and SIGTTO's publication, *LNG Ship-to-Ship Transfer Guidelines*, plus some applicable EN standards and national regulations, can be used as references, but specific regulations and standards for bunkering of LNG fueled vessels should be developed. The ISO/TS 18683:2015 document filled in some of the gaps.

Since then, the European (and global) LNG bunkering infrastructure has developed further and industry bodies, such as SGMF, provide online database information on LNG availability around the globe. Furthermore, EMSA published their comprehensive *Guidance on LNG Bunkering to Port Authorities and Administrations* in January 2018 to fill in some of the regulatory gaps and provide guidance to ports on LNG bunkering and permitting. This guidance does not replace any national or local regulations or standards that may be applicable but is complementary and aimed at harmonizing requirements throughout ports in Europe.

As LNG use increases, it is expected that many other ports will offer LNG bunkering, even if just by truck. As part of the EU's Trans-European Transport Network (TEN-T) program, a directive has been established targeting refueling capabilities in a sufficient number of TEN-T seaports by 2025 and inland ports by 2030. TEN-T funding has already been made available for development and construction of several LNG infrastructure projects within the EU.

The 2018 EMSA guidance is part of the tools provided by the EU to support uniform application of Directive 2014/94/EU on the deployment of alternative fuels infrastructure.

Asia: In Asia, LNG is typically more costly than in North America or Europe. In addition, there are no IMO emission control areas (ECAs) located in Asia that mandate low sulfur fuel. These are some of the reasons there has historically been less development in Asia for the use of LNG as a vessel fuel for non-LNG carriers. However, LNG bunkering facilities and the appropriate regulatory framework is developing in the region.

Singapore's Maritime and Port Authority (MPA) is in the forefront of these efforts to set up LNG bunkering facilities. Singapore is currently one of the world's largest bunkering ports for oil fuels and it is located on major shipping lanes, so it is well positioned to be a major center for LNG bunkering. Initial efforts have focused on ship-to- ship LNG bunkering from small bunker vessels, and Singapore has carried out studies on the required regulatory framework and technical requirements for LNG bunkering together with the requirements for personnel training, safety zones and safety standards. These efforts have helped deliver Singapore's first LNG bunkering vessel, the *FuelLNG Bellina*, in early 2021.

Other ports in Asia are also active. For example, in China LNG bunker infrastructure is growing to support the Chinese government development plans and compliance with the fuel sulfur requirements in the regional and coastal Chinese ECAs. Also in Japan, in October 2020 the *Kaguya* LNG bunkering vessel made the first ship-to-ship LNG bunkering in Japan when re-fueling the *Sakura Leader*, the first large LNG fueled ship to be built in Japan.

13 SAFETY AND RISK ASSESSMENTS

LNG presents hazards that are different than conventional marine fuels, such as heavy fuel oil (HFO) and marine gas oil (MGO). If released at normal ambient temperatures and pressures it will form a flammable vapor, so the release of LNG or natural gas should be prevented at all stages of the bunkering process. Furthermore, in its liquid phase, LNG is cold enough that it can cause ordinary steel to become brittle and crack, so any contact with steel structures and decks should be avoided. Because of these hazards and others that can occur, safety and the prevention of leakage need to be among the primary objectives in the development of LNG bunkering system designs and procedures. Note that IACS developed Recommendation No.142 *LNG Bunkering Guidelines*, to provide general guidance on LNG bunkering and which includes specific guidance on the LNG bunkering operations risk assessment.

The three primary safety objectives for bunkering operations are as follows:

- Prevent the occurrence of any hazardous release of gas or liquid.
- In the event of a release, prevent or contain any hazardous situations.
- If a hazardous incident does occur, limit the consequences and harmful effects.

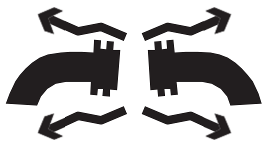
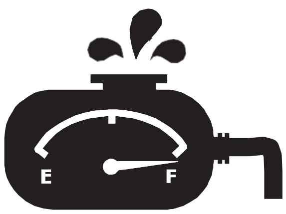
13.1 MAJOR HAZARDS

The primary hazards of LNG are:

- **Serious injuries to personnel in the immediate area if they come in contact with cryogenic liquids.** Skin contact with LNG results in effects similar to thermal burns and with exposure to sensitive areas, including eyes, tissue can be damaged on contact. Prolonged contact with skin can result in frostbite and prolonged breathing of very cold air can damage lung tissue.
- **Brittle fracture damage to steel structures exposed to cryogenic temperatures**. If LNG comes into contact with normal shipbuilding steels, the extremely cold temperature makes the steel brittle, potentially resulting in the cracking of deck surfaces or affecting other metal equipment.
- **Formation of a flammable vapor cloud**. As a liquid, LNG will neither burn nor explode; however, if released from bunkering equipment, it will form a vapor cloud as the LNG boils at ambient temperatures. To result in a fire or explosion, the vapor cloud must be in the flammable range, which for methane is between 5 and 15 percent by volume in air, and there must be an ignition source present.
- **Asphyxiation.** If the concentration of methane is high enough in the air, there is a potential for asphyxiation hazard for personnel in the immediate area, particularly if the release occurs in confined spaces.

Table 1 below is from the ABS report, *Bunkering of Liquefied Natural Gas-fueled Marine Vessels in North America* and offers a useful overview of hazards and the sources of the hazards during the LNG bunkering process.

Table 1 LNG Bunkering Initiating Events and Causes

Initiating Events	Common Causes
Leaks from LNG pumps, pipes, hoses or tanks 	• Corrosion/erosion • Fatigue failure • Hose failure • Improper maintenance • Piping not cooled down prior to transfer • Seal failure • Use of inappropriate hoses (e.g., not LNG rated) • Vibration • Improper installation or handling • Improper bunkering procedures
Inadvertent disconnection of hoses 	• Improper hose connection • Hose failure • Excessive movement of the loading arm or transfer system • Inadequate mooring or mooring line failure • Supply truck drives or rolls away with hose still connected • Supply vessel drifts or sails away with hose still connected • Extreme weather (wind, sea state) • Natural disaster (e.g., earthquake)
Overfilling/overpressuring vessel fuel tanks 	• Operator and level controller fail to stop flow when tank is full
External impact 	• Cargo or stores dropped on bunkering equipment (piping, hoses, tanks) • Another vessel collides with the receiving vessel or bunkering vessel • Vehicle collides with bunkering equipment

Some of the key hazards are discussed in more detail as follows.

Gas or LNG Release: The release of natural gas or LNG is to be prevented because of its flammable and cryogenic nature leading to many of the hazards identified in Table 1.

1. There are a number of factors affecting the consequence potential of an LNG release, including: the surface it is released on, the amount released, air temperature, surface temperature, wind speed, wind direction, atmospheric stability, proximity to offsite populations and location of ignition sources. Although LNG vapors can explode (i.e., create large overpressures) if ignited within a confined space, such as a building or ship, there is no evidence suggesting that LNG is explosive when ignited in unconfined open areas.

2. The primary way to avoid gas release is to make sure at no time a route exists for the gas or liquid to escape over the full length of the bunkering system from the supply tank to the receiving tank, including all pipes and hoses which may contain gas or liquid at any time in the process. No release should occur during the hook-up or disconnect of any components during the bunkering process. To ensure no release occurs at system connect or disconnect, purging of the bunker piping systems with inert gas prior to connect or disconnect is necessary.

3. The bunkering system should be designed so that no breakage or overloading of the bunkering system components will occur during the bunkering process, including consideration of relative motions between the LNG supply tank and the receiving vessel under the full range of wind and weather conditions that could occur during the bunkering process, and considering the range of relative drafts and trims that could occur, plus any motions that may occur from ships passing nearby.

4. In the case of overload or breakage of the connecting hoses, the use of special breakaway fittings and dry-disconnect couplings should prevent the release of any gas or liquid.

5. In the event of bunkering shutdown, measures need to be in place to remove any retained gas or liquid in the system, particularly liquid. Retained LNG can boil off and create hazardous high pressure in the bunkering system.

Fire: One of the greatest safety hazards to the bunkering process is fire at or in the vicinity of the bunkering operations and piping systems. The reason fire is so dangerous is that natural gas is highly flammable and will readily fuel and expand a fire if it is released in the vicinity of the fire. In addition, the heat from fire can cause rapid boil-off of LNG in the vicinity of the fire, which can lead to system component rupture and feed gaseous fuel directly into the fire, greatly expanding the hazard from the fire. The best way to avoid fire is to avoid release of gas and exclude any sources of fire or ignition from the vicinity of the bunkering operation and to have in place measures to fight and prevent the spread of fires that could affect the bunkering operation area.

Rollover and Density Variation: As described in the section on operational issues on the receiving ship, rollover and density variation can be a hazard when bunkering LNG fuel because LNG density changes significantly with change in temperature and as a result of gas boil-off. A hazardous rollover incident can occur when LNG with different density from that in the tank is bunkered without properly mixing the LNG in the tank during the bunkering operation. If a rollover incident occurs, rapid gas boil-off and the subsequent generation of large amounts of vapor could lead to gas release through the pressure relief valves or impair the tank containment. This is more of a risk while a vessel is stationary than for a rolling vessel at sea because the vessel motion will cause mixing. Measures as described in the bunker operation sections of this Advisory should be used to properly mix new and old LNG.

Cryogenic Temperatures: The cold temperature (about -162°C) of LNG is a hazard to normal steel, other materials, and personnel. It will cause embrittlement of normal steel leading to fracture and can similarly cause failure of other materials, such as rubber. It is an obvious hazard to any personnel handling LNG system components. Special materials, such as cryogenic stainless steels, should be used for structures like drip trays that could be exposed to LNG. Countermeasures, such as water curtains, can be used to prevent excessive cooling of any regular steel structures that could be exposed to LNG. Insulation is also necessary on any exposed components, particularly in areas where personnel will be working.

13.2 SAFETY AND SECURITY ZONES

The use of safety and security zones around the LNG bunkering operation are necessary to prevent the creation and spread of hazardous situations that may result from the LNG bunkering. The intent is to prevent accidental gas release as a result of damage to the LNG bunkering system and to prevent ignition of any released gas. The two types of zones have different purposes and definitions. Note that IACS Recommendation No.142 also includes specific guidance on LNG bunkering safety and security zones.

Furthermore, the aforementioned ISO/TS 18683:2015 and ISO 20519:2017 standards also provide processes for the determination of the safety and security zones. The use of tools such as the SGMF BASiL (Bunkering Area Safety information LNG) software can be used to provide a quantitive means to determine the bunkering safety zone. Refer also to the ABS *Guidance Notes on Gas Dispersion Studies of Gas Fueled Vessels*.

13.2.1 SAFETY ZONE

The purpose of a safety zone is to designate an area where only essential personnel with proper training are allowed to enter and where no sources of ignition are allowed. The extent of the zone is determined by various criteria depending on the regulation or reviewing authority. The safety zone extent should include all surrounding areas where the likelihood or probability of flammable mixtures occurring due to accidental release of LNG or natural gas are considered high enough to be a risk to the vessel and personnel. The flammable mixture risk probability can be determined during a risk assessment process.

13.2.2 SECURITY ZONE

The purpose of the security zone is to create an area of sufficient size that keeps other vessels, vehicles, equipment, and cargo operations far enough away so that they pose little risk of damaging or interfering with the LNG bunkering system and equipment. This zone is intended to keep nonessential personnel far enough away so that injury by any hazardous incident during the bunkering operation is unlikely, and to make it difficult for a person to intentionally damage or interfere with the bunkering system and equipment.

The requirements regarding how to mark off the zones, what signs are needed, how to enforce the zones, which personnel can enter the zones, and what safety equipment and PPE are needed are to be specified in the operating manuals prepared for the bunkering operation.

Distances: The size of the zones depend on an assessment of the hazards and how they are affected by distance from the bunkering operation or other potential sources of gas release. Hazard levels decline as the distance from the source is increased and the distance at which the hazard probability is considered low enough to be accepted without special measures or precautions in effect can be determined by several means. The hazard identification and risk assessment processes are normally where the distances will initially be set, as they should fully explore the hazards to be encountered.

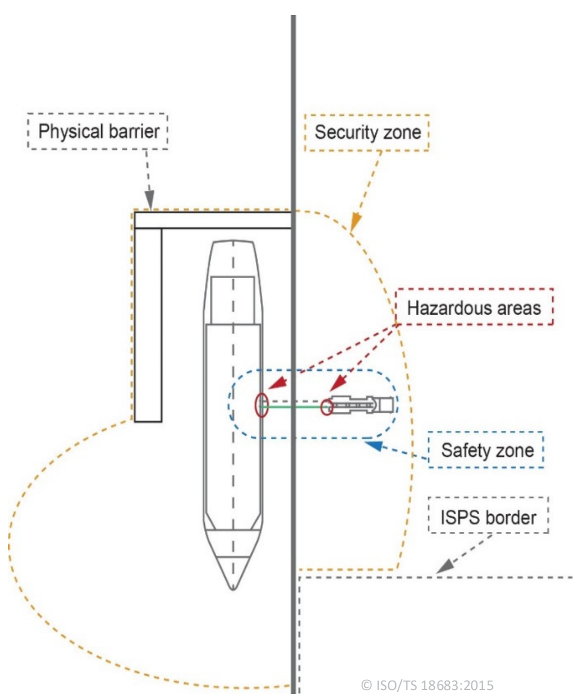


Figure 9. Example of Safety and Security Zones

The criteria to apply for setting the distances can come from several sources, including regulatory requirements, criteria established by the approving organizations during the review process, and from standards incorporated into the risk assessment process. In some cases, the extent of zones can change based on local or port requirements or based on the characteristics of a particular bunkering operation, facility or vessel.

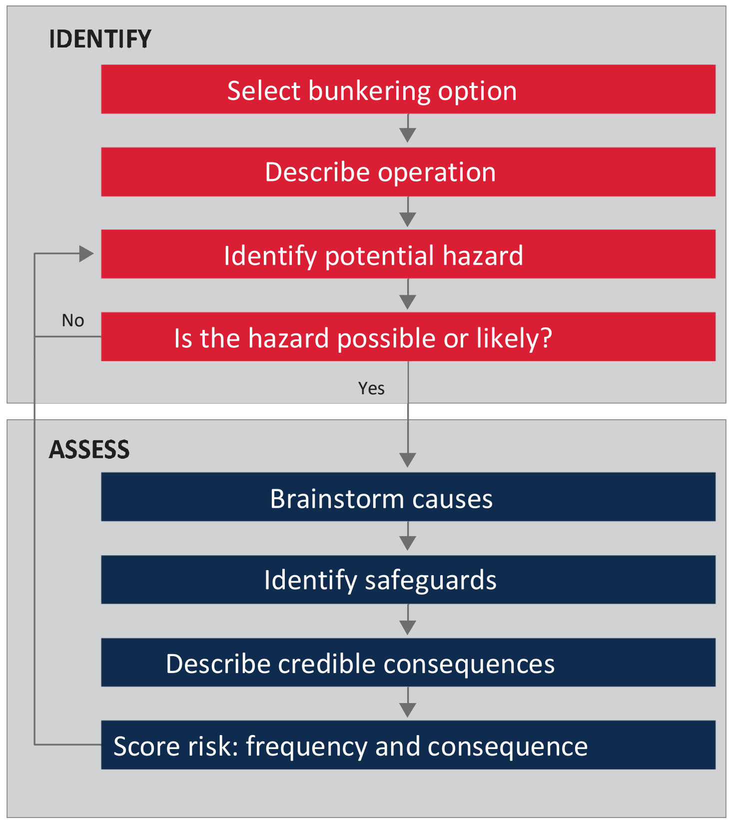
13.3 RISK ASSESSMENT METHODOLOGY AND REPORTING

Since LNG and natural gas offer a range of significant hazards, most regulatory organizations having jurisdiction over LNG bunkering will require several studies to be carried out. Which studies are needed and when they should be performed should be defined in the early planning for a bunkering project in consultation with the applicable regulators. The key types of studies that may be required are as follows.

13.3.1 RISK ASSESSMENT

In general, the bunkering facility or vessel should plan on preparing a risk assessment that addresses bunkering activities to help define the risk reduction measures that should be considered. The risk assessment characterizes the hazards and risks that may occur during the LNG bunkering operation. Risk assessment methods may be qualitative or quantitative and should follow recognized standards, such as ISO 31010, *Risk Management – Risk Assessment Techniques*. The basic risk assessment of the bunkering operation would consider details of both the bunker supplier and the receiving ship, even if only a typical receiving ship is considered (several different receiving ships may use the same bunker supplier).

The bunker supplier could be a vessel or a fixed facility. If it is a facility or LNG terminal, the scope of the risk assessment study may be for bunkering only or the study could be part of other risk assessment studies carried out for the facility, such as a siting study, fire risk assessment (FRA), waterway suitability assessment (WSA) and security assessment. The basic steps in the risk assessment process are shown in the chart.



Section 6 of the ABS report, *Bunkering of Liquefied Natural Gas-fueled Marine Vessels in North America*, offers more details on the different types of studies that may be required for an LNG supply facility or terminal, particularly for one in North America. In the same report, *Appendix A – Risk Assessment Workshop Templates* contains a good reference on the details on how to carry out a risk assessment study. A detailed description of risk assessment methodology also can be found in ISO/TS 18683:2015. The ABS *Guidance Notes on Risk Assessment Applications for the Marine and Offshore Industries* is available for download from the ABS website (www.eagle.org) and may be referenced for additional risk assessment guidance.

There are two primary approaches to risk assessment, normally described as qualitative or quantitative. Which to use depends on the level of detail required for hazards and consequences identification. A qualitative risk assessment evaluates identified hazards from a hazard analysis in general terms (low, medium, high) and offers ways to reduce these risks. It may be considered suitable for bunkering operations that follow standard procedures that have already been found to offer safe operation in other bunkering operations. In cases where LNG bunkering is a new operation in a port area, severe consequences are possible, a complicated bunkering operation is planned, unusual vessels or circumstances are involved, or in ports where it is required, a more detailed quantitative risk assessment may need to be performed.

In some cases, an in-between analysis, referred to as a semi-quantitative risk assessment, which is less rigorous than a full quantitative assessment, could be suitable. Which approach is required depends very much on the situation and the approving regulatory organization requirements, plus what level of assessment will make the owners and operators of both the LNG bunker supplier and the receiving ship comfortable with the intended bunkering operations. It is important to discuss the planned risk assessment process with the approval organizations early on in the process to confirm the proposed approach is acceptable. Whether a qualitative or quantitative approach is required is subjective and for the same bunkering supplier or specific bunker operation some approval organizations may accept a qualitative approach, while others may request a quantitative approach, and usually the more stringent requirement would apply, unless a consensus approach can be negotiated.

The risk assessment process normally includes the following main steps:

- Assembly of a team of experts who can provide objective and knowledgeable input on identifying risks and hazards, evaluate their consequences, and suggest counter measures
- Identification of potential hazards
- Assessment of the likelihood that the hazard will occur
- Assessment of the potential consequences. Depending on the concerns of the owner or operator, the consequence assessment could consider a variety of impact types, including impacts to people (both onsite and offsite), impacts to the environment, property damage, business interruption and reputation
- Identification of risk reduction measures if the risk of a hazard is considered unacceptable

13.3.2 HAZARD ANALYSIS

Hazard identification (HAZID) is the core of the risk assessment process. A HAZID study is normally carried out in a work-shop setting by a multidisciplinary team. Its primary function is to review possible hazardous events that may occur during the planned operation based on detailed engineering information, previous accident history, and judgment of the participants. Depending on the specific methodology used (e.g., what-if, failure modes and effects analysis), the team will document what can go wrong, potential causes and consequences of that event, and what safety measures can prevent or mitigate the event.

A full range of hazardous effects that could occur after a hazardous event should be considered. These include fire, explosion, injury to personnel, damage to equipment and structures, shutdown of nearby activities, and cryogenic hazards. The hazardous events and effects are normally placed into a risk matrix. Based on the risk matrix, risks can be ranked in terms of importance (from low probability, low consequence risks to high probability, high consequence risks). In the risk matrix, it can be highlighted which risks are unacceptable without countermeasures to reduce either the probability, consequence, or both. The focus of the risk matrix should be consequences that affect people, followed by damage to equipment or structure.

Some of the key definitions of hazard events and consequences as described in Appendix A in the ABS report, *Bunkering of Liquefied Natural Gas-fueled Marine Vessels in North America* are shown in the following three tables.

Typical definitions for the likelihood of events are given in Table 2.

Table 2. Likelihood Categories

Category	Category Descriptions
Almost Certain (E)	Occurs 1 or more times per year
Likely (D)	Occurs once every 1 to 10 years
Possible (C)	Occurs once every 10 to 100 years
Unlikely (B)	Occurs once every 100 to 1,000 years
Rare (A)	Occurs once every 1,000 to 10,000 years

Representative consequence categories are shown in Table 3.

Table 3. Representative Consequence Categories

Severity Categories	Impacts			
	Death and Injury	Economic	Environmental	Reputation
Low (1)	Low level short-term subjective inconvenience or symptoms. No measurable physical effects. No medical treatment.	No shutdown, costs less than $1,000 to repair.	No lasting effect. Low-level impacts on biological or physical environment. Limited damage to minimal area of low significance.	Public concern restricted to local complaints. Ongoing scrutiny/attention from regulator.
Minor (2)	Objective but reversible disability/ impairment and/or medical treatment injuries requiring hospitalization.	No shutdown, costs less than $10,000 to repair.	Minor effects on biological or physical environment. Minor short-term damage to small area of limited significance.	Minor, adverse local public or media attention and complaints. Significant hardship from regulator. Reputation is adversely affected with a small number of site-focused people.
Moderate (3)	Moderate irreversible disability or impairment (< 30%) to one or more persons.	Operations shutdown, loss of day rate for 1-7 days and/or repair costs of up to $100,000.	Moderate effects on biological or physical environment but not affecting ecosystem function. Moderate short-medium term widespread impacts (e.g., oil spill causing impacts on shoreline).	Attention from media and/ or heightened concern by local community. Criticism by Non-Governmental Organizations (NGO). Significant difficulties in gaining approvals. Environmental credentials moderately affected.
Major (4)	Single fatality and/or severe irreversible disability or impairment (> 30%) to one or more persons.	Operations shutdown, loss of day rate for 7-28 days and/or repair costs of up to $1,000,000.	Serious environmental effects with some impairment of ecosystem function (e.g., displacement of species). Relatively widespread medium-long term impacts.	Significant adverse national media/public/NGO attention. May lose license to operate or not gain approval. Environment/ management credentials are significantly tarnished.
Critical (5)	Short or long-term health effects leading to multiple fatalities, or significant irreversible health effects to > 50 persons.	Operations shutdown, loss of day rate for more than 28 days and/or repair costs more than $1,000,000.	Very serious effects with impairment of ecosystem function. Long-term widespread effects on significant environment (e.g., unique habitat, National Park).	Serious public or media outcry (international coverage). Damaging NGO campaign. License to operate threatened. Reputation severely tarnished. Share price may be affected.

The risk of a hazard is based on the combination of the likelihood and consequence assessment, allowing risks of different hazards, operations and potential accidents to be compared using a common measuring stick.

Table 4 presents examples of risk levels assigned for each combination of likelihood and severity. Risk levels rated as high are considered unacceptable and require countermeasures and these are highlighted in red. Risk levels considered low and possibly acceptable are highlighted in green and ones considered medium are highlighted in orange. Each owner and/or operator has unique considerations and risk tolerances, thus risk levels should be tailored to reflect those individual organizational risk tolerances.

Table 4. Risk Levels

Likelihood Categories	Consequence Severity				
	Low	Minor	Moderate	Major	Critical
	1	2	3	4	5
Almost Certain (E)	Medium	Medium	High	High	High
Likely (D)	Moderate	Medium	Medium	High	High
Possible (C)	Low	Moderate	Medium	High	High
Unlikely (B)	Low	Low	Moderate	Medium	High
Rare (A)	Low	Low	Moderate	Medium	Medium

A detailed report should be issued at the end of the risk assessment process that fully describes the HAZID participants, study basis, processes used, identified hazardous events and effects, risk matrix, action plan and summary of follow-up actions. The report and retained records should allow others to follow the reasoning used and the HAZID to be refined and repeated at a later date as circumstances change or based on review comments by regulatory organizations and involved parties. Any recommendations from the risk assessment process should be forwarded for consideration by project personnel completing the design, or planning the operations, maintenance, and emergency response activities for the bunker supplier and the bunkering operation. It is critical that the risk assessment process be well-planned and comprehensive.

13.4 SIMULTANEOUS OPERATIONS (SIMOPS) STUDY

A simultaneous operations (SIMOPS) assessment may be required if owners/operators wish to perform other activities, such as cargo or passenger loading, while bunkering. For LNG bunkering, a SIMOPS assessment would focus on how other activities could increase the likelihood or consequences of an LNG release. For example, if cargo operations are located too close to bunkering locations, cargo could be dropped on LNG piping or hoses during lifting operations, resulting in an LNG release. Another example is the risk that might be posed by operation of equipment (e.g., a crane) that is not rated for hazardous area service in close proximity to a tank vent during bunkering.

The SIMOPS study should:

- Identify operations that potentially threaten bunkering; and
- Decide whether those operations should be prohibited or can be allowed under specific, controlled conditions.

A SIMOPS assessment should address the following items:

- Identification and description of modes of operation
- SIMOPS risk assessment
- Identification and development of risk mitigation measures

The specific mitigation measures identified in the SIMOPS assessment may be incorporated into the operations manual, standard operating procedures, or may be managed as a separate process.

In addition, ISO/TS 18683:2015 requires a quantitative risk analysis for all bunkering operations involving SIMOPS.

14 LIST OF GUIDANCE DOCUMENTS AND SUGGESTED REFERENCES

Several industry organizations have issued guidance documents that contain useful information about LNG bunkering.

SIGTTO: The Society of International Gas Tanker and Terminal Operators (SIGTTO) is a widely respected private organization formed in 1979 by the major participants in the LNG transportation business. It has observer status at IMO. SIGTTO actively promotes best operating practices and guidelines, training and development within the industry and provides input on regulatory issues. Further information is available on its website: www.sigtto.org. SIGTTO issues a wide variety of publications, some of which are directly relevant to LNG bunkering and bunker vessels, and these can provide useful guidance on recommended best practices for preparing for and carrying out a bunkering operation. A list of SIGTTO's publications is available on its website. A few key publications are as follows:

- *Ship-Shore Compatibility Questionnaire*
- *Liquefied Gas Fire Hazard Management*
- *Guidance for the Prevention of Rollover in LNG Ships*
- *A Justification into the Use of Insulation Flanges (and Electrically Discontinuous Hoses) at the Ship/Shore and Ship/Ship Interface*
- *Guidance for the Prevention of Rollover in LNG Ships*

SGMF: The Society for Gas as a Marine Fuel (SGMF) was established in 2013. It was set up to focus on the newly developing use of LNG as a fuel on non-LNG carrier vessels, and the bunkering process for these vessels. SGMF now has observer status at IMO and has issued a number of publications and best practices. Its importance to operators of LNG fueled vessels and bunkering is expected to grow rapidly as SGMF grows in membership and the number of LNG fueled vessels increases. Further information is available on its website: www.sgmf.info.

- *TGN06-07 Ver1.0 Gas as a Marine Fuel: Bunker Station Location Considerations and Recommendations; January 2021*
- *FP00-04 Ver3.0 Gas as a Marine Fuel: An Introductory Guide; March 2020*
- *FP04-02 Ver2.0 Bunkering of Ships with LNG Competency and Assessment Guidelines; September 2017*
- *TGN06-06 Ver1.0 LNG Bunkering with Hose Bunker Systems - Considerations and Recommendations; February 2020*
- *TGN06-05 Ver1.0 Recommendations for Linked Emergency Shutdown (ESD) Arrangements LNG Bunkering; May 2019*
- *TGN06-04 Ver1.0 Manifold Arrangements for Gas Fuelled Vessels; May 2019*
- *FP08-01 Ver1.0 Simultaneous Operations (SIMOPs) During LNG Bunkering; May 2018*
- *FP07-01 Ver2.0 Safety Guidelines – Bunkering; March 2017*
- *FP05-01 Ver1.0 Contractual Guidelines - Quantity and Quality; September 2015*
- *FP02-01 Ver1.0 Recommendations of Controlled Zones During LNG bunkering; May 2018*

NFPA: The National Fire Protection Association (NFPA) is an international nonprofit organization established in 1896. It provides and advocates codes and standards, research, training, and education designed to reduce the burden of fire and other hazards. NFPA has published codes which apply to the design, installation, operation, and maintenance of LNG engine fuel systems on vehicles of all types, including marine vessels, and including fueling (bunkering) systems. These codes can be viewed for free or purchased on its website: www.nfpa.org. Several relevant codes related to LNG bunkering are as follows:

- NFPA 52: Vehicular Gaseous Fuel Systems (Chapter 8, Commercial Marine Vessels and Pleasure Craft)
- NFPA 59A: Standard for the Production, Storage, and Handling of Liquefied Natural Gas (LNG)

In addition to the referenced industry organizations, several international and governmental agencies, as well as classification societies, have issued regulations and guidance documents that are relevant to LNG bunkering. Some of the key ones are listed as follows:

International Maritime Organization (IMO)

Information available at: www.imo.org

- IGF Code (2017): *International Code of Safety for Ships Using Gases or Other Low-flashpoint Fuels*
- IGC Code (2016): *International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk*

International Organization for Standardization (ISO)

Information available at: www.iso.org

- ISO/TS 18683:2015, *Guidelines for Systems and Installations for Supply of LNG as Fuel to Ships*
- ISO 31010, *Risk Management – Risk Assessment Techniques*

- *ISO 20519: 2017, Ships and marine technology – Specification for bunkering of liquefied natural gas fuelled vessels*
- *ISO 28460:2010, Petroleum and natural gas industries — Installation and equipment for liquefied natural gas — Ship-to-shore interface and port operations*
- *ISO 21593:2019, Ships and marine technology – Technical requirements for dry-disconnect/connect couplings for bunkering liquefied natural gas*

International Association of Classification Societies (IACS)

Information available at: www.iacs.org.uk

- LNG Bunkering Guidelines; IACS Recommendation No**.** 142
- Risk assessment as required by the IGF Code; IACS Recommendation No. 146
- Survey of liquefied gas fuel containment systems; IACS Recommendation No. 148
- IACS Unified Interpretations of the IGF Code

American Bureau of Shipping (ABS)

Publications available at: www.eagle.org

- *Rules for Building and Classing Marine Vessels*
- *Rules for Building and Classing Marine Steel Barges*
- *Guide for LNG Bunkering*
- *Guidance Notes on Risk Assessment Applications for the Marine and Offshore Industries*
- *Guidance Notes on Failure Mode and Effects Analysis (FMEA) for Classification*
- *Bunkering of Liquefied Natural Gas-fueled Marine Vessels in North America*
- *Advisory on Gas and Other Low Flashpoint Fuels*

United States Coast Guard (USCG)

Information available at: www.uscg.mil

- Policy Letter CG-521 01-12, (2012): Equivalency Determination – Design Criteria for Natural Gas Systems
- Policy Letter CG-521 01-12, Ch-1 (2017): Equivalency Determination – Design Criteria for Natural Gas Systems (Change-1)
- Policy Letter CG-OES 01-15: Guidelines for Liquefied Natural Gas Transfer Operations and Training of Personnel on Vessels using Natural Gas as Fuel
- Policy Letter CG-OES 02-15: Guidance Related to Vessels and Waterfront Facilities Conducting Liquefied Natural Gas (LNG) Marine Fuel Transfer (Bunkering) Operations
- USCG CG-OES Policy Letter No. 01-17 - Guidance for Evaluating Simultaneous Operations (SIMOPS) during Liquefied Natural Gas (LNG) Fuel Transfer Operations
- LGC NCOE Field Notice 01-2017 – 14-Aug-17 - Recommended Process for Analysing Risk Of Simultaneous Operations (SIMOPS) During Liquefied Natural Gas (LNG) Bunkering

European Maritime Safety Agency (EMSA)

Information available at: www.emsa.europa.eu

- Final Report of the EMSA Commissioned Study on Standards and Rules for Bunkering of Gas-Fuelled Ships
- Guidance on LNG Bunkering to Port Authorities and Administrations

15 APPENDIX - LNG CHARACTERISTICS

Typical LNG Chemical Components and Composition

Component Name	Chemical Formula	Composition (Molar Percentage)	Average Composition* (Molar Percentage)
Methane	CH_4	84% to 99%	90.4%
Ethane	C_2H_6	0.1% to 14%	6.4%
Propane	C_3H_8	0% to 4%	1.8%
Butane	C_4H_{10}	0% to 2.5%	0.9%
Nitrogen	N	0% to 1.8%	0.5%
Other	–	< 1%	0%

*Average composed from various worldwide source compositions

15.1 TYPICAL LNG HEATING VALUES, METHANE NUMBER AND WOBBE INDEX

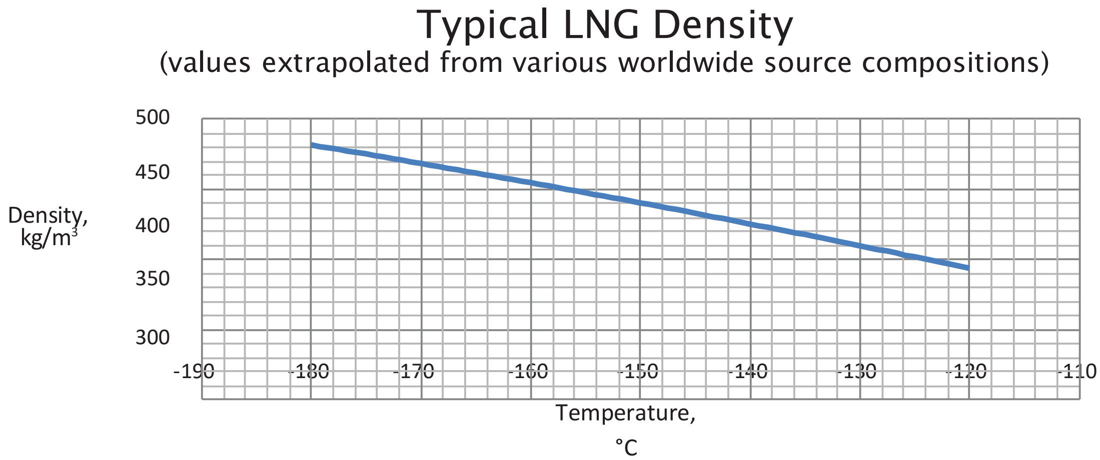
Property	Value	Average Value*
Higher Calorific Value (Higher Heating Value)	52,990 kJ/kg to 55,280 kJ/kg (22,780 BTU/lb to 23,770 BTU/lb)	54,182 kJ/kg (23,294 BTU/lb)
Lower Calorific Value (Lower Heating Value)	47,870 kJ/kg to 49,760 kJ/kg (20,580 BTU/lb to 21,390 BTU/lb)	48,924 kJ/kg (21,034 BTU/lb)
Methane Number	70 to 100	83
Lower Wobbe Index	48 MJ/Nm^3 to 51.5 MJ/Nm^3	50 MJ/Nm^3

*Average composed from various worldwide source compositions

15.2 TYPICAL LNG DENSITY

Temperature	Density Range	Average Density
-180°C (-292°F)	449.0 kg/m^3 to 500.8 kg/m^3 (28.0 lb/ft^3 to 31.3 lb/ft^3)	482.5 kg/m^3 (30.1 lb/ft^3)
-175°C (-283°F)	442.3 kg/m^3 to 494.3 kg/m^3 (27.6 lb/ft^3 to 30.9 lb/ft^3)	476.0 kg/m^3 (29.7 lb/ft^3)
-170°C (-274°F)	435.4 kg/m^3 to 487.7 kg/m^3 (27.2 lb/ft^3 to 30.4 lb/ft^3)	469.3 kg/m^3 (29.3 lb/ft^3)
-165°C (-265°F)	428.3 kg/m^3 to 481.1 kg/m^3 (26.7 lb/ft^3 to 30.0 lb/ft^3)	462.6 kg/m^3 (28.9 lb/ft^3)
-160°C (-256°F)	421.1 kg/m^3 to 474.3 kg/m^3 (26.3 lb/ft^3 to 29.6 lb/ft^3)	455.6 kg/m^3 (28.4 lb/ft^3)
-155°C (-247°F)	413.6 kg/m^3 to 467.5 kg/m^3 (25.8 lb/ft^3 to 29.2 lb/ft^3)	448.5 kg/m^3 (28.0 lb/ft^3)
-150°C (-238°F)	405.8 kg/m^3 to 460.4 kg/m^3 (25.3 lb/ft^3 to 28.7 lb/ft^3)	441.2 kg/m^3 (27.5 lb/ft^3)
-145°C (-229°F)	397.8 kg/m^3 to 453.2 kg/m^3 (24.8 lb/ft^3 to 28.3 lb/ft^3)	433.8 kg/m^3 (27.1 lb/ft^3)
-140°C (-220°F)	389.5 kg/m^3 to 445.8 kg/m^3 (24.3 lb/ft^3 to 27.8 lb/ft^3)	426.2 kg/m^3 (26.6 lb/ft^3)

*Average composed from various worldwide source compositions



15.3 100 PERCENT METHANE SATURATED PROPERTIES

Liquid Temperature		Vapor Pressure (Boiling Pressure)		Saturated Liquid Density		Average Density	
°C	°F	bar (gauge)	psi (gauge)	kg/m3	lb/ft3	kg/m3	lb/ft3
-166	-266.8	-0.33	-4.74	420.4	26.24	1.3	0.08
-164	-263.2	-0.19	-2.82	417.6	26.07	1.5	0.10
-162	-259.6	-0.04	-0.62	414.8	25.89	1.8	0.11
-160	-256.0	0.13	1.87	412.0	25.72	2.1	0.13
-158	-252.4	0.32	4.69	409.2	25.54	2.4	0.15
-156	-248.8	0.54	7.86	406.4	25.37	2.7	0.17
-154	-245.2	0.79	11.40	403.6	25.19	3.1	0.19
-152	-241.6	1.06	15.33	400.8	25.02	3.5	0.22
-150	-238.0	1.36	19.68	398.0	24.85	3.9	0.25
-148	-234.4	1.69	24.47	395.2	24.67	4.4	0.28
-146	-230.8	2.05	29.73	392.4	24.50	4.9	0.31
-144	-227.2	2.45	35.47	389.6	24.32	5.5	0.34
-142	-223.6	2.88	41.73	386.8	24.15	6.1	0.38
-140	-220.0	3.35	48.53	384.0	23.97	6.8	0.42
-138	-216.4	3.85	55.88	381.2	23.80	7.5	0.47
-136	-212.8	4.40	63.82	378.4	23.62	8.2	0.51
-134	-209.2	4.99	72.36	375.6	23.45	9.0	0.56
-132	-205.6	5.62	81.53	372.8	23.27	9.8	0.61
-130	-202.0	6.30	91.36	370.0	23.10	10.7	0.67
-128	-198.4	7.02	101.87	367.2	22.93	11.7	0.73
-126	-194.8	7.80	113.07	364.4	22.75	12.7	0.79
-124	-191.2	8.62	125.00	361.6	22.58	13.8	0.86
-122	-187.6	9.49	137.68	358.8	22.40	14.9	0.93
-120	-184.0	10.42	151.13	356.0	22.23	16.1	1.00

The ABS Global Gas Solutions team provides industry leadership, offering guidance in liquefied natural gas (LNG) floating structures and systems, gas fuel systems and equipment, gas carriers, and regulatory and statutory requirements. The team supports specification reviews, risk and hazard assessments, bunkering suitability reviews, project management for new construction and feasibility studies.

ABS provides industry-leading classification, preliminary planning and advice as well as approval in principle (AIP) services for the next generation of floating LNG assets that will enable new approaches to the worldwide transport and use of natural gas.
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