Risk focus: LNG Bunkering - Second edition

A guide to safe LNG bunkering practices

UK P&I CLUB IS MANAGED BY **THOMAS MILLER**

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International Maritime Organization (IMO) 2023 Strategy Sets Ambition for Net-Zero Greenhouse Gas (GHG) Emissions from International Shipping by 2050.

The maritime industry is experiencing a transformative shift, largely propelled by international decarbonisation efforts and the growing demand for cleaner alternative fuels. The IMO, through its Greenhouse Gas (GHG) Strategy, has set a course to reduce GHG emissions from shipping by at least 50% by 2050, compared to 2008 levels. In response, Liquefied Natural Gas (LNG) has emerged as a leading transitional marine fuel due to its significant reduction in sulphur oxides (Sox), nitrogen oxides (NOx), carbon dioxide (CO2), and particulate matter compared to conventional fossil fuels. This trend is further driven by rising global demand for natural gas, particularly in fast-developing markets such as China and geopolitical disruptions like the conflict in Ukraine, which have accelerated shifts in energy sourcing and supply chains.

The growth of LNG as a marine fuel is not only regulatory but also market driven. According to Class DNV's Alternative Fuels Insights (AFI) platform, 642 LNG-fuelled vessels are currently in operation, excluding LNG carriers, with a record-breaking 169 of these delivered in 2024 alone. The same year also saw 264 new LNG-fuelled ship orders – more than double the total orders placed in 2023 – signalling an accelerating commitment across the maritime sector. Projections indicate that the number of LNG-powered vessels could double by the end of the decade, solidifying LNG's role as a critical component in the transition toward low-emission shipping.

To support this transition, marine engine manufacturers have advanced the development of propulsion systems capable of operating on low-flashpoint and low-sulphur fuels. In parallel, abatement technologies such as exhaust gas cleaning systems (scrubbers) have been deployed to further reduce emissions from existing fleets. The operational advantages of LNG are also notable – it offers immediate compliance with current environmental regulations, reduces the need for fuel treatment, and is associated with cleaner combustion that can lead to lower engine maintenance requirements. Today, technologies supporting LNG use are widely available, including reciprocating piston engines, gas turbines, various LNG tank types, and related process equipment.

Despite these advancements, widespread LNG adoption brings unique challenges, particularly in terms of infrastructure and safety. Although LNG carriers have safely utilized cargo boil-off as fuel for decades, the application of LNG on other vessel types demands stricter safety protocols and enhanced crew training. As LNG bunkering expands across major ports in Europe, North America, and Asia, the industry must address operational risks, standardize best practices, and invest in bunkering infrastructure to support the increasing number of LNG-powered vessels. Moreover, while LNG bunkering is scaling up, there remains a relative scarcity of historical data on bunkering incidents and insurance claims, underscoring the need for continued focus on safety, training, and risk mitigation.

Introduction

LNG bunkering is a complex operation that demands meticulous planning and strict adherence to safety protocols. The process involves transferring LNG from a supply vessel or terminal to a receiving vessel's storage tanks (see **Figure 1**), necessitating careful execution to ensure both safety and operational efficiency. A key initial step in this process is understanding the type of containment system used on the vessel, as each tank type requires specific preparation procedures.

The bunker tank conditioning process begins with cleaning and drying to remove any contaminants and moisture, followed by inerting with nitrogen to eliminate oxygen and minimize the risk of flammable atmospheres. Once inerted, the tanks are gassed up by introducing LNG vapour to displace the inert gas and create a suitable environment for cryogenic operations. This is followed by the cooling down phase, a gradual process that lowers the tank temperature to approximately -160°C, preventing rapid vaporization and excessive boil-off gas during loading. These steps are critical to maintaining tank integrity and ensuring a stable, controlled environment for LNG transfer.

Effective LNG management goes beyond initial preparation and includes ongoing operational practices such as LNG heel management, pressure control, and vapour handling. Maintaining a small volume of LNG – known as LNG heel – within the tank helps stabilize internal temperature and pressure, reducing the risk of excessive boil-off gas. Careful monitoring and control of tank pressure during loading are essential to prevent overpressure conditions. Additionally, effective boil-off gas management is crucial and can be achieved through re-liquefaction, use as fuel, or returning the vapour to the supply vessel, depending on operational needs and safety considerations.

(a) Ship to ship method (b) Truck to ship method (c) Pipe to ship method

Figure 1: *Types of LNG transfer arrangements*

Types of LNG Bunker Containment Systems

Due to the cryogenic nature of LNG – stored at approximately -162°C – containment systems must not only provide insulation and prevent leakage but also maintain structural integrity under thermal and mechanical stress. The International Maritime Organization (IMO) has classified LNG containment systems into several types, each with specific design characteristics tailored to vessel size, fuel requirements, and operational profile. The most widely used systems are Type A, Type B, Type C, and membrane containment systems, all of which offer varying advantages in terms of volume efficiency, safety, complexity, and cost.

IMO Type A

IMO Type A containment systems are prismatic, non- pressurized tanks that feature a full secondary barrier for safety in case of leakage. They are designed for low-pressure storage and are built into the structure of the ship, requiring a full secondary barrier due to their lower design standards for crack propagation analysis. A key benefit of Type A tanks is their high-volume efficiency, typically 30–40% more than Type C tanks, which is crucial for vessels that require larger quantities of LNG but are limited by hull space. These tanks are reinforced with longitudinal bulkheads, enhancing their anti-sloshing characteristics, a valuable feature for maintaining fuel stability during transit in rough seas.

Maximum allowable relief valve setting (MARVS) – less than 0.7 barg

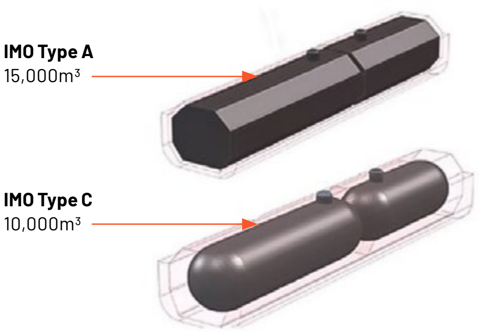


Figure 2: *IMO Type A and Type C tanks*

IMO Type B

Type B tanks are also non-pressurized but are structurally more robust than Type A, requiring only a partial secondary barrier due to their comprehensive design evaluations, including fatigue life and crack propagation analysis. These tanks are typically spherical (Moss-type) or prismatic, and they represent a design philosophy that balances safety with cost-efficiency by reducing the need for extensive secondary containment. Moss-type spherical Type B tanks are among the most iconic in LNG shipping, easily recognizable by their large dome-shaped structures above deck.

While Type B tanks are mostly used on large LNG carriers, their application in bunkering is limited due to their size, weight, and integration complexity.

Maximum allowable relief valve setting (MARVS) – less than 0.7 barg

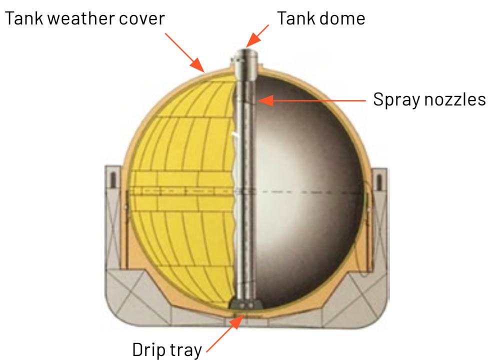


Figure 3: *IMO Type B tanks*

IMO Type C

Type C tanks are self-supporting, pressurized tanks, most commonly used for LNG-fuelled vessels and smaller bunker ships. Constructed from stainless or nickel steel, these tanks are designed to handle pressures ranging from 4.5 to 10 bar, allowing for the containment of boil-off gas without venting or reliquefication. Their cylindrical or spherical geometry makes them ideal for modular installation, especially in vessels with limited space or those requiring flexible fuel system configurations. Due to their simplicity, durability, and ease of certification, Type C tanks dominate the market for LNG propulsion on ferries, offshore vessels, and smaller commercial ships. They require minimal integration with the ship's hull, simplifying construction and reducing installation time. However, their volume efficiency is lower compared to Type A and membrane systems, making them less ideal for vessels with high LNG consumption or limited fuel storage areas.

Maximum allowable relief valve setting (MARVS) – Typically between 4 to 10 barg.

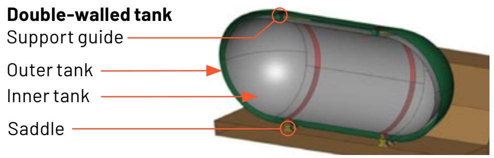


Figure 4: *IMO Type C tanks*

Physical Properties of LNG

Composition

Liquefied Natural Gas (LNG) is primarily methane (CH_4), typically 85–95%, with small quantities of ethane, propane, butane, and nitrogen. The exact composition depends on the gas source and treatment process.

Boiling Point

LNG boils at approximately -162°C (-259°F) at atmospheric pressure. It remains in liquid form only under cryogenic conditions, requiring insulated storage tanks.

Flash Point

LNG does not have a flash point in the traditional sense because it must vaporize before ignition. However, once vaporized, methane has a flash point of -187°C, indicating that its vapours are flammable well below ambient temperatures.

Vapour Density

Methane gas (LNG vapours) is lighter than air with a vapour density of 0.55 (air = 1). However, when released, LNG vapours are initially cold and heavier than air until they warm up – this allows the vapour to initially remain low and spread near the ground or the sea level.

Expansion Ratio

LNG has a high expansion ratio of approximately 1:600. That means 1 m3 of LNG expands to about 600 m3 of natural gas at room temperature and atmospheric pressure. This property makes it efficient for storage and transport but poses risks during accidental release.

Colour and Odour

LNG is colourless, odourless, and non-toxic in its liquid form. Since methane is odourless, odorants are usually added only when it is re-gasified and sent to distribution pipelines.

Flammability

LNG is highly flammable in vapour form once it has evaporated into methane gas. Natural gas, primarily composed of methane, has a flammability range of approximately 5% to 15% by volume in air. This means that if the gas concentration falls within this range, it can ignite in the presence of an ignition source. The flash point of methane is –187°C (–304.6°F), indicating that it can form flammable mixtures at extremely low temperatures. Additionally, the autoignition temperature of methane is above 530°C (986°F), which is the temperature at which it can ignite spontaneously without a spark or flame.

Ageing of LNG

Ageing refers to the gradual change in LNG composition during storage due to boil-off gas (BOG) losses. Lighter components (like nitrogen and methane) tend to evaporate first, leaving behind a heavier LNG mixture. This affects both the energy content and combustion properties over time and must be managed to ensure consistency in performance.

Risks Involved in LNG Handling

Cryogenic Burns and Frostbite

LNG is stored at extremely low temperatures (approximately -162°C). Direct contact with the liquid or other cold surfaces can cause severe cold burns or frostbite. Symptoms include intense pain, swelling, and potential tissue damage. Such injuries require immediate medical attention and can be life-threatening if extensive.

Asphyxiation Risks

LNG vapours are primarily composed of methane, which is colourless, odourless, and non-toxic. However, in confined or poorly ventilated spaces, the displacement of oxygen by methane can lead to asphyxiation. This poses a significant risk during leaks or spills, especially in enclosed areas.

Fire and Explosion Hazards

While LNG itself is not flammable in its liquid state, upon release, it rapidly vaporizes and can form a flammable gas cloud. If this vapour cloud encounters an ignition source, it can lead to flash fires, jet fires, or even explosions.

Structural Damage from Cryogenic Spills

Spills of LNG on the ship's structure can lead to brittle fracture of steel components not designed for cryogenic temperatures. This can compromise the vessel's integrity and safety. Additionally, LNG spills on water can rapidly vaporize, creating large vapour clouds that may pose further risks.

Static Electricity and Ignition

The movement of LNG and its vapours can generate static electricity, which, if discharged, may ignite flammable gases. To mitigate this risk, personnel should wear anti-static clothing and footwear and ensure proper grounding of equipment during operations.

Overpressure and Phase Transition Hazards

Entrapped LNG in transfer lines or tanks can lead to overpressure situations. If LNG is released into water, it can undergo Rapid Phase Transition (RPT), a violent expansion that may cause explosions. Proper purging of transfer lines and careful monitoring of pressure levels are essential to prevent such incidents.

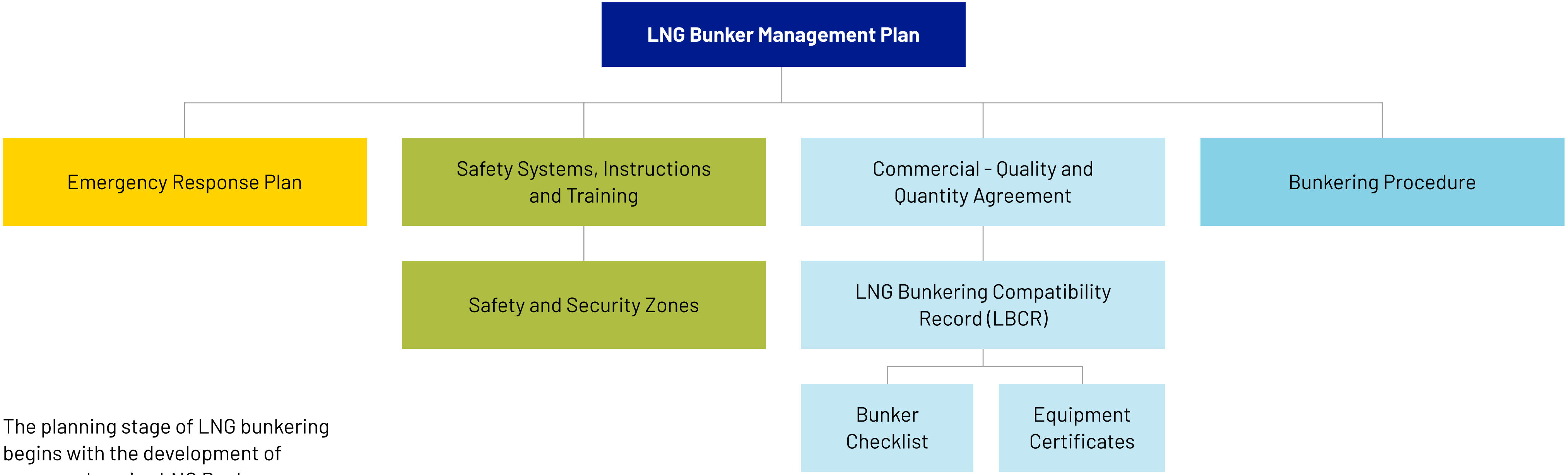
Sloshing and Tank Stability

During ship movement, LNG within tanks can shift, a phenomenon known as sloshing. Excessive sloshing can damage tank structures and affect vessel stability. Maintaining appropriate fill levels and controlling ship motions are vital to minimize this risk.

Emergency Shutdown and Release Systems

In the event of an emergency, systems like Emergency Shutdown Systems (ESD) and Emergency Release Couplings (ERC) are designed to halt LNG transfer and safely disconnect hoses. Regular testing and maintenance of these systems are crucial to ensure their functionality during critical situations.

Bunkering Planning and Process



The planning stage of LNG bunkering begins with the development of a comprehensive LNG Bunker Management Plan (LNGBMP). This plan, recommended by the International Association of Classification Societies (IACS) and the Society for Gas as a Marine Fuel (SGMF), outlines the essential documentation and procedures needed to ensure that LNG bunkering is carried out safely and in a controlled manner.

Commercial – Quality and Quantity Agreement

In 2021, BIMCO initiated a project to develop a suite of LNG fuel clauses for time charter parties, recognizing the growing number of LNG-fuelled ships in operation and the need for bespoke clauses to address the unique aspects of LNG as a marine fuel. The LNG Fuel Quality Clause, part of this suite, outlines the specifications that LNG must meet to ensure compatibility with the vessel's engine and safe operation.

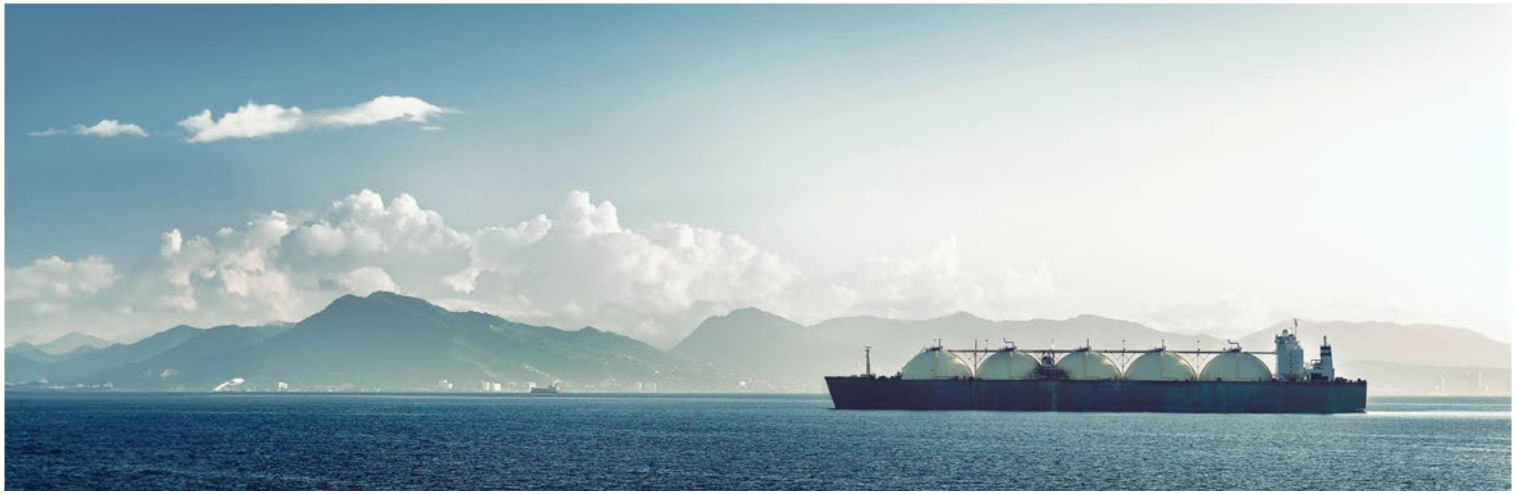
According to this clause, charterers are required to supply LNG fuel that:

- Is free of foreign matter,
- Complies with the latest edition of ISO 23306, "Specification of liquefied natural gas as a fuel for marine applications",
- Includes a minimum methane content,
- Contains a maximum combined content of ethane, propane, and butane,
- Limits the maximum combined quantity of corrosives or other contaminants,
- Meets a minimum lower heating value, and
- Specifies an acceptable methane number.

Additionally, charterers must provide the owners with a copy of the Bunker Delivery Note (BDN) issued in accordance with the International Code of Safety for Ships using Gases or other Low-flashpoint Fuels (IGF Code). Failure to comply with these specifications renders the charterers liable for any loss or damage caused to the owners or the vessel. This clause ensures that the LNG supplied is of appropriate quality to maintain engine performance and safety standards. As a part of the agreement, a comprehensive compatibility assessment (LBCR) is required; this is usually done by the supplier and the operators of the receiving vessel.

Custody Transfer System

Custody transfer equipment is typically fitted on the LNG supply vessel to measure both the energy content and quantity of LNG delivered during bunkering. Since LNG is priced based on its energy content, accurate determination of both mass or volume and energy value is essential at the time of transfer. Mass-based measurement is generally preferred, as it avoids the need for density correction required in volume-based methods. The supply vessel is usually better equipped than the receiving ship, often using continuous metering systems such as Coriolis (mass) or ultrasonic (volume) flow meters, which provide real-time measurements with high accuracy when properly calibrated. Additional equipment may include temperature and density sensors or a gas chromatograph to monitor variations in LNG composition. These systems ensure precise data collection, accounting for any LNG consumed by the supply vessel itself or delivered to multiple recipients during the same operation.



LNG Bunkering Compatibility Record (LBCR)

A Bunkering Compatibility Record is a crucial document that ensures LNG bunkering operations are carried out safely and efficiently. It serves as a confirmation that both the delivering and receiving parties have agreed on the compatibility of their systems, equipment, and procedures before the operation begins. This record includes both scenario-specific checks, which are confirmed well in advance, and those that need to be re-verified before each individual bunkering process.

Risk Assessment Integration

A comprehensive risk assessment is vital throughout the design, planning, and operational phases of LNG bunkering. Methods such as Formal Safety Assessment (FSA), Quantitative Risk Assessment (QRA), Hazard Identification (HAZID), Hazard and Operability Study (HAZOP), and Failure Modes, Effects, and Criticality Analysis (FMECA) should be implemented. The findings of these assessments are integrated into the operational procedures to ensure proactive hazard mitigation. This integration guarantees that potential hazards are identified and addressed in line with industry best practices, enhancing the overall safety and efficiency of LNG bunkering.

System and Safety Compatibility

Before the bunkering operation can proceed, a thorough compatibility check must be conducted. This check includes the evaluation of physical connection points, alignment of manifold heights, compatibility of Emergency Shut Down (ESD) systems, hazardous area overlaps, and the functionality of safeguards like electrical isolation and leak detection systems. Additionally, transfer systems must meet relevant ISO or national standards, and all parties must agree on safety and emergency response protocols to prevent accidents.

Technical and Operational Readiness

The bunkering system's design and construction must be executed by qualified, experienced professionals according to recognized standards. The construction process should adhere to quality assurance standards, ensuring that the system remains operable under variable conditions, such as tidal movements and changes in vessel draft. It is also essential that the operation does not result in any unintended release of gas into the atmosphere. Proper vapour management systems should be in place and tested before the operation commences.

Crew Competence and Communication

Operators must be trained, certified, and competent, with the Person in Charge (PIC) assuming a central role in coordinating activities between the bunker supplier, receiving vessel, and shore authorities. Clear communication protocols must be established in advance, with agreed-upon signals and handover responsibilities. Furthermore, Simultaneous Operations (SIMOPS) must be carefully evaluated, and the roles and risk- sharing arrangements of all involved parties must be clearly defined to prevent interference between concurrent activities.

Environmental and Operational Conditions

The LNG to be supplied must meet all agreed specifications, including methane number, temperature, and pressure. Weather conditions, such as wind speed, wave height, and the risk of lightning, must be monitored and kept within acceptable limits. Tidal movements, port activities, and any potential conflicts at anchorage must be assessed in collaboration with local authorities and Vessel Traffic Services (VTS). Additionally, the receiving tank volume and temperature must be checked before bunkering to ensure they are within acceptable limits.

Emergency Preparedness

Emergency preparedness is a cornerstone of LNG bunkering operations. Procedures for testing the Emergency Shut Down (ESD) system, managing trapped LNG volumes, and implementing cryogenic protection systems like water curtains should be clearly defined and agreed upon. Compatibility checks for Emergency Release Couplings (ERCs) and other critical safety equipment must also be completed. All safety zones and security measures must be clearly delineated and in place before the bunkering operation proceeds. Surge Analysis and Evaluation during ESD valve shut off is another important aspect which needs to be considered.

Hazard Identification (HAZID)

HAZID is a systematic process designed to identify potential hazards in LNG bunkering operations. The primary objectives of HAZID are to identify hazards, assess their consequences, evaluate existing safeguards, and recommend actions to mitigate risks. The HAZID process involves assembling a multidisciplinary team to identify hazards using guidewords. After identifying hazards, each is ranked based on its potential impact and the effectiveness of existing safeguards. The bunkering process is broken down into smaller steps – such as preparation, connection, inerting, cooling down, transfer, and disconnection – ensuring that potential hazards are systematically addressed at each stage.

Hazard and Operability Study (HAZOP)

HAZOP is a more detailed, structured technique used to identify potential hazards and operability issues in complex systems. In LNG bunkering, HAZOP focuses on identifying deviations from design intent that could lead to hazards. It involves analysing process flow diagrams (PFDs) and piping and instrumentation diagrams (P&IDs) to detect deviations in parameters such as flow, pressure, temperature, and composition. Each deviation is examined for its causes, consequences, and existing safeguards. Recommendations are made to modify the design or operations to mitigate these risks, ensuring that LNG bunkering activities are safe and efficient.

Simultaneous Operations (SIMOPS)

SIMOPS refers to the concurrent execution of multiple operations in the same location during the same timeframe. In LNG bunkering, this may involve simultaneous cargo handling, maintenance, and bunkering activities. Managing SIMOPS requires identifying potential conflicts between these activities, assessing the associated risks, and implementing controls to mitigate those risks. Communication and emergency response plans must be coordinated across all involved parties to prevent operational disruptions. Effective SIMOPS management ensures that LNG bunkering operations can proceed safely without interference from other concurrent activities.

As a minimum, the following should be checked prior to engaging in any LNG bunkering operation:

- Have the regulating authority, bunkering facility, and receiving vessel harmonized their safety and emergency response plans?
- Are written operational procedures available for all parties involved?
- Have the actions from previous risk assessments (HAZID, HAZOP, FMECA, etc.) been handled and closed out?
- Does the bunkering facility and receiving vessel comply with relevant ISO or national standards for transfer systems, safety equipment, and emergency protocols?
- Is the design of the bunkering system, including the emergency release system (ERS) and vapour management systems, completed by qualified personnel in accordance with industry standards?
- Are the bunkering systems designed to prevent the release of gas to the atmosphere during operations?
- Can the operation be carried out without a release of gas to the atmosphere? Is the vapour return line procedure in place to prevent any release?
- Has the emergency release system (ERS) procedure been agreed upon, and are systems in place and connected?
- Are nitrogen lines available and correctly connected to the system?
- Have the mooring equipment and mooring configuration been verified and approved according to the mooring plan?
- Is the bunker station location confirmed as suitable for the operation?
- Is the transfer system sizing and loading on the manifold within the operational range of the bunker hose/loading arm arrangement?
- Is the closure speed of valves within the recommended limits?
- Has the transfer system been leak-tested before the start of the operation?
- Are there physical safeguards in place to prevent the inadvertent connection of liquid to vapour or vapour to liquid lines?
- Are the receiving tank volume and temperature within acceptable limits before bunkering begins?
- Are the LNG properties to be supplied, such as temperature and pressure, within agreed specifications?
- Are tidal motions and changes in freeboard during the planned bunkering operation observed and accounted for?
- Are communication systems (hardware, software, signals, and language) between the PIC, the ship's crew, and the bunker delivery personnel compatible and established?
- Have all safety and emergency protocols been agreed upon, including safety and security zones?
- Are the Emergency Shut Down (ESD) systems compatible, and can the system be tested before the operation starts?
- Can the operation be performed safely considering the potential for concurrent activities, such as cargo handling and changes in vessel draft?
- Has the compatibility of the transfer system and bunker connections been verified, ensuring that all equipment meets ISO standards and safety protocols, including electrical isolation and anti-static principles?
- Have the hazardous, safety, and security zones been reviewed and confirmed to comply with local/national regulations?
- Are the weather conditions (wave height, wind speed, current, and weather forecasts) within acceptable limits for safe operation?
- Are cryogenic protection systems, such as water curtains and insulated hose saddles, compatible with the bunkering system?
- Have the procedures for draining, purging, and inerting the system been agreed upon and documented?
- Have all systems been properly disconnected and secured post-bunkering?
- Have all operational risks associated with hazardous areas between the receiving vessel and the bunkering facility been addressed and controlled?

Mooring Analysis

Mooring analysis is essential for ensuring the safety of the bunkering operations, whether conducted ship-to-ship (STS) or at a terminal. Tools like OPTIMOOR analysis can be used to simulate and evaluate mooring arrangements under various environmental and operational conditions, using industry- recognized methods. In particular, guidance from the *OCIMF Effective Mooring, 3rd Edition (2010)* should also be applied to ensure best practices in mooring design, line selection, and operational procedures. This guidance helps assess the impact of wind, current, waves, and passing ships on moored vessels, supporting predictions of mooring line loads, vessel motions, and fender responses. In STS scenarios, mooring analysis tools are useful for modelling side-by-side configurations between the LNG Bunker vessel (LNGBV) and receiving ship, while at terminals, they aid in evaluating berth suitability under specific tidal, draft, and trim conditions. By identifying potential issues such as uneven line loads or overstressed moorings, and allowing for optimization of line tensions and configurations, mooring analysis – guided by standards like those from OCIMF – supports safe, efficient, and compliant LNG bunkering operations.

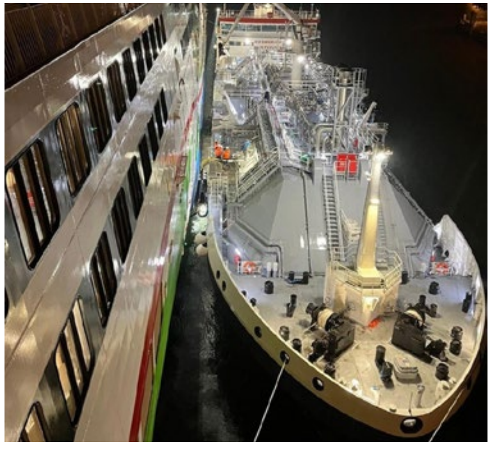


Image Source: Elenger Marine

Due to the relatively low density of LNG cargo, a significant portion of the cargo tanks stays above the waterline, because the vessel's overall draught remains shallow. This configuration, coupled with the weight of onboard bunkering equipment, can result in a low centre of gravity (GM), making LNGBVs more susceptible to pronounced roll motions. While LNGBVs typically operate within sheltered port areas, future operational requirements may necessitate transits to less sheltered or more distant locations.

To ensure the safety of both vessels during bunkering operations, appropriate fendering arrangements are crucial. These arrangements depend on factors such as the freeboard and design of the receiving vessel. Traditional solutions include the use of pontoon spacers and Yokohama pneumatic fenders. Yokohama fenders, known for their low reaction force at low deflection, are particularly suitable for vessels with sensitive equipment and are extensively used for ship-to-ship transfers at sea, see **Figure 5** below.

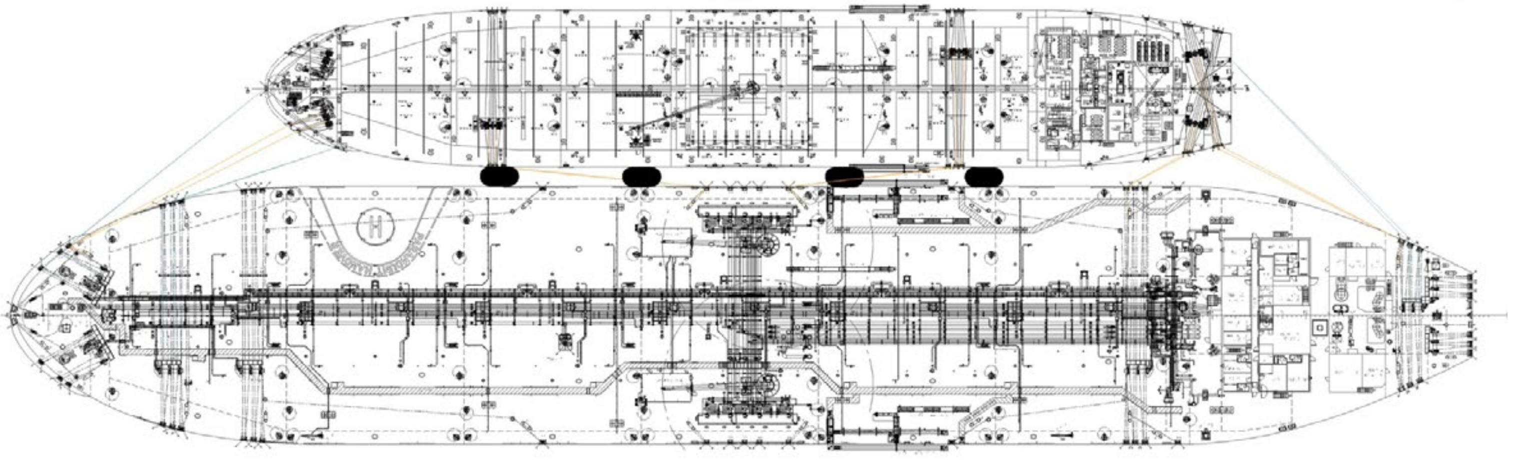


Figure 5: *Standard STS Fendering Arrangement with Yokohama Fenders*

However, advancements in design have led to innovative solutions. For instance, some modern LNG bunker vessels feature integrated outrigger fendering systems. These systems eliminate the need for manual deployment of fenders and spacer pontoons, replacing them with an integrated outrigging system that can be operational in five minutes with the push of a button. The design also includes a telescopic crane extending over 40 meters, adjustable to any required reach, and is compatible with all known and upcoming LNG-fuelled vessels.

In conclusion, selecting the appropriate fendering arrangement is essential for the safe operation of LNG bunker vessels. While traditional methods like pontoon spacers and Yokohama fenders remain in use, innovative designs such as the outrigger fendering system offer enhanced safety and operational efficiency.

Image Source: Elenger Marine

Crew Training for IGF Code Compliant Vessels

The International Convention on Standards of Training, Certification, and Watchkeeping for Seafarers (STCW) sets forth essential training and certification requirements for personnel working on ships governed by the IGF Code. Section A-V/3 of the STCW Code specifically outlines the mandatory minimum standards of competence for both basic and advanced training to ensure safe handling, operation, and emergency response related to low-flashpoint fuels such as LNG.

Basic Training Requirements

All seafarers assigned to designated safety duties related to the use, care, or emergency handling of fuels on IGF Code-compliant ships must hold a Certificate of Proficiency (COP) in Basic Training. This certification aligns with the competencies specified in Table A-V/3-1, which focus on fuel properties, hazard recognition, safety procedures, and emergency protocols. Alternatively, personnel already holding a valid COP for liquefied gas tanker cargo operations under Regulation V/1-2 may be considered to meet the basic training criteria for IGF Code vessels.

Advanced Training Requirements

Masters, engineers, and any personnel with direct responsibility for fuel systems must obtain a COP in Advanced Training per Table A-V/3-2. To qualify, candidates must complete approved advanced training and accrue at least one month of relevant seagoing service, including participation in three LNG bunkering operations – two of which may be substituted with simulator-based training. Additionally, those certified under Section A-V/1-2 for liquefied gas tanker operations may qualify, provided they also meet the basic training standards and have completed either the required bunkering operations or three cargo operations on a liquefied gas tanker, along with at least three months of relevant seagoing service within the past five years.

Safety and Security Zones

To ensure the safe and secure execution of bunkering operations, clearly defined safety and security zones must be established and maintained throughout the process. The safety zone is designated to control ignition sources and restrict access strictly to essential personnel, minimizing the risk of exposure to flammable gases in the event of an accidental release. Its size is typically determined using vapour dispersion modelling for the largest credible leak – such as a hose rupture or flange leak – employing advanced computational tools like FLACS (Flame Acceleration Simulator).

FLACS is a CFD-based (Computational Fluid Dynamics) software widely used for simulating complex LNG release scenarios including jetting, flashing, and two-phase flows. CFD refers to the use of numerical methods and algorithms to model and analyse the behaviour of fluids – in this case, LNG vapours – under various conditions. It allows engineers to predict how gas clouds will disperse in different environments by accounting for factors like wind speed, temperature, terrain, and nearby structures. These simulations produce validated dispersion results that are critical for defining flammable zones. Alternatively, a risk-based assessment may be used, provided it does not define a zone smaller than the minimum hazardous area or regulatory setback distances.

Once the zone is defined, all non-essential activities are prohibited within this zone during operations, see **Figure 6**. Complementing this, the security zone encompasses a wider perimeter, established through a detailed risk assessment to monitor and control external threats such as nearby vessel traffic or shore-side activities. It aims to mitigate risks from potential incidents that could affect the operation and identifies areas where consequences to personnel or the public may exceed acceptable thresholds. If required, physical barriers may be incorporated into the zone's boundaries, ensuring they do not impede emergency access. Both zones are determined during the planning phase and must be actively enforced during bunkering to maintain operational integrity and safety.

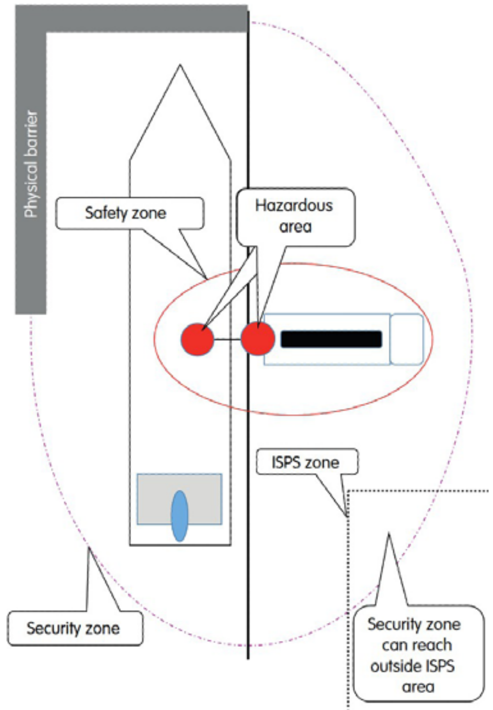


Figure 6: *Safety and Security Zones Illustration*

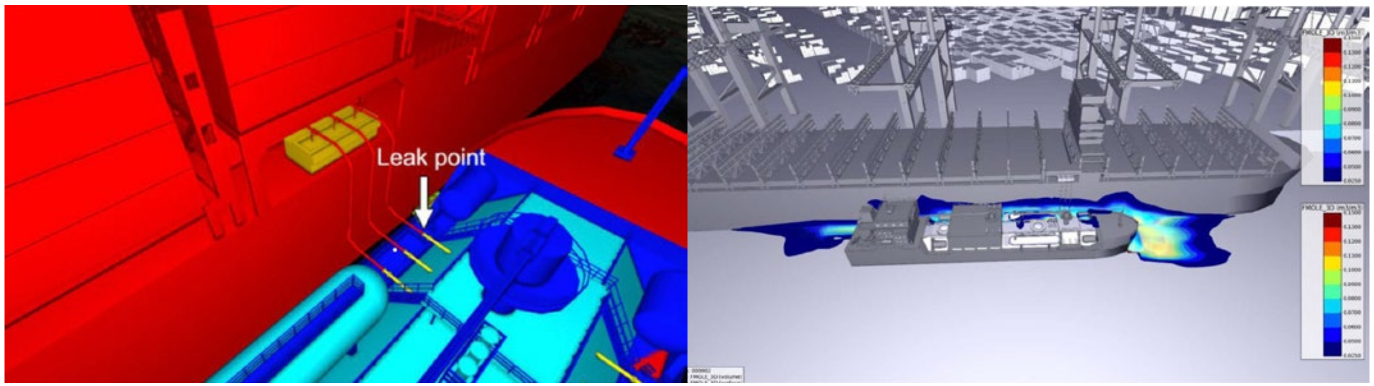


Image Source: Flame Acceleration Simulator

Tank Preparation for Bunkering

The preparation of LNG fuel tanks before initial loading or after maintenance is a critical multi-stage process that ensures operational safety, structural integrity, and fuel purity. These operations – drying, inerting, gassing-up, and cooling-down – require external support, as most vessels are not equipped with onboard systems for these procedures. Facilities such as terminals or bunkering vessels must provide nitrogen, inert gas, and warm LNG vapour for the operation.

Drying

The drying process aims to remove humidity and reduce the dew point inside the LNG tank to prevent the formation of hydrates.

Dry air is introduced to displace atmospheric air, typically using bottom-filling methods when dry air is denser than ambient air or top-filling methods when it is lighter. The process involves the use of a portable dew point meter to measure humidity levels at different tank levels. The operation continues until the dew point reaches at least -40°C or below, verified at the top sampling point.

Once drying is complete and the target dew point is reached, valves are closed to isolate the tank.

- Dew point of dry air supplied: ≤ -45°C at manifold sampling point
- Sampling frequency: Hourly (top, middle, and bottom of tank)
- Tank pressure: Maintained as close to atmospheric pressure.

Support Equipment: Dry air or nitrogen.

Inerting

Inerting is done to replace the dry air in the tank with inert gas, typically nitrogen.

Inert gas (typically nitrogen) is introduced at the tank's bottom through the liquid line, and the displaced air exits via the vent mast. Continuous gas sampling at the upper, middle, and lower sections of the tank ensures oxygen concentration decreases progressively. The inerting process is complete when oxygen levels drop to ≤ 2% and the dew point stabilises below -40°C. Once the target parameters are reached, the inert gas supply is stopped, and the tank is sealed to maintain a positive internal pressure.

- Inert gas dew point: ≤ -45°C
- Oxygen content (sampling points): Final: ≤ 2.0%
- Tank pressure: To be kept less than 80% of MARVS and maintained positive post-operation.
- Sampling frequency: Hourly (upper, middle, and lower parts of the tank)

Support Equipment: Nitrogen or inert gas supplied from external facilities.

Drying & Inerting with Nitrogen

In some operations, nitrogen can be used directly for both drying and inerting, simplifying the process by removing the need for a separate drying stage.

Procedure:

Nitrogen is introduced through the vapour main and displaces air through the liquid main and vent mast. The oxygen levels and dew point are closely monitored, with final values not exceeding 2% O2 and -40°C respectively. The tank is sealed to maintain positive pressure once the inerting process is complete.

Support Equipment: Nitrogen supplied from external facilities.

Gassing-Up

Gassing-up replaces the inert gas in the tank with warm natural gas (methane-rich vapour) to prepare the tank for LNG loading.

Lighter warm LNG vapour being lighter is introduced at the top of the tank, pushing the inert gas out through the filling lines and vent mast. Initially, vented gas is directed to the mast until 5% methane is detected. Once the methane concentration reaches 5%, the exhaust vapour is redirected to the bunkering facility through the vapour return line. This process continues until Nitrogen content drops below 1%, and hydrocarbon content exceeds 99% at all sampling points. Prior to gassing- up, hose and pipe connections are purged with nitrogen, and a leak test is performed. The supply of LNG vapour is gradually ramped up to ensure efficient displacement of the inert gas.

- Initial O2 content before operation: ≤ 2.0%
- Initial dew point: ≤ -40°C
- Methane (CH4) content at vent mast:
- Start diverting to facility: ≥ 5%
- Final tank concentration: ≥ 99%
- Tank pressure: Slightly higher than atmospheric and maintained stable.
- Sampling frequency: Hourly (upper, middle, and lower tank levels)

Support Equipment: LNG vapour, nitrogen (for purging), bunkering facilities.

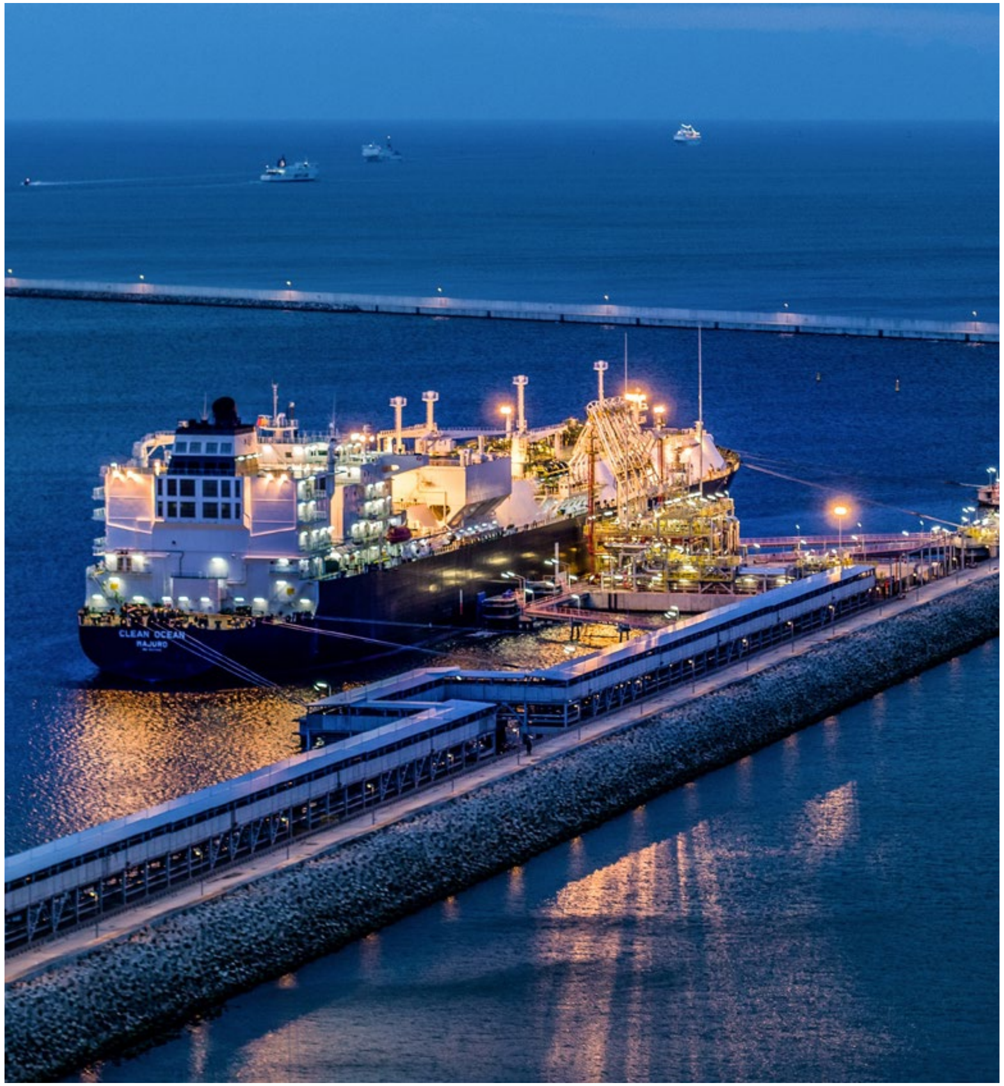
Cool-Down

The final stage of tank preparation involves cooling the LNG tank to cryogenic temperatures to prevent thermal shock during LNG loading and minimise boil-off gas (BOG) generation. The tanks are provided with spray lines which are spread across the tank to ensure even cooling of the tank.

LNG is sprayed into the tank through dedicated spray lines until the average tank temperature reaches -130°C. The cooling process is gradual, with a controlled temperature reduction rate not exceeding -10°C per hour. Tank and spray line temperatures are closely monitored using temperature sensors, and data is recorded manually every 15 minutes. The system must have protection against overpressure, and any generated vapour is routed to the external facility via the vapour return manifold. Initial LNG spraying is done slowly to cool the bunkering hose and spray line, after which the spray rate may be adjusted according to system specifications. Cooling continues until all components are adequately chilled and tank pressures stabilise.

- Target tank temperature: ≤ -130°C (average)
- Cooling rate: ≤ -10°C/hour
- Tank pressure: Maintained to manage BOG
- Spray inlet pressure: Controlled as per spray nozzle design
- Temperature recording interval: Every 15 minutes
- BOG generation: Monitored and returned to external facility

Support Equipment: LNG for cooling, external vapour return facilities.



Bunkering Procedures

Before commencing LNG bunkering operations, a set of essential pre-conditions must be fulfilled to ensure safe, compliant, and efficient transfer. These conditions apply to both the bunker supplier and the receiving vessel.

Pre-Bunker Transfer Checklist

A pre-transfer checklist must be jointly completed by both parties. Once signed, it serves as a formal permit to begin bunkering operations. Operations must be paused or halted if any conditions change significantly during the process.

Weather Conditions

Forecasted and observed weather conditions must fall within the operational limits of the mooring and transfer systems. Factors that could restrict or delay operations include visibility, wind direction and speed, wave height and period, and the presence of electrical storms.

Communications

Reliable communication channels should be agreed upon and tested prior to the start of operations. Where verbal communication is limited by language barriers, standard visual signals must be clearly understood by all personnel involved.

Lighting

Adequate illumination is required throughout the bunkering area. In the event of lighting failure or insufficient lighting during low visibility, operations must be suspended until proper lighting is restored. Emergency lighting is only to be used to safely stop operations, not to continue them.

Authorisations and Notifications

Any necessary permits or notifications required by regulatory or port authorities must be obtained and complied with prior to starting the operation.

Mooring

The vessel(s) must be securely moored in accordance with the agreed mooring plan. Environmental factors such as wind, tide, swell, passing traffic, ice, and any changes to draft or trim must be considered. All mooring equipment, including lines, fenders, and winches, should be visually inspected for wear or damage prior to use.

Safe Access

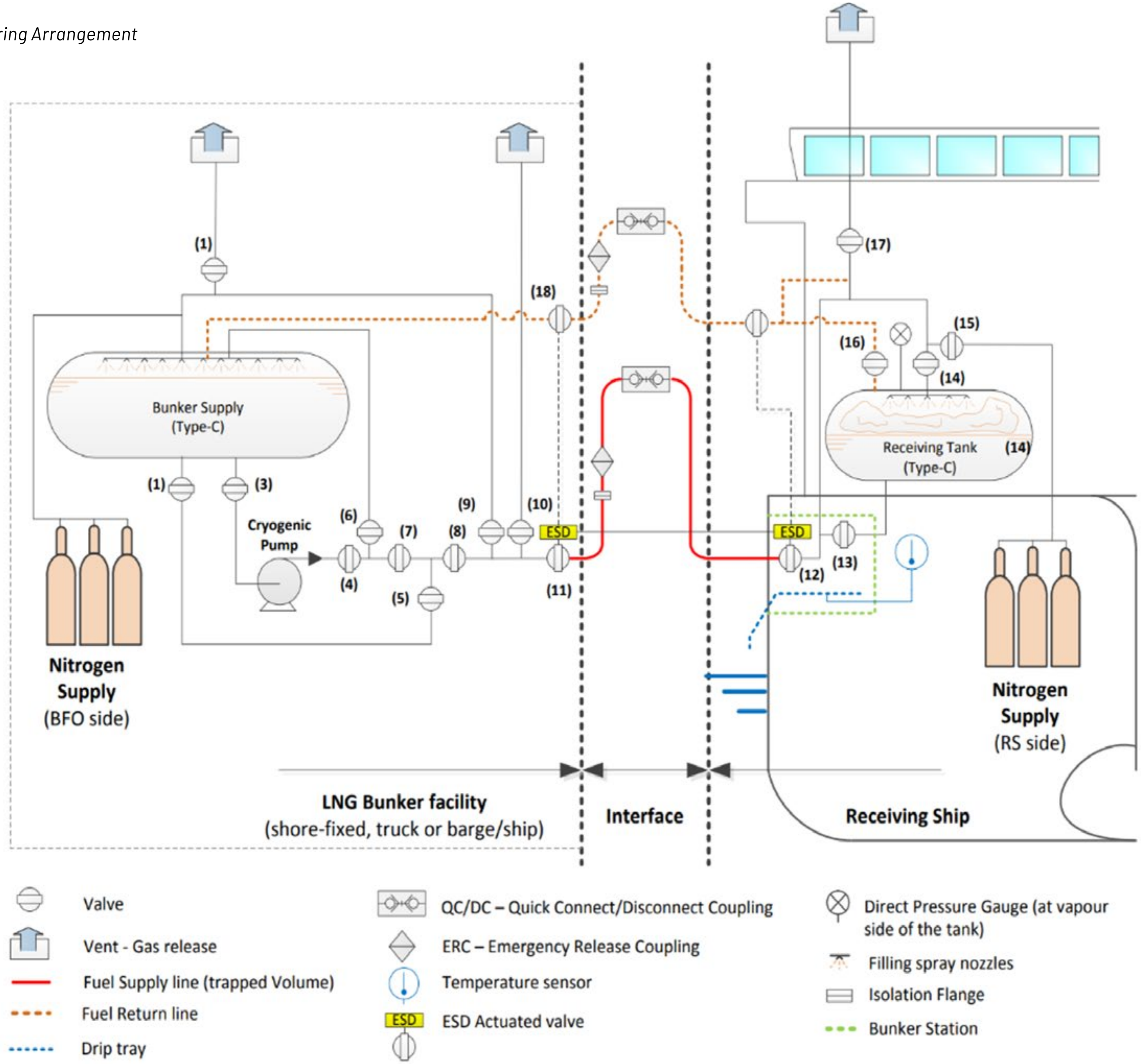
A safe means of access must be provided between the bunker vessel and the receiving ship for the duration of the operation.

Preparations and Inspections

Prior to connection, the bunkering system should be drained, purged, and inerted with nitrogen. All inspections and safety checks must be documented in the pre-bunker checklist. Preparations include:

- Establishing safety and security zones
- Isolating non-EX equipment in hazardous areas
- Setting communication equipment to low power
- Confirming personnel rest/work hours compliance
- Verifying PPE readiness and use
- Testing ESD and ERS systems
- Inspecting hoses and connections
- Checking LNG tank levels, temperatures, and pressures
- Confirming tanks are oxygen-free and cold
- Agreeing on transfer rates and loading limits
- Ensuring cryogenic protection is available
- Verifying fire and gas detection systems
- Securing doors and ventilation in safety zones
- Earthing and immobilising road tankers
- Reviewing weather forecasts
- Confirming compatibility between parties
- Conducting leak and pressure tests after connecting

Figure 7: *Generic LNG Bunkering Arrangement*



During Bunkering

Proper execution of the bunkering process requires constant supervision and active monitoring of both equipment and environmental conditions.
Figure 7 below shows a generic LNG Bunkering arrangement.

Supervision

Qualified personnel must supervise the operation, ensuring all safety protocols are maintained. Only approved simultaneous operations should be carried out. Throughout the operation, mooring conditions must be monitored, transfer rates carefully controlled, and tank conditions (pressure, temperature, fill level) continually observed.

Access to safety zones should be strictly limited, and the entire system must be checked regularly for leaks.

Bunker Transfer Process

Once the cool-down phase is complete and the system is stable, LNG transfer can begin gradually. The rate can then be increased in a controlled manner to the pre-agreed rate. Transfer should be immediately stopped if any anomaly is observed, and operations may only resume after the issue has been resolved. All personnel should be familiar with emergency shutdown and release procedures.

Topping Off

As the tank nears full capacity, the transfer rate should be reduced to an agreed topping-up speed. This stage requires close attention to prevent overfilling or excessive pressure. The ESD system must not be used as a routine method to terminate the operation at high-level limits.

Vapour Management

Vapour pressure must be actively managed to prevent overpressurisation.

Different systems require different approaches:

- For atmospheric tanks, vapour return lines or other methods like condensing or compression units may be used.
- For Type C tanks, LNG can be sprayed from the top to limit vapour pressure buildup, eliminating the need for vapour return lines.

After Bunkering

Once transfer is complete, shutdown and disconnection procedures must be followed in accordance with best practices and applicable regulations.

Post-Transfer Checklist

A comprehensive checklist should be completed by both the supplier and the receiving ship, covering all required shutdown, disconnection, and reporting procedures. This may include notifying the relevant Flag State and Port Authorities.

Draining and Purging

Residual LNG in transfer lines must be safely drained. All lines and hoses must then be purged with nitrogen to remove any remaining natural gas. If hoses have sagged into a “U” shape, pooled LNG may remain; this can be evaporated using warm water. Proper purging ensures that a flammable atmosphere does not persist at the connection points.

Purging should be done in a manner that avoids gas release into the atmosphere and must follow system-specific procedures. For systems using hard arms, SIGTTO’s guidelines should be followed.

Disconnection of Hoses or Arms

Before disconnection, methane levels in the system should be confirmed to be below 2% by volume using calibrated gas detection equipment. After disconnection, the transfer lines should be sealed to prevent ingress of air or moisture, which can lead to ice formation and safety hazards during future operations.

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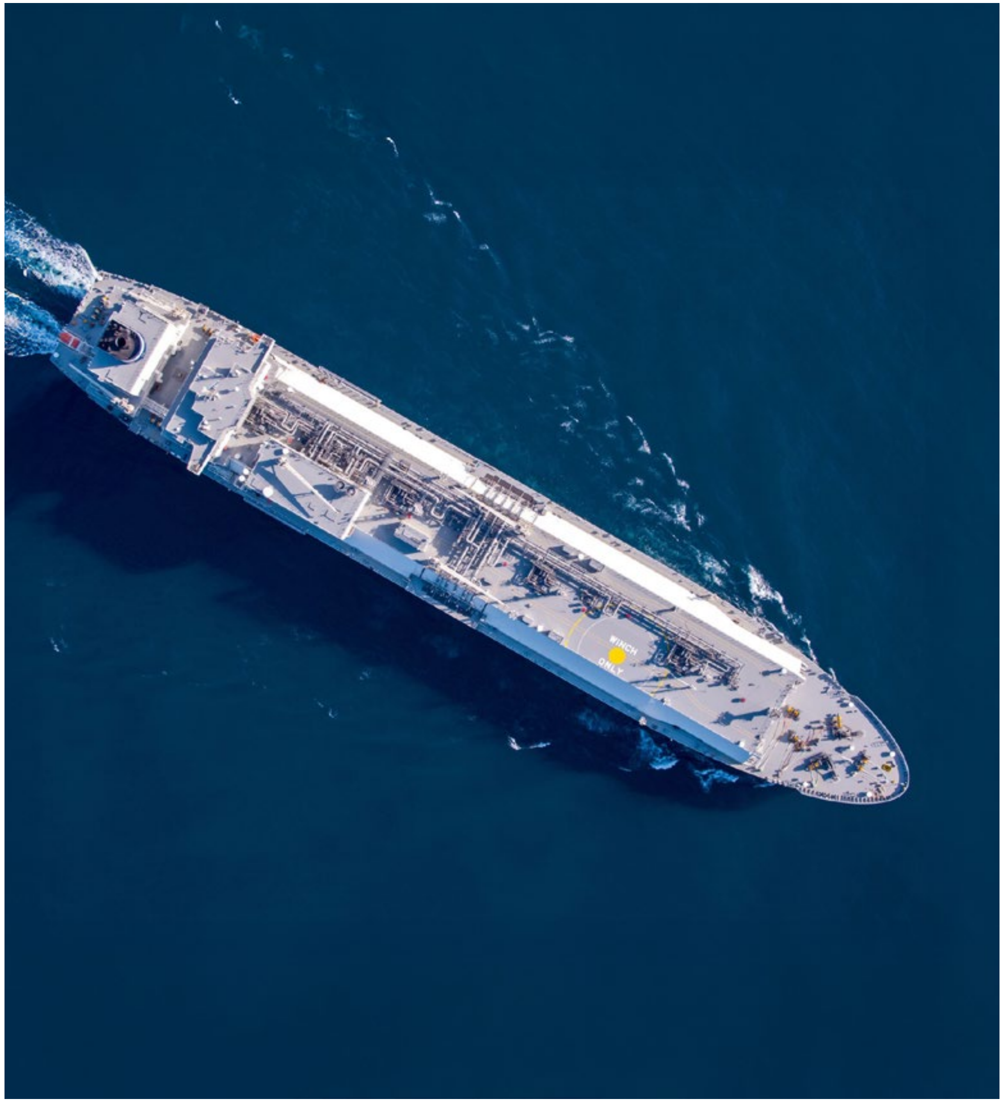

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