AMMONIA BUNKERING: TECHNICAL AND OPERATIONAL ADVISORY

June 2024

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Limited contributions to this advisory have graciously been provided by the following companies:

1. Amogy
2. Maersk Tankers
3. Navigator Gas
4. SIGTTO (The Society of International Gas Tanker and Terminal Operators)

INTRODUCTION

The marine industry is undergoing considerable changes as a result of the increasingly strict gaseous air emission legislation imposed by the International Maritime Organization (IMO), aiming for the reduction of greenhouse gas (GHG) emissions from ships. It is estimated that shipping contributes to 3 percent of the world's carbon dioxide (CO_2) emissions, and the marine industry has a responsibility to contribute to a more sustainable future.

As a result, IMO outlined its first Greenhouse Gas Strategy for the maritime sector in 2018 and revised it in 2023. The revisions include, but are not limited to:

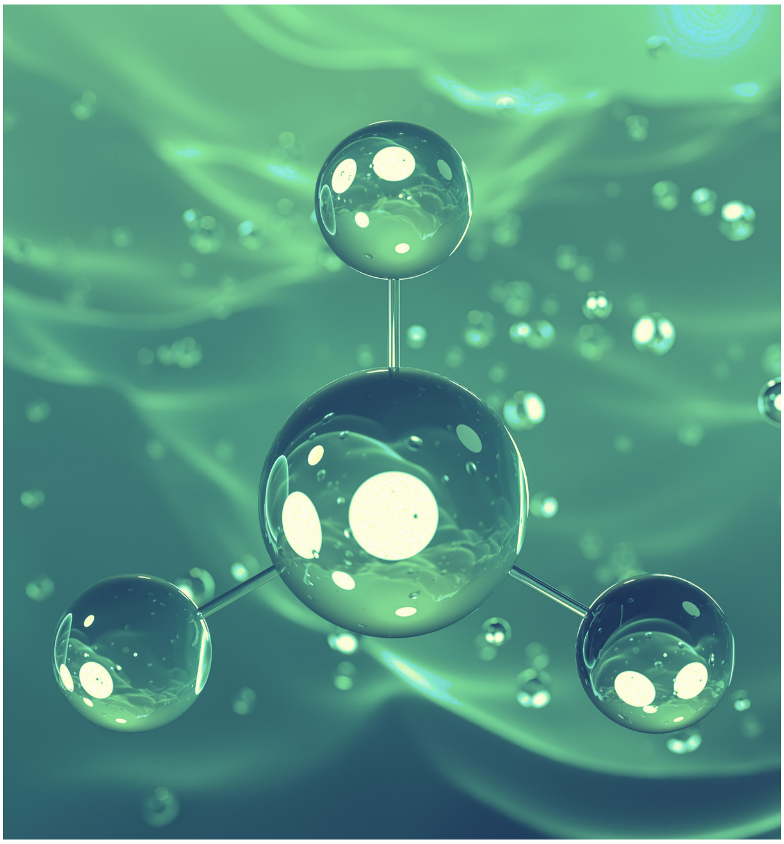
- The reduction of the CO_2 emissions per transport work, at an average across international shipping by at least 40 percent by 2030, compared to 2008
- Uptake of zero or near-zero GHG emission technologies, fuels and/or energy sources which are to represent at least 5 percent, striving for 10 percent, of the energy used by international shipping by 2030
- Reach GHG emissions from international shipping to Net Zero by or around 2050

The 2023 IMO GHG Strategy also introduces indicative checkpoints to reach this revised target, namely, to reduce:

- The total annual GHG emissions from international shipping by at least 20 percent, striving for 30 percent, by 2030, compared to 2008
- the total annual GHG emissions from international shipping by at least 70 percent, striving for 80 percent, by 2040, compared to 2008

With an increasing interest in reducing GHG emissions, global industries are looking for ways to reduce their carbon emissions either by using low carbon fuels with carbon capture and storage technologies or by using alternate clean fuels.

Among the alternate fuel options, ammonia has piqued the interest of the marine industry due to its zero-carbon fuel properties and the ability to produce ammonia from renewable and sustainable sources. Therefore, the adoption of ammonia as marine fuel is expected to become one of the means to meet the emissions legislations imposed by IMO. Accordingly, owners, operators, designers and shipyards around the world are considering the advantages that operating on ammonia 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 to respond to the need for better understanding by members of the maritime industry on the issues involved with bunkering ammonia as fuel. It is intended to provide guidance on the technical and operational challenges of ammonia bunkering, both from the bunker vessel's perspective (or land-side source) and from the receiving vessel's perspective.

This Advisory is not intended to discuss the ammonia value chain in detail. For additional information about ammonia value chain, we recommend the ABS *Sustainability Whitepaper Ammonia as Marine Fuel* (October/2020) and the ABS publication *Beyond the Horizon: Carbon Neutral Fuel Pathways and Transformational Technologies* (2024).

GENERAL INFORMATION ABOUT AMMONIA

CHARACTERISTICS

Ammonia is an inorganic compound of nitrogen and hydrogen, with the formula NH_3. It is a colorless gas at room temperature with a distinctive odor. Ammonia becomes a liquid at high pressure, making it ideal for storage and transportation.

Ammonia's flammability range is narrower than other low flash point or gaseous fuels that have been considered for the marine industry. In open dry air, the flammability range is 15.2 to 27.4, by Vol%. However, under certain conditions, there can be a risk of fire and explosion, and safety concepts must consider these risks.

Ammonia is toxic and very reactive. It reacts violently and explosively with oxidizing gases such as chlorine, bromine, acids, and other halogens. When ammonia is inhaled, swallowed or absorbed via skin contact, it reacts with water in the body, producing ammonium hydroxide. This chemical is very corrosive and damages cells in the body on contact. Ammonia exposure at low concentration can be irritating to the eyes, lungs and skin. Additionally, direct exposure at high concentration is considered immediately life threatening. The effects may include, but are not limited to, difficulty breathing, chest pain, bronchospasms and pulmonary edema. Due to these toxicity issues, ammonia is classified as a hazardous substance, with level and time of exposure being controlled by several national standards.

Materials are to be carefully selected when being proposed for ammonia services. Ammonia is incompatible with various materials and, in the presence of moisture, reacts with and corrodes copper, brass, zinc and various alloys forming a greenish/blue color. In general, no component made of copper, nor its alloys must be installed in the vicinity of the bunkering manifold (such as temperature and pressure gauges, switches, valves, and plugs). Iron, steel and specific non-ferrous alloys resistant to ammonia should be used for tanks, pipelines and structural components where ammonia is used. As storage temperature rises, oxygen content has a greater impact on material and can cause stress corrosion cracking. For this purpose, the allowable oxygen content for storage temperature is given in Chapter 17 of the IGC Code.

The key properties of ammonia are shown below in Table 1.

Table 1: Ammonia properties.

Item	Ammonia
Energy Density (MJ/L)	12.9
Latent Heat of Vaporization (LHV) (MJ/kg)	18.8
Heat Vaporization (kJ/kg)	1371
Autoignition Temperature (°C)	651
Liquid Density (kg/m^3)	696 (at -33° C)
Adiabatic Flame Temperature at 1 Bar (°C)	1800
Molecular Weight (g/mol)	17.031
Melting Point (°C)	-77.7
Boiling Point (°C)	-33
Critical Temperature (°C)	132.25
Critical Pressure (Bar)	113
Flammable Range in Dry Air (%)	15.15 to 27.35
Minimum Ignition Energy (mJ)	8
Cetane Number	0
Octane Number	~130

AMMONIA AS MARINE FUEL

Among the use of alternative fuels under consideration by the marine industry (i.e., methane, methanol, hydrogen, ammonia, biofuel), ammonia can produce near or net-zero carbon emissions when burned in internal combustions engines or used as fuel on board fuel cells, respectively. The carbon emissions from the combustion of ammonia are associated with and dependent on the type and amount of the pilot fuel used. Use of biofuel as pilot fuel may further reduce the emissions (refer to Part 6, Chapter 5, Section 1 of the ABS *Rules for Building and Classing Marine Vessels*).

In addition, the emissions of sulfur dioxide, heavy metals, hydrocarbons and polycyclic aromatic hydrocarbons (PAHs) drop to zero (or near zero, depending on the pilot fuel used); and particulate matters (PM) are also substantially reduced compared to conventional fossil fuels. However, particular attention needs to be paid to potential presence of ammonia slip, N_2O or NOx emissions, due to the imperfect combustion of ammonia and the use of pilot fuels.

These emissions will need to be kept as low as possible by further adjustment and development of the engine technology or using an onboard exhaust gas treatment technology. Currently, hydrogen for ammonia production is typically produced by means of steam methane reforming (SMR) or autothermal reforming (ATR) of natural gas (gray ammonia). If the CO_2 emissions from the process of converting natural gas are captured and stored, the ammonia is typically referred to as blue.

Moreover, the production of blue ammonia retains a dependency on fossil fuels. Therefore, green ammonia, which is produced from hydrogen made from renewable energy sources (green hydrogen), is generally considered to be the end-solution for the decarbonization which leads to a sustainable fuel cycle, while blue ammonia is seen to have an intermediate role.

The potential well-to-wake GHG emissions of green ammonia are estimated to be around 91 percent lower than for gray ammonia, and 85 percent lower than heavy fuel oil (HFO) and marine gas oil (MGO). The gray ammonia production network is already well established globally, ensuring easier accessibility across major ports worldwide. This will help green ammonia become readily available for bunkering and distribution once sufficient production and infrastructure are in place. On the other hand, when compared with liquid hydrogen or liquefied natural gas (LNG) which can be stored at temperatures of -253° C and -162° C respectively, liquid ammonia can be stored and transported at -33° C near atmospheric pressure, which allows for easier adaptation of existing fuel infrastructure on ships and at ports.

REGULATORY ORGANIZATIONS

This section lists the main organizations involved in the process of reviewing the ammonia bunkering system designs and arrangements:

INTERNATIONAL MARITIME ORGANIZATION (IMO)

The IMO's safety-related regulations for international shipping are regulated through the International Convention for the Safety of Life at Sea (SOLAS, 1974, as amended) convention. To accommodate the interest in using gaseous and liquid fuels with a flashpoint of less than 60° C, the IMO adopted the International Code of Safety for Ships using Gases or Other Low-Flashpoint Fuels (IGF Code) by including a new Part G to SOLAS II-1 in 2015.

- **International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IGC Code)**

  As with LNG bunkering ships, the IGC Code would be applicable to anhydrous ammonia bunkering ships which are subject to the SOLAS convention, and also to the ships typically required by flag Administrations for bunkering vessels or barges operating solely in their sovereign waters.

- **International Code of Safety for Ships using Gases or Other Low-Flashpoint Fuels (IGF Code)**

  As indicated above, the IGF Code is the most appropriate IMO instrument to deal with ammonia as a marine fuel until the organization develops non-mandatory guidelines or amends SOLAS instruments to cover its application. For the use of ammonia as marine fuel, IMO is developing the Interim Guidelines for Ships Using Ammonia as Fuel associated with the International Code of Safety for Ships Using Gases or other Low-Flashpoint Fuels (IGF Code). The basic intent of the Interim Guidelines is to provide provisions for the arrangement, installation, control and monitoring of machinery, equipment and systems using ammonia as fuel to minimize the risk to the ship, its crew and the environment, having regard to the nature of the fuels involved.

The goal and functional requirement-based structure of the IGF Code, together with the clear path to approval of fuels not directly covered by the requirements through the alternative-design process, means the IGF Code has the right framework for approving all gases and low-flashpoint fuels.

INTERNATIONAL ASSOCIATION OF CLASSIFICATION SOCIETIES (IACS)

IACS has been active in developing Unified Requirements (URs), Unified Interpretations (UIs), and Recommendations (Rec) to support application of the IGF Code, many of which are transferrable to ammonia, or other gases or low-flashpoint fuels. As of today, IACS has released the UR H1 related to control of ammonia releases in ammonia fueled vessels.

CLASSIFICATION SOCIETIES

As a world-class classification society, ABS will have a significant role in reviewing the design and construction of ammonia fueled vessels, including the bunkering systems on the receiving ship and any ammonia bunkering ship, such as liquefied gas carriers and barges. In addition to reviewing the design and surveying the construction according to its own Rules, ABS may act as a Recognized Organization (RO) for compliance with national and international requirements on behalf of the flag Administrations.

As part of the ABS development of specific requirements for the use of ammonia as fuel, ABS has published the *Requirements for Ammonia Fueled Vessels* (2023). This document provides guidance for the design, construction, and survey of vessels utilizing ammonia as fuel.

FLAG ADMINISTRATIONS

Flag Administrations have the primary responsibility for enforcing international and national regulations related to the ships under their registry and the associated bunkering systems, processes, and procedures, which in some cases can be more restrictive than class Rules or international regulations. Some flag Administrations delegate the design review and survey processes to the classification societies acting as ROs.

PORT STATES

Port State regulations cover more aspects of the bunkering process than either class Rules or flag Administration regulations since they oversee the interface bunkering zones, risk to local area and routine port operations. Typically, Port States specify requirements for the actual bunker procedure, permissible bunkering locations, restrictions on bunkering times and weather conditions, simultaneous operations, bunkering supply facilities, training, required documentation, acceptability of risk assessments and permits.

THE SOCIETY OF INTERNATIONAL GAS TANKER AND TERMINAL OPERATORS (SIGTTO)

SIGTTO has been instrumental in the development of the IGC Code and offers the most relevant marine experience for the carriage of anhydrous ammonia in bulk. With a membership encompassing shipowners/operators and terminal operators, it also provides the most competent source of experience on cargo loading and unloading and the ship-to-ship transfers of liquefied gases.

THE SOCIETY FOR GAS AS A MARINE FUEL (SGMF)

SGMF was established in 2013 from a SIGTTO-driven initiative. Most of the SGMF's activities, focus, and publications have been on LNG as the marine gas fuel. However, it is understood that the scope of its activities will expand to include other gases being considered for marine fuels, notably hydrogen and ammonia. Accordingly, SGMF has released the publication *Ammonia as Marine Fuel* which covers technical considerations, systems design, bunkering facilities, and processes associated with ammonia operations.

INITIAL CONSIDERATIONS

GENERAL

While specific requirements for ammonia bunkering are under discussion by all marine stakeholders, the requirements for shipping ammonia as cargo, including loading and unloading operations, have been established in the marine industry and are covered by the IMO International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IGC Code) and incorporated in the ABS *Rules for Building and Classing Marine Vessels Part 5C Chapter 8* "Vessels Intended to Carry Liquefied Gases in Bulk". For the use of ammonia as bunker fuel, all segments of the marine industry (including IMO, Class Societies, Port Authorities, and industry agencies) are working to develop requirements and procedures specific for the ammonia bunkering operations. Refer to the section "Regulatory Organization" of this Advisory for the current activities of each marine industry segment.

The table below shows a general comparison between the ammonia as cargo and ammonia as bunker fuel in the view of the receiving vessel.

Table 2: Comparison of ammonia cargo and ammonia bunkering.

Item	Ammonia as Cargo	Ammonia as Bunker Fuel
Guideline and procedures	Well established	Under development
Specifications	Chemical or fertilizer	Fuel for internal combustion engines or fuel cells
Vapor return line	Required	Based on the bunkering and storage conditions
BOG management	Required	Required
Tank size and flow rate	Higher capacity and flow rate	Expecting lower capacity and flow rate comparing to ammonia as cargo, with broad range of capacity and flow
Operational frequency	Low, limited to ammonia carriers	Very high, applies to various type of vessels
Operational experience	Limited to industry use	Not established
Operational modes	Fewer combinations	Several combinations
Gas dispersion and release study	Limited to terminal	Various studies ongoing
Mitigation measures	Requirement in IGC Code	Risk assessment by IGF Code

TEMPERATURE AND PRESSURE CONDITIONS

Liquefied ammonia can be stored and transported in three different conditions: fully refrigerated, semi-refrigerated and non-refrigerated (or pressurized). The estimated temperature and pressure ranges of each condition are indicated in the table below.

Table 3: Liquefied ammonia storage conditions.

Ammonia Storage Condition	Fully Refrigerated	Semi-Refrigerated	Non-Refrigerated (or Pressurized)
Temperature	-33° C	-9° C to 4° C	Ambient temperature
Pressure	Close to atmospheric pressure	2 to 4 bar(g)	7 bar(g) up to 18 bar(g)

Given the above temperature/pressure conditions, the viability of various transfer configurations between the supplier and the receiving ship should be considered:

Transfer across similar storage conditions – Ammonia transfer across similar storage temperature and pressure conditions is highly viable. While the operational principles for fully refrigerated and semi-refrigerated transfers are the same, non-refrigerated (or pressurized) requires a storage tank and transfer system to be designed to withstand higher pressure. Non-refrigerated ammonia is stored at ambient temperature conditions, eliminating the low-temperature operations, but increasing the risk of leakage due to high pressure.

Transfers from colder to warmer storage conditions – Ammonia transfer from fully refrigerated to semi-refrigerated is economically viable, provided the pumps in a fully refrigerated system will have the sufficient discharge pressure needed to achieve semi-refrigerated storage conditions. Ammonia transfer from fully refrigerated/semi-refrigerated storage systems to non-refrigerated systems will require booster pumps with much higher discharge pressure to meet the pressure requirements. This is also technically feasible, but transfer of ammonia from colder to warmer conditions may cause technical and operational issues.

Transfers from warmer to colder storage conditions – Transfer of ammonia from warmer to colder storage conditions is commercially not viable considering the requirements for additional cooling mechanisms to meet the receiving tank conditions. Therefore, transfers from non-refrigerated to fully refrigerated/semi-refrigerated are considered economically unviable.

AMMONIA QUALITY AND SAMPLING

There is no specific standard for the verification of the ammonia bunkering quality. Future ISO standards or internationally accepted guidelines that present new quality measurement methods and procedures may also be considered. A sample composition limit table for ammonia fuel is given below in Table 4.

The ammonia bunker supplier and buyer must provide written consent regarding the bunker parameters. The ammonia bunker supplier must supply bunker(s) of quality, according to the specifications agreed upon between the ammonia bunker supplier and buyer. The certificate of quality issued by the ammonia bunker supplier(s) should be representative of the bunker(s) delivered.

Measuring the quality of ammonia requires knowledge of its composition and the sampling and analysis of its components. The composition of ammonia can be determined by way of gas chromatography (GC), utilizing a vaporizer while in a gas phase or a Raman analyzer while in a liquid phase. A competent person must calibrate the ammonia quality measurement equipment periodically to ensure precision and traceability. In addition, the water content in anhydrous ammonia can be tested per CGA G-2.2, Guideline Method for Determining min. of 0.2 percent Water in Anhydrous Ammonia.

Due to the safety and toxicity concerns of ammonia fuel, considerations have been made for the sampling of ammonia in IMO MEPC 81 amendments indicating that the requirements in paragraphs 10 and 11 of Regulation 14 and paragraphs 5.1, 5.2, 8.1 and 8.2 of Regulation 18 of MARPOL Annex VI referring to in use and onboard fuel sampling do not apply to gas fuels, unless local authority instructs otherwise. Relevant amendment is also considered in Appendix I of MARPOL Annex VI, Form of International Air Pollution Prevention (IAPP) Certificate, as per Regulation 8.

Table 4: Typical ammonia sample fuel composition limits.

Specification Parameter	Units	Limit	Test Method
NH_3 (Anhydrous Ammonia)	% (w/w)	99.5 Minimum	Evaporative Residue
Water Minimum %	% (w/w)	0.2 Minimum	CGA G-2.2/ISO 7105
Oil Maximum %	ppm	5 Maximum	FTIR Analysis/ISO 7106
Oxygen	ppm	2.5 Maximum	No Specific Standard Developed Yet
Appearance	N/A	Clear, Colorless Liquid or Gas	Visual

AMMONIA QUANTITY

The amount of ammonia transferred is calculated from measurements taken before and after the transfer. The following elements shall be measured and reported in the Bunker Delivery Note (BDN) to ascertain the energy content of the bunker transferred:

- Lower calorific (heating) value, higher calorific (heating) value and density
- Mass of bunker(s) transferred

The bunker calculations are to be performed by the person in charge of the bunker vessel and the receiving vessel or their authorized representatives (when engaged), such as bunker surveyors. Otherwise, an automated bunker metering system could calculate the quantity delivered.

The person in charge onboard the bunker supply vessel must complete the Bunker Delivery Note (BDN), and the Chief Engineer or their representative on board receiving vessel must observe and validate all calculations and measurements related to the computation of the supplied quantity in the BDN.

AMMONIA BUNKERING

This section provides details and guidelines for vessels engaged in ammonia transfers and bunkering. It provides comprehensive guidance on the delivery of ammonia from bunkering facilities to receiving vessels, covering all bunkering scenarios through three main transfer methods.

METHODS OF BUNKERING

The three main methods of ammonia bunkering to ships are listed below:

Truck-to-Ship – This is the process of transferring ammonia from trucks or truck trailers to a receiving vessel using ammonia as fuel. Typically, the tanks on the truck are pressurized and store ammonia at ambient temperature. To increase bunker capacity and transfer rates, a manifold may be used to connect several trucks simultaneously to supply the receiving vessel. Truck-to-ship transfer operations may provide greater operational flexibility, but at the same time could induce operational restrictions and limitations due to consideration by the local Authority.

Ship-to-Ship – Ship-to-ship bunkering is the most popular mode for transferring fuel to oceangoing vessels, such as container ships, tankers, and bulk carriers, which require large fuel capacities and greater quantity of fuel to be bunkered.

Terminal-to-Ship – Transfers ammonia from an ammonia storage terminal pipeline connected to receiving vessels via a hose assembly or loading arm.

The ammonia portable fuel tank as a method of ammonia bunkering is not addressed in this Advisory since the use of this method is currently under evaluation by IMO.

The table below lists the advantages and disadvantages of the three different bunkering options.

Table 5: Advantages and disadvantages of different bunkering methods.

	Truck-to-Ship	Ship-to-Ship	Terminal-to-Ship
Advantages	• High flexibility • Bunkering directly at berth • Low investment • Experience in place	• High flexibility • High bunkering rates • High bunkering volume • Bunkering directly at berth or anchor • Aid SIMOPS	• High tank capacity • High bunkering rates • Low opex • Vast experience
Disadvantages	• Low bunkering rates • Low volumes • Challenges with SIMOPS • Safety challenges due to frequent connection/ disconnection	• High capex • High opex • Regulatory challenges • No dedicated infrastructure at this time	• Fixed locations • Low flexibility • High capex • Typically not practical for large ships

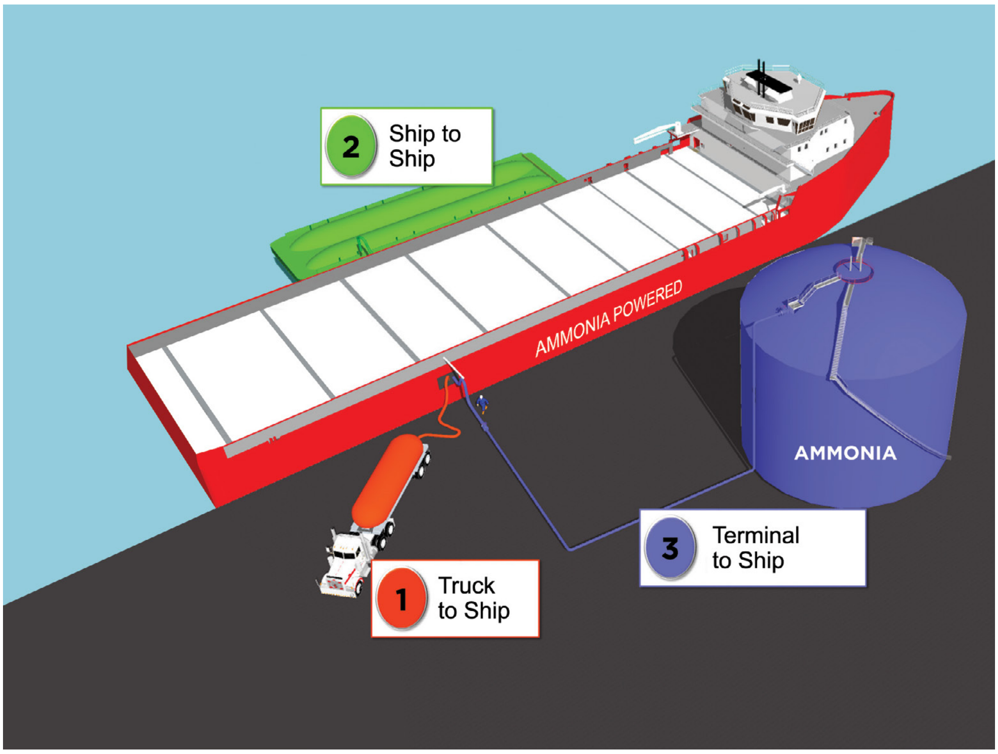


Figure 1: Bunkering methods.

DESIGN OF BUNKER STATIONS

The location of the bunker stations is a critical factor for determining the level of risk associated with the ship's bunkering operation since the flammability and toxicity characteristics present a possible risk to the ship in the case of leakage. Bunker stations for liquified or flammable gas fuels are to be located on open decks to provide sufficient natural ventilation per IGC and IGF Code requirements. The requirements also refer to special consideration and risk assessment for the application of enclosed or semi-enclosed bunker stations that could require additional safety measures. For ammonia fuel specific, having enclosed bunkering stations with suitable mitigation systems (i.e., continuous ventilation, gas detection and water spray systems) may facilitate the control of any ammonia leakage during bunkering operation and prevent or limit the release of toxic gases to atmosphere, subject to verification and validation during the risk assessment and gas dispersion studies.

The design of the bunker stations is to consider at least the following design features:

- Segregation towards other areas on the ship
- Hazardous and toxic area plans for the ship
- Requirements for forced ventilation
- Requirements for leakage detection (e.g., gas detection and low temperature detection)
- Safety actions related to leakage detection (e.g., emergency ventilation, water screen system, gas detection and low temperature detection)
- Access to bunkering station from non-hazardous areas through airlocks
- Monitoring of bunkering station by direct line of sight or by CCTV
- Safe mooring of bunkering vessels
- Adequate lifting equipment for hose/arm connection
- Adequate space around bunker connections for personnel access

Please refer to Section 8 of the ABS *Requirements for Ammonia Fueled Vessels* for further details of the arrangement of bunkering stations.

TRANSFER ASSEMBLIES

There are two main types of transfer assemblies utilized for bunker transfers:

HOSE ASSEMBLY

Hose assembly is the traditional way to bunker fuels constituted by the hose/end fittings and connection couplings at each side. Two types of flexible hoses (one for liquid and the other for vapor, as applicable) connect the supplying and receiving tanks. The bunker hoses are to be identified according to a defined system, so there will be no risk of using an incorrect hose type. The hoses with end fittings must have a suitable size and length, be in good condition, be visually checked, and be within the last replacement date before all transfer operations, following local and class rules. Preferably, the number of different hoses is to be kept to a minimum.

RIGID/MECHANICAL LOADING ARM

Full rigid arms are provided with rigid insulated pipe sections to transfer ammonia to the receiving vessel. These arms are typically installed on fixed bunkering stations or bunker vessels. In addition to the support, the use of mechanical rigid bunkering arms helps to ensure the safety of the bunkering operation and allow precise connection/disconnection. The arms optimize the overall bunkering duration and increase the possibility of delivering bunker connections at varying heights.

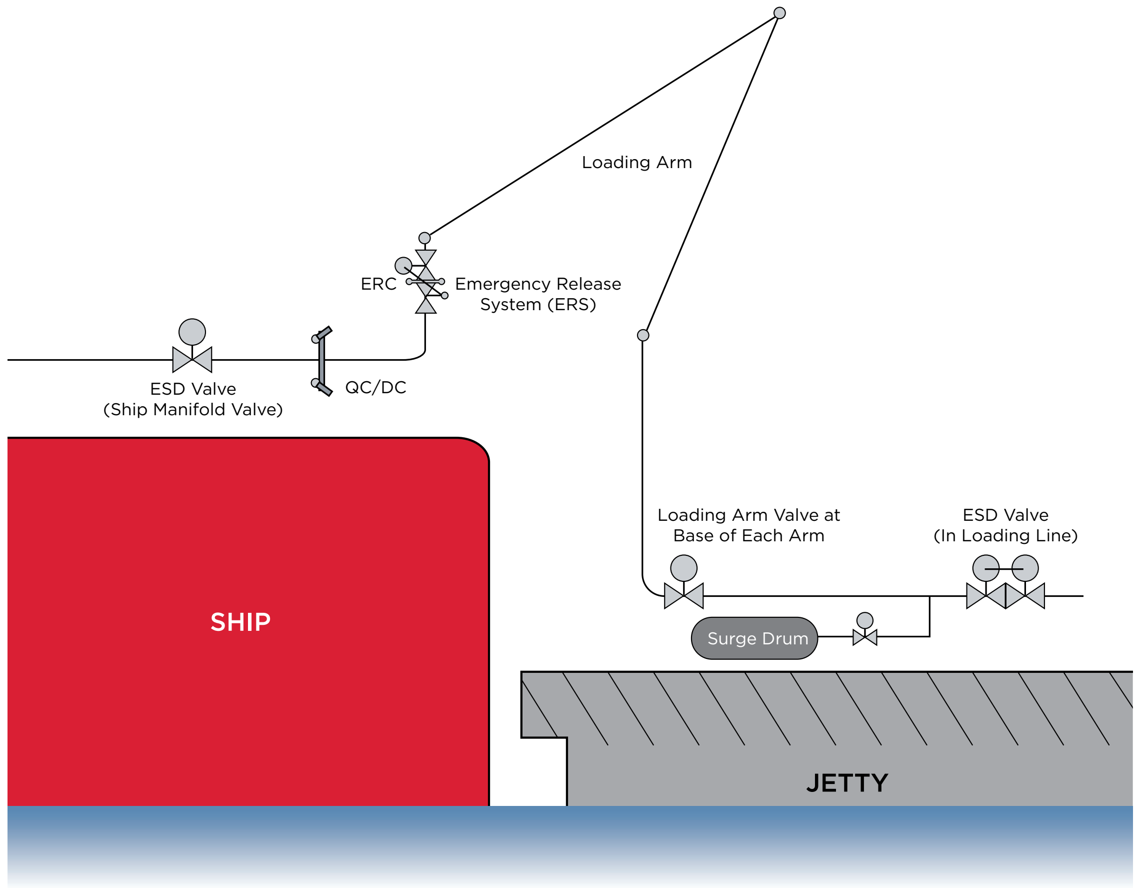


Figure 2: Typical mechanical loading arm.

EQUIPMENT FITTED WITHIN TRANSFER ASSEMBLIES

All the equipment associated with the bunkering operations is to be maintained and tested per the respective manufacturers' guidelines and recommendations. Specific requirements from relevant authorities are to be taken into consideration as well. Some of the important transfer assembly components are explained below with further details.

BUNKER HOSES

Ships' fuel hoses are to comply with the requirements in Part 5C, Chapter 13, Section 8-3.2 of the ABS *Rules for Building and Classing Marine Vessels.* Bunker hoses are also to comply with ISO 5771:2024 "Rubber Hoses and Hoses Assemblies for Transferring Anhydrous Ammonia – Specification." This international standard specifies the minimum requirements for rubber hoses used to transfer ammonia in liquid or in gaseous forms at temperatures from -40° C to +55° C. As it is limited to the performance of the hoses and hose assemblies, this standard does not include specifications for end fittings.

The ammonia liquid/vapor transfer hoses must be specially designed and constructed to prevent corrosion and sustain low temperatures (-33° C). The harmful effects of ammonia on rubber hoses, such as swelling, degradation and reduced lifespan require careful consideration. Appropriate material selection, regular inspections, proper storage, compatibility tests, and implementation of appropriate cleaning practices can minimize the negative impact of ammonia on rubber hoses, ensuring their longevity and optimal performance. It is recommended that the bunker hoses be stored blanked from both ends and slightly pressurized with nitrogen to avoid corrosion.

EMERGENCY RELEASE OR BREAKAWAY COUPLING (ERC/BAC)

The bunkering manifold should be designed to withstand the external loads during bunkering. These couplings act as the weakest part of the transfer assembly and break off if any force exerted on them exceeds the limit. The connections at the bunkering station should be of dry-disconnect type, equipped with additional safety dry break-away coupling/self-sealing quick release to avoid any external leakages. The couplings should also be of a standard type. The ERC/BACs can be disconnected either by the ESD system in case of an emergency situation on the vessel, or by a breaking pin or similar means when the tension on the bunkering/hose assembly exceeds the normal operating threshold.

QUICK CONNECT/DISCONNECT COUPLING (QCDC)

The quick connect/disconnect couplings consist of a nozzle and a receptacle which permits quick connection and disconnection of the bunker facility's hose system to the manifold of the receiving vessel in a safe manner and without employing bolts. These should be dry-disconnect type couplings in order to minimize or completely eliminate any releases or spills of ammonia during normal disconnecting operation. ISO is expected to develop standards for these couplings for ammonia bunkering in the longer term in the same way as ISO 21593:2019 "Technical Requirements for Dry-Disconnect/Connect Couplings for Bunkering Liquefied Natural Gas" was developed for LNG dry-disconnect couplings.

GROUNDING AND USE OF ISOLATION FLANGES

Additional precautions should be taken to prevent ignition due to electrical arcing during bunkering operations. Arcing can be caused by static electricity buildup in the bunker hose or differences in electrical potential between the receiving ship and bunker supplier's facility, including the quay or pier, trucks, bunker ships, etc.

- Terminal-to-ship bunkering: Loading arms for terminal-to-ship bunkering are metallic, an excellent electrical conductor with a very low resistance to electricity flow. This presents a danger of electric arcing at the manifold during the connection and disconnection of the shore hose and loading arm due to changes in electrical potential between the ship and the terminal.
- Truck-to-ship bunkering: The truck must be electrically grounded, and the wheels have to be secured to prevent unintended drive away.
- Ship-to-ship bunkering: An electric isolation flange is required to break the continuous electrical path between the ship and the bunker vessel.

An effective way of preventing arcing is to isolate the ship and the bunker supplier by 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 or LNG applications, but the principles are equally applicable to all such connections.

The isolating flange prevents arcs from passing between the receiving ship and bunkering 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 flange, but with the rest of the bunker hose string electrically continuous. Prior to starting any bunkering operation, the responsible bunkering crew should check that all connections between the receiver and supplier vessels, such as mooring lines, gangways, cranes, and any other physical connections, are properly isolated. 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.

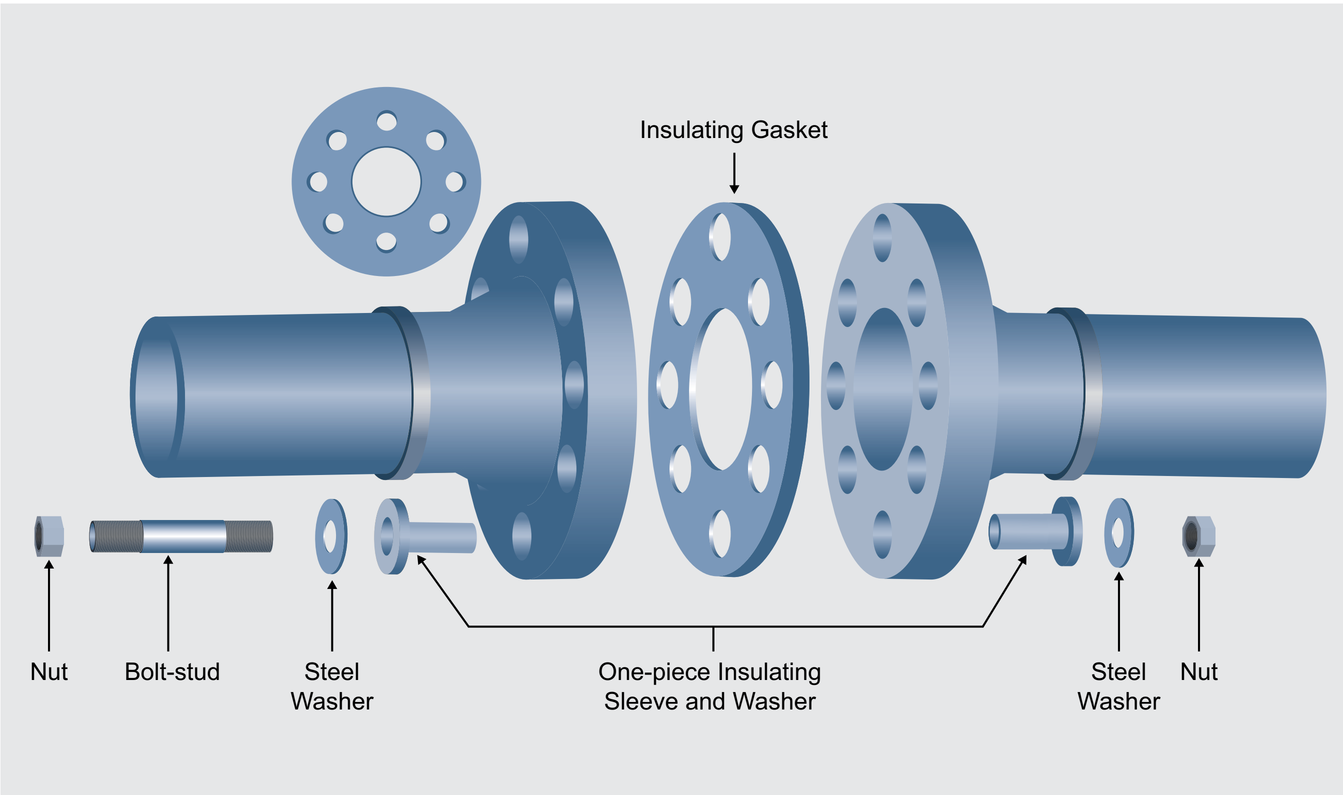


Figure 3: Details of the isolation flanges.

MOORING EQUIPMENT

The bunker supplier and the receiving ship must have good quality mooring lines and winches. Fairleads must be of a closed type, class approved, and comply with recognized standards. Moorings should be sufficient to keep the ship(s) restrained during anticipated wind, tide and weather conditions, and any expected surges from passing ships. The overhanging of mooring should be avoided as far as practicable. For safety reasons, soft mooring lines (or tails) should be used. Suitable fendering is to be deployed by the bunker supplier.

If mooring lines are subject to uneven loading due to vessel drift, the mooring line is at risk of failing, which could result in injury to port personnel and cause significant damage to ship or port structure. Considering the mooring arrangement and compatibility are critical for safety during bunkering operations, the installation of a mooring line load monitoring system is recommended, which can reduce these risks by providing real-time monitoring of the tension in each mooring line during the operations. This facilitates safe and efficient securing of a vessel by alerting port operators and the vessel master to any instance of uneven loading, allowing remedial action to be taken.

INERTING AND PURGING SYSTEMS

Atmospheric control within the ammonia fuel tanks and fuel storage hold spaces are to be arranged in compliance with the requirements in Part 5C, Chapter 13, Section 6/10 and 11 of the ABS *Rules for Building and Classing Marine Vessels.* The required fuel handling manuals should detail operational requirements prior dry-docking and after undocking incorporating the practices to be followed for gas-freeing, inerting, and gassing-up the tanks prior to first fill and for repair, inspection, and maintenance operations.

As required in Section 8 of the ABS *Requirements for Ammonia Fueled Vessels*, bunkering systems are to be capable of inerting and gas/air-freeing. When not engaged in bunkering, the bunkering systems are to be free of ammonia. Before commencing bunkering, the inerting process, which involves displacing air with inert gas, typically dry nitrogen, is to be initiated in order to control the moisture but also remove any flammable gas mixture within the bunker systems. After the bunker systems have been inerted, a gassing-up operation is to be carried out to replace the inert atmosphere with NH_3 vapor, preventing nitrogen entering in the fuel tank. A leak/pressure test is to be carried out to verify the integrity of the bunkering system prior to starting the transfer operation. After bunkering, the bunker hoses are to be drained and any remaining liquid or vapor in the bunkering lines should be purged using the inert gas so that they are free of NH_3. Due to the toxicity and very potent odor of ammonia, no ammonia should be released to the air or sea during normal operations or maintenance. Therefore, all ammonia is to be captured during purging operations by the ammonia treatment and vent control systems considering the safety of personnel in bunkering vicinity and the environment.

Selection of inert gas medium to be used on board the ammonia-fueled vessels also requires careful consideration due to the potential chemical reaction between ammonia fuel and the inert medium. To avoid such phenomenon, use of nitrogen as the inert gas is highly recommended. Please also note that the stored or the produced nitrogen on the vessel is to have an oxygen content of no more than 5 percent by volume.

BOIL OFF GAS (BOG) MANAGEMENT

Considering the toxicity of ammonia presents, boil off gas management enables ships to safely handle the unused or excessive BOG to maintain safe pressure levels in the fuel tanks and to prevent the tank relief valves from opening during normal operation or upset situation of the vessel. Releasing of fuel vapor to atmosphere through the tank relief valves/vent mast is only permitted in case of an emergency (e.g. fire scenario) on board the vessel. As the vessels are generally idling during bunkering operations, hence no consumption or burning of fuel vapor from the fuel tanks, special consideration is needed for the BOG management systems on both the receiving vessel and supplier sides. The IGF Code permits several methods to manage the BOG, including thermal oxidation, re-liquefication, cooling and pressure accumulation.

Receiving vessels with fully refrigerated or semi-refrigerated fuel tanks are normally required to be designed with a re-liquefication plant as part of the BOG/tank management system, while the vessels with pressurized Type -C tanks are required to be designed for 18 bar which corresponds to the ammonia vapor pressure at 45° C.

There are several possible combinations of ammonia bunkering with fully refrigerated tanks, semi-refrigerated tanks, and pressurized tanks. Some of those possible combinations are explained below with further details;

- Both the supply and receiving tanks are pressurized (P): This configuration may be the most common and most cost-effective bunkering option available, as it does not require a vapor return system or specific equipment to adjust the delivery pressure and/or temperature.

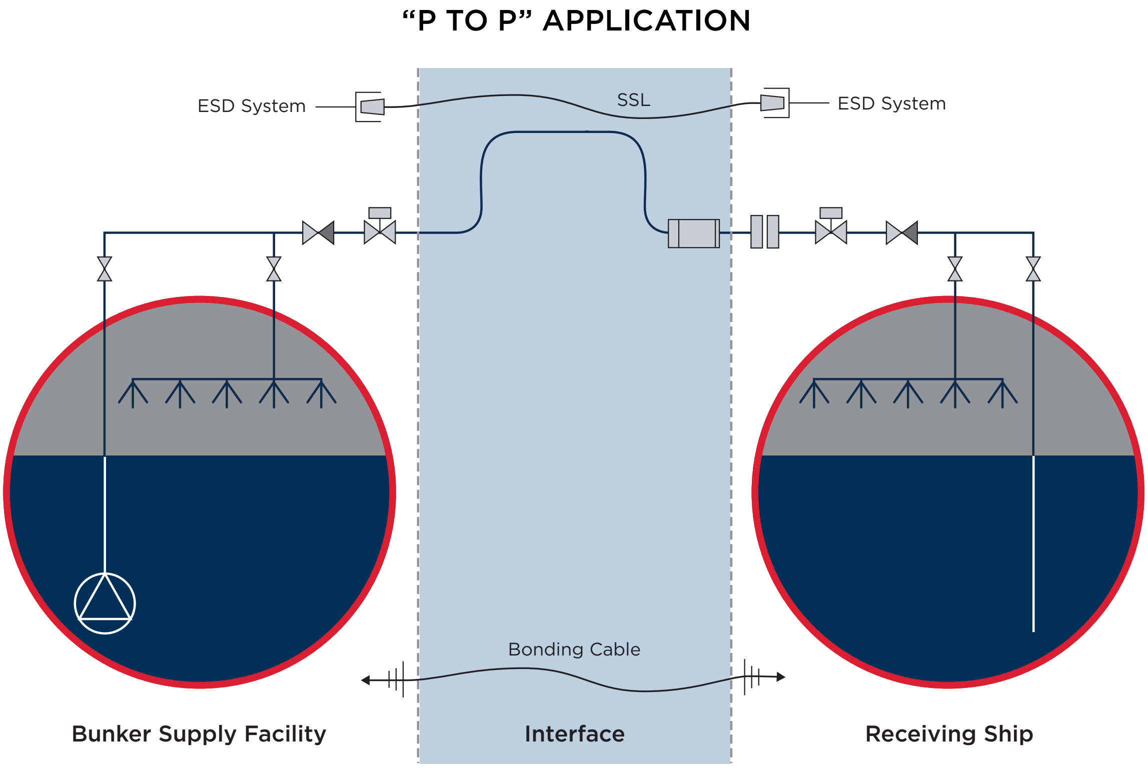


Figure 4.1: Typical detail of ammonia bunkering – P to P application.

- Bunker supply tank is fully refrigerated (FR) or semi-refrigerated (SR) and the receiving tank is pressurized: In that case, the bunker vessel should have a specific system/equipment to generate delivery pressure and temperature (e.g. vaporizer with pressure/temperature control) as required for the transfer operation.

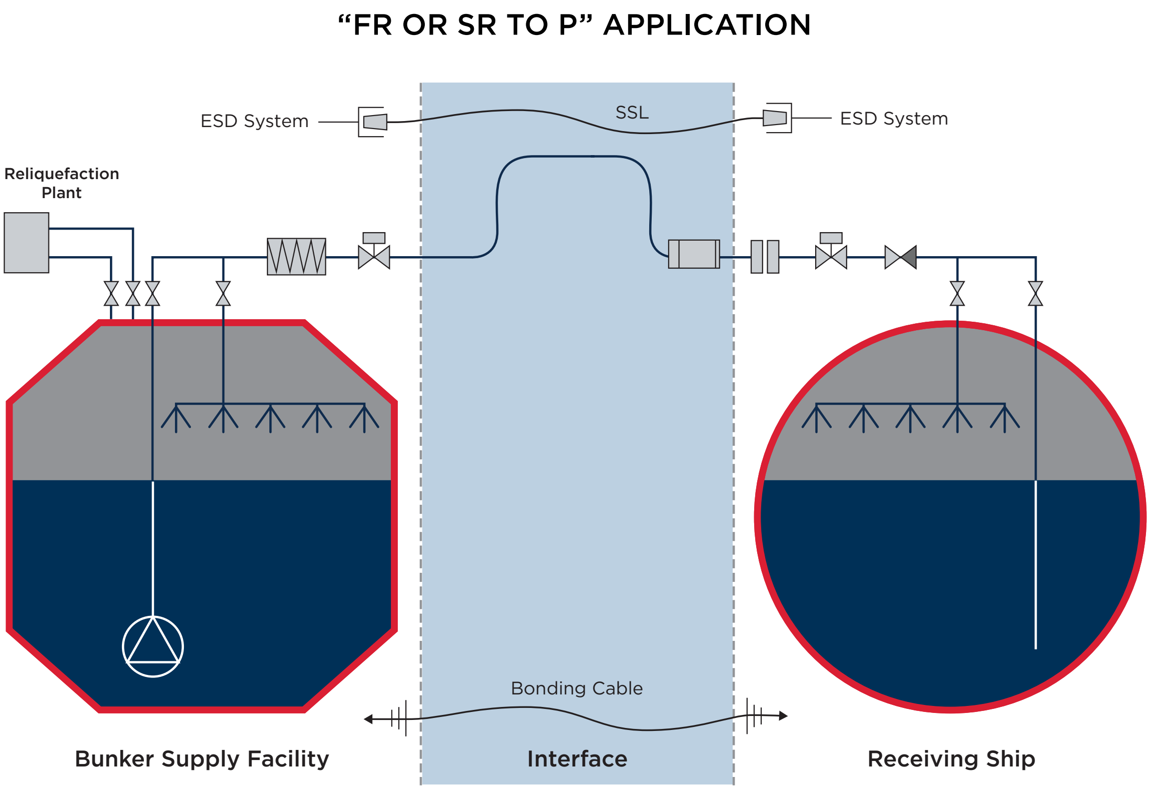


Figure 4.2: Typical detail of ammonia bunkering – FR to SR to P application.

- Fully refrigerated bunker tank to a fully refrigerated receiving tank: Precautions are to be taken to ensure that the supply is precisely at the temperature required by the receiving tank. Principles of LNG bunker transfer operation, as it is well established in the industry, may be followed and vapor return line is normally provided in this configuration.

"FR TO FR" APPLICATION

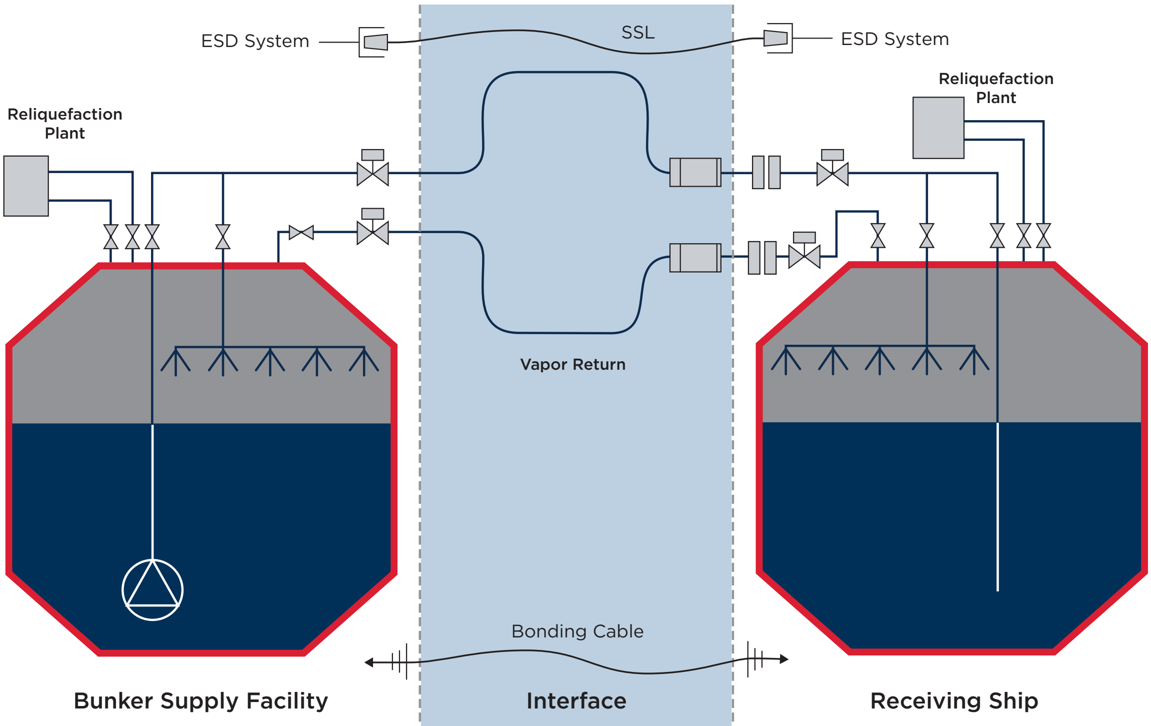
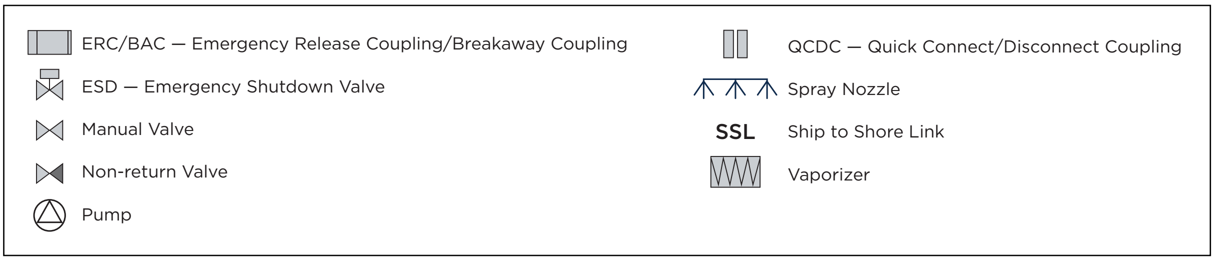


Figure 4.3: Typical detail of ammonia bunkering – FR to FR application.



COMMUNICATION

All communication systems, electrical equipment, and other equipment, including those in hazardous areas, must be safe and reliable. At least two reliable and independent communication channels are to be available as part of contingency communications. Bunkering transfers are not to start until all parties have confirmed clear communications with each other.

A communication plan should be agreed by all parties before commencing operations, including the communications equipment used within hazardous zones, which will be appropriately classified if required.

During bunkering, the person-in-charge (PIC) must communicate directly and immediately with all personnel involved in the bunkering operation. Communication devices used in bunkering should comply with recognized standards for such devices acceptable to the administration.

The ship-shore link (SSL) or equivalent means to a bunkering source provided for automatic ESD communications should be compatible with the receiving ship and the delivering facility ESD system.

RISK ASSESSMENT AND GAS DISPERSION ANALYSIS

It is essential that all ammonia bunkering operations are undertaken with diligence and due attention is to be paid to prevent leakage of ammonia, liquid or vapor, and to control all sources of ignition. So, it is important that throughout the ammonia bunkering chain, each element is carefully designed and installed ensuring dedicated safety and operational procedures executed by trained personnel. Risk assessment guidelines are provided by industry standards and may be enforced by Port Authorities.

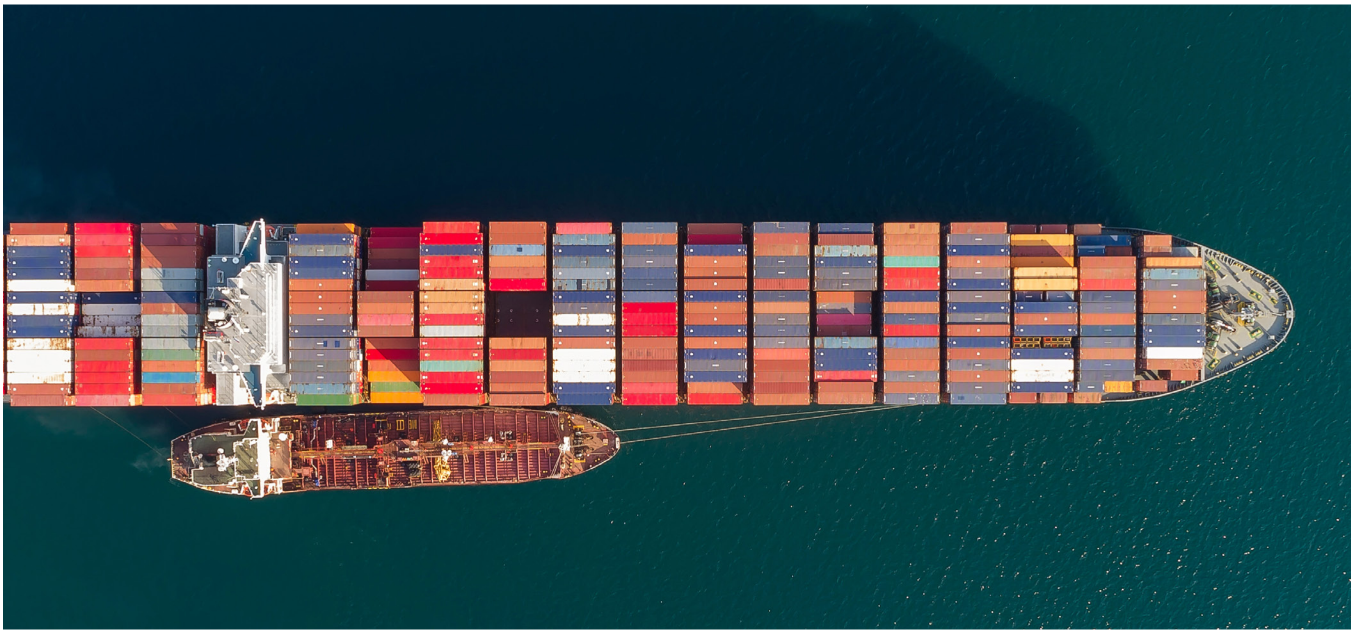
RISK ASSESSMENT

Risk assessments (both quantitative and qualitative) are to be conducted to assess the associated risks and hazards of the bunkering operation. ISO/TS 18683:2021 "Guidelines for Safety and Risk Assessment of LNG Fuel Bunkering Operations" may be used as reference. This document gives guidance on the risk-based approach for the design and operation of the bunker transfer system. It also provides minimum functional requirements, qualified by a structured risk assessment approach, taking into consideration LNG properties and behavior, simultaneous operations and all parties involved in the operation. Toxicity adds an additional element to consider, but the cryogenic risks and the high expansion ratios are applicable to both LNG and liquefied anhydrous ammonia releases drive the consideration of SIMOPS and the hazardous areas, safety zones and security zones that will be required to undertake safe bunkering of anhydrous ammonia in port areas.

Representatives from the supply and receiving vessels are held accountable for completing the risk assessment. The assessment should be conducted in accordance with relevant standards and regulations. The bunkering operation specific risk assessment should cover at least:

- Preparations before and upon arrival
- Approach and mooring
- Testing and connection of equipment
- Ammonia transfer
- Pressure management and vapor return
- Completion of bunker transfer and disconnection of equipment
- Un-berthing and departure bunkered vessel
- Risks to personnel and environment

More information can be found on risk assessments in the ABS *Guidance Notes on Risk Assessment Applications for the Marine and Offshore Industries*.



GAS DISPERSION ANALYSIS

A gas dispersion analysis must be able to model the most probable credible release and the maximum possible credible release that could occur during a bunkering operation. Some of the factors to consider during the analysis are: hose/pipe size, flow rate, lag in emergency shutdown after activation, temperature of the ammonia being transferred, trapped ammonia between emergency shutdown devices (ESD) when shutdown is activated, typical weather conditions, etc. For example, the supplier can use a hazard modeling program capable of conducting a vapor dispersion analysis that can help categorize toxic areas where vapor could exist if a leak or spill occurred. A large spill of ammonia in a port implies a risk of serious health effects to workers and the general population, which should be evaluated by a probabilistic risk assessment combining the likelihood and the severity of events leading to exposure of humans to airborne ammonia considering the best available risk management measures. Alternately, a simplified but more conservative way to evaluate these factors is for the supplier to use relevant references to designate the toxic or gas dangerous areas and identify the safety and security zones, as applicable.

Results of the Gas Dispersion Analysis should be used when determining the limitation of SIMOPS and safety, security, exclusion zones to refer during bunkering operations as well as the coverage of toxic zones on the vessel.

SIMULTANEOUS OPERATIONS (SIMOPS) STUDY

For any operations performed simultaneously during bunkering operations, a simultaneous operations (SIMOPS) study is to be conducted. This should include activities such as:

- Cargo handling
- Passenger and crew embarking/disembarking
- Dangerous goods loading/unloading and of any other goods (such as stores, provisions and waste)
- Handling of chemical products and other low flash point products
- Bunkering of fuels other than ammonia and lubricants
- Maintenance, construction, testing and inspection activities
- Port and terminal activities
- Unexpected events, such as breakdowns

The study results should include identification and description of all possible SIMOPS. The results of risk assessments and the gas dispersion analysis described above should then be used when determining SIMOPS limitations. Risk assessment mitigation measures may be incorporated into the standard operating manuals and procedures or used as a stand-alone process.

CONTROLLED ZONES

Controlled zones are defined based on the results of the gas dispersion analysis, risk assessments, relevant international requirements, and determined by the local authorities that may include the following:

- Hazardous areas: areas where only appropriately rated electrical fixed/portable equipment shall be used. Only essential personnel are allowed in these areas during bunkering operation mainly to connect or disconnect the transfer hoses or piping. Hazardous areas associated with ammonia are typically limited to enclosed and semi-enclosed areas.
- Safety zones: zones where ignition sources are adequately controlled with limited access to only authorized persons and their activities. Forming of safety zones during bunkering operations is essential as they help to prevent and/or reduce any unexpected damage that may occur after the leakage of ammonia. Safety zones are generally determined by the bunker suppliers or terminals based on the bunker characteristics, potential leak rate, ambient temperature, wind characteristics, and surrounding traffic. Consequently, the bunkering risk assessments and gas dispersion studies can also assist in determining the appropriate extent of safety zones and provide practical insights for port authorities and flag states.
- Toxic zone: areas established per local requirements, where toxic fumes could be harmful to personnel during activities such as bunkering connections and disconnections. In addition, the toxic zones on the receiving vessel are determined by the class requirements.
- Security zones: zones are to be established around the ammonia bunkering activity area to reduce external interference.

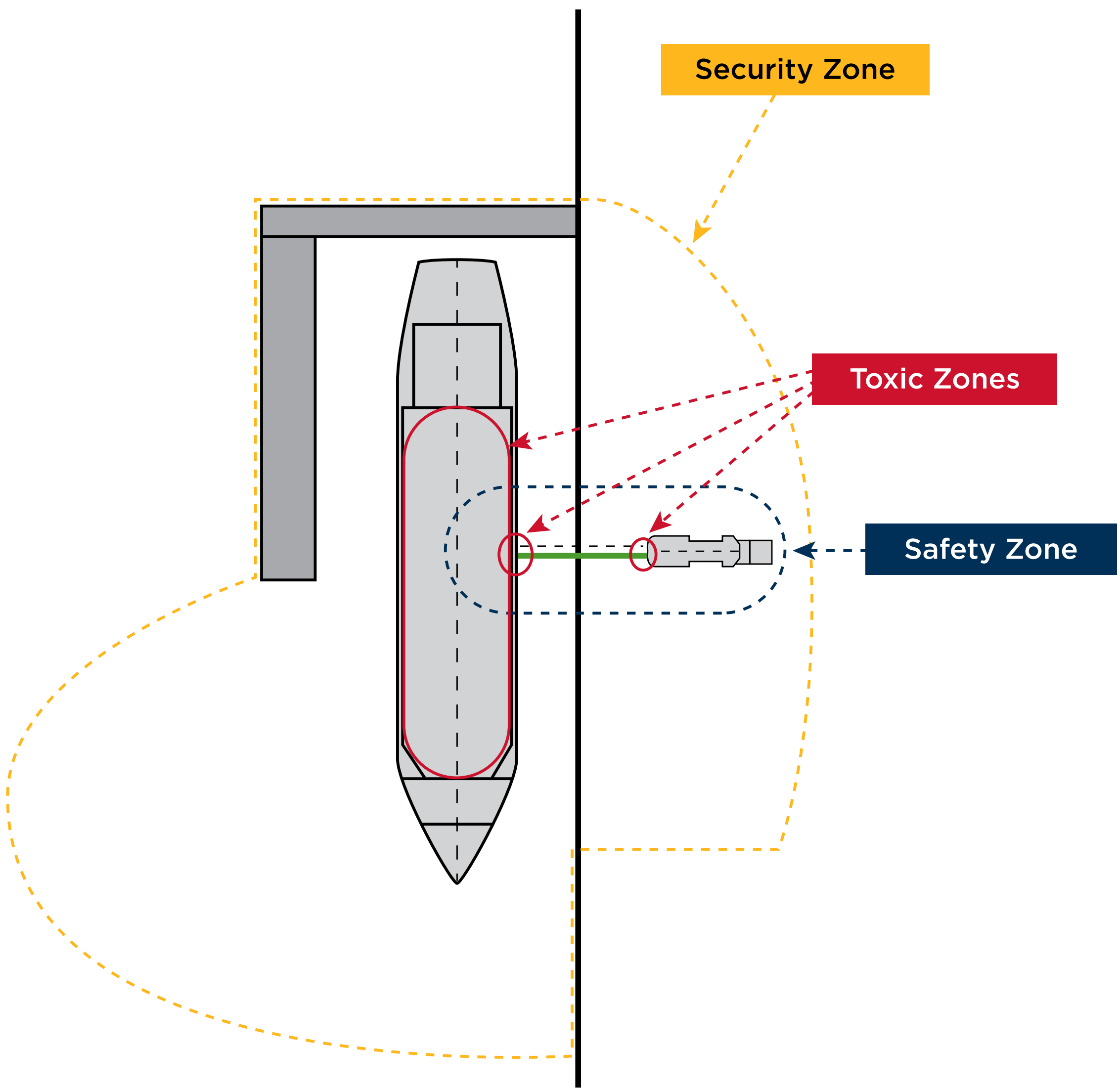


Figure 5: Typical example of controlled zones.

BUNKERING OPERATIONS

AMMONIA BUNKERING PLAN

An ammonia bunkering plan shall be developed to ensure the safe and effective operation of ammonia bunkering processes. This plan shall demonstrate and document all proof of compliance with the regulations of all relevant authorities and industry practices. The ammonia bunkering plan should include, but not be limited to, the following:

- Purpose, objective and safety policies
- Compatibility assessment
- Risk management
- Organization planning
- Communication
- Management of change
- Emergency procedure
- Training
- Operations, procedures and checklists (include SIMOPS if applicable)
- Equipment handling and maintenance

BUNKERING PERMIT

A fuel transfer/bunkering permit may be required by the port authority prior to bunkering operations. These permits enforce safe and environmentally conscious bunkering operations. Permissions are sought by the supplier prior to planned operations. The requirements depend on location and apply to all owners, people in charge and any other associated personnel.

A bunkering permit may include, but is not limited to the following requirements:

- Spill and recovery plan and contingency planning; suitable spill kits available.
- Compliance with all local, national or international regulatory requirements for fuel transfers.
- Personnel training and training sessions provided.
- Written operational plans and procedures including all activities distributed to all involved parties.
- Safe access between supplier and receiver.
- Emergency and evacuation procedures in place.
- Proper use and display of signages.

SHIP COMPATIBILITY

Mooring and bunker equipment should be compatible in design so the bunker operation can be conducted safely. At a minimum, the compatibility of the following equipment and installation should be assessed and confirmed:

- Communication/ESD systems
- Bunker connection and bunker station location
- The relative freeboard differences
- Transfer system specifications (e.g,. type and size of hose connections), locations and loading on manifolds and connection order
- Pumping transfer system specifications (flow rate, temperature, pressure, etc.)
- Vapor return line, if applicable
- Nitrogen line
- Mooring arrangement/equipment
- Hazard (flammable/toxic)/safety zones
- Fendering/pontoon arrangements

RESPONSIBILITIES OF BUNKERING OPERATIONS

Each party in the bunkering operation should be fully aware of their roles and responsibilities in the process.

PORT AUTHORITIES

- Ensuring the bunker supplier meets all criteria before, during, and after bunkering, including but not limited to ensuring:
  - Bunkering operations adhere to local requirements, international rules and best practices
  - Risk analysis and risk assessment have been completed
  - Control zones are defined
- Acceptance of all bunkering operations and their locations
- Validation of credentials of person-in-charge
- Validation of the bunker supplier according to the requirements
- Approval of SIMOPS
- Setting the criteria for ammonia bunkering operations: weather conditions, sea state, wind speed and visibility.

PERSON-IN-CHARGE (PIC)

The PIC is the individual designated by the bunker supplier to be responsible for the bunker delivery, transfer, and bunkering documentation. If the supplier is a bunker vessel or a truck, the PIC may be the ship's master or the driver, respectively, provided with relevant qualifications and authorization for the bunkering operation. The PIC's role and responsibilities shall include the following:

- Commencing and ending the bunkering operation
- Ensuring that all required communications are made with the implementing authority
- Ensuring declaration of inspection forms and checklists are completed
- Confirming with the master(s), or their representatives, the correct relative location of vessels, mooring and placement of fenders
- Conducting a pre-operations meeting with the receiver's designated personnel

- Evaluating present and forecasted meteorological conditions for the duration of the operations
- Monitoring communications throughout the operations
- Verifying and ensuring that site-specific risk mitigation measures, including monitoring and safety zones, are in place
- Ensuring that the transfer system is in good working condition and the ESD system is connected correctly and tested
- Ensuring the transfer system and associated emergency release systems are capable of safe connection/ disconnection
- Confirming that the SIMOPS assessment has been carried out, if applicable
- Monitoring fuel transfer rates and vapor management
- Advising the master or their representatives when bunkering is completed
- Ensuring that, when necessary, all incidents are reported to the implementing authority and port master promptly using the most direct means, followed by a detailed report of the circumstances of the incident or occurrence is submitted to the port master as required

MASTER (RECEIVING VESSEL)

The master is responsible for the ship, personnel, bunker's safety and all matters related to the whole operation. The master or the appointed bunker-in-charge officer is to liaise with the PIC of the bunkering source for the operations and come to a written agreement of the following:

- Transfer procedure, including cooling down and if necessary, gassing up; the maximum transfer rate at all stages and volume to be transferred
- Actions to be taken in an emergency
- Complete and sign the bunker safety checklist

Upon completion of bunkering operations, the ship PIC should receive and sign a BDN for the fuel delivered, signed by the bunkering source PIC.

PRE-BUNKERING VERIFICATION

Prior to conducting bunkering operations, pre-bunkering verification, including but not limited to the following, should be carried out and documented on the bunker safety checklist:

- All communications methods, including SSL
- Operation of fixed gas and fire detection equipment
- Operation of portable gas detection equipment
- Operation of remote-controlled valves
- Inspection of hoses and couplings
- Operation of water spray system
- Function testing of tank level alarms
- Drip trays under bunkering manifolds may be filled with water before the bunkering operations, which will absorb the ammonia in case of leakage and will reduce the gas dispersion.

Documentation of successful verification should be indicated by the mutually agreed and executed bunkering safety checklist signed by both PICs.

CONDITIONS FOR TRANSFER

Warning signs listing safety precautions to be taken during fuel transfer should be posted at the access points to the bunkering area.

During the transfer operation, personnel in the bunkering manifold area should be limited to essential staff only. All staff engaged in duties or working in the vicinity of the operations should wear appropriate personal protective equipment (PPE). Failure to maintain the required conditions for transfer should be a cause to stop operations. Transfer should not be resumed until all required conditions are met.

EMERGENCY PROCEDURES AND SAFETY

Specifying emergency procedures to be carried out during the bunkering operations (including duties, roles, and actions of all personnel and organizations involved) is essential for the safety and security of personnel and the environment. The emergency protocols must be specific to each bunkering method, and the response strategy must be developed based on the associated risk assessment.

To ensure that the emergency procedures are effective, risk assessment techniques should be used to identify all potential hazards and their consequences, and response strategies should be developed to mitigate these risks. The emergency procedures should address at least the following:

- Ammonia leakage
- Hose failure
- Hose quick-release arrangements
- Mooring line failure
- Communication failure
- Personnel injuries
- Fire
- Blackout
- Ship collision
- Fender burst

Before the bunkering operation, the emergency procedure shall be agreed between the receiving vessel and the bunker supplier. In case of emergency, the supplier and receiving vessel should evaluate the situation and act accordingly.

PREVENTIVE MEASURES

Local and remote control, alarm, and monitoring safety functions should be provided to maintain operations within pre-set parameters for all ammonia bunkering operations. Operations not within the boundaries of the pre-set parameters or activation of safety functions are to be equipped with audible and visual alarms in the bunkering control location. Bunkering controls are typically located at the supplier manifold, receiving manifold and receiving ship cargo control room/engine control room.

The temperatures, pressures, flow rates, and functions of the ammonia bunkering system are to be controlled as follows:

- A control and monitoring system should be provided in the bunkering control location.
- The control and monitoring systems are to be able to identify faults in the equipment and process system.
- Indications of parameters necessary for safe and effective operations are to be provided.

Tank pressure and levels should be monitored at the bunkering control location. An overfill alarm and automatic shutdown should be installed and marked at the site. Remote reading manifold pressure gauges and transmitters with isolation valves are to be fitted to indicate the pressure between stop valves and hose connections.

PERSONAL PROTECTION EQUIPMENT (PPE)

PPE requirements for personnel on the receiving vessel and supplier vessel are specified in Subsection 5/11 of the ABS *Requirements for Ammonia Fueled Vessels* and Chapter 14 of the IGC Code, respectively.

Personnel involved in normal bunkering operations and working as emergency responders in case of ammonia leakage must wear appropriate PPE as follows:

- Emergency responders who need to access contaminated areas to make the system safe will need a chemical-resistant gastight suit and a self-contained breathing apparatus (SCBA).
- Operators handling ammonia are to be provided with chemical-resistant gastight protective clothing, boots and gloves to a recognized standard. One self-contained positive pressure air-breathing apparatus incorporating a full-face mask is also to be available for an operator needing to quickly escape to a safe area.
- Other staff should have short duration self-contained breathing apparatus to allow them to escape to a place of safety/gas protection room should ammonia leak occur.

In addition, portable gas detectors and explosion-proof lamps may also be provided. Decontamination shower and eyewash are to be provided near the bunkering stations.

Risk of exposure to personnel involved in bunkering operations can be reduced by implementing lifting arrangements for heavy bunkering hoses, quick-disconnect couplings and breakaway devices, remote control stations for overseeing operations, flushing and draining systems for residual removal, temporary mechanical shielding at connection points and others.

Terminals or local authorities responsible for bunkering operations may require specific PPE based on local safety and health regulatory agencies such as the Occupational Safety and Health Administration (OSHA) in the United States. Additional PPE may also be required based on the expected exposure time to ammonia vapor and liquid.

OPENINGS TO SAFE SPACES

Openings to safe spaces where ammonia vapor could enter should be closed during bunkering. Designated doors are to be defined for personnel transit, which should be closed after use.

Evacuation of personnel to an enclosed space (i.e., safe haven), preferably within the accommodation area, may be designated to respond against the effects of a major ammonia release during the bunkering operation. This safety measure is under development in the IMO Interim Guidelines for Ships Using Ammonia as Fuel.

FIREFIGHTING EQUIPMENT

The following firefighting equipment shall be readily accessible to the crew and be available during the bunkering operations:

- Fire main
- Suitable extinguishing media: dry chemical powder, appropriate foam, water or fog spray
- Dry chemical powder fire extinguishers provided to cover all possible leak points

LEAKAGE DETECTION SYSTEMS

For ship-to-ship bunkering, gas and liquid detectors shall be installed on both the receiving and the supplier vessels as per IGF and IGC Code requirements, respectively. For other bunkering methods, additional gas and liquid detectors may be required as per the results of the risk assessments enforced by Port Authorities.

WATER SPRAY SYSTEM

Ammonia can be easily absorbed in water, so a water spray system may be used to help reduce the rate of gas dispersion by absorbing any ammonia clouds caused by leakages. Please note that the ammonia cloud dispersion will be largely affected by the ambient conditions, including humidity and wind speed/direction. Precautions are also to be made for the resulting aqueous ammonia solution (ammonium hydroxide) which is caustic and can corrode surfaces. The water spray system on the receiving or supplier vessel is to be capable of remote activation and located in an accessible area.

ESD SYSTEM

During an emergency, an ESD system should be designed to safely and effectively stop the transfer of ammonia (and vapor, where applicable) between the ammonia bunkering facility and the receiving ship. The ESD control system is a linked system that can be triggered automatically or manually by either party (on board the receiving ship and within the bunkering facility) to shut down the transfer during an emergency. The ESD system's activation design requirements must comply with class rules. ESD must be activated when the threshold pressure is reached, and the coupling must be compatible.

Some examples of events that could initiate an ESD system include:

- High tank pressure
- Excessive ship movement
- Abnormal pressure in the transfer system
- Loss of instrument pressure
- Loss of electricity
- Gas detection
- Manually initiated shutdown
- Fire detection

There are different ESD level considerations and applications in the industry. The following is given as an example:

- ESD-1: Shuts down the ammonia transfer process in a controlled manner (stops pumps and closes the valves)
- ESD-2: Disconnects the Emergency Release Coupling (ERC)

For additional requirements about the ESD functions, refer to Section 15 of the ABS *Requirements for Ammonia Fueled Vessels*.

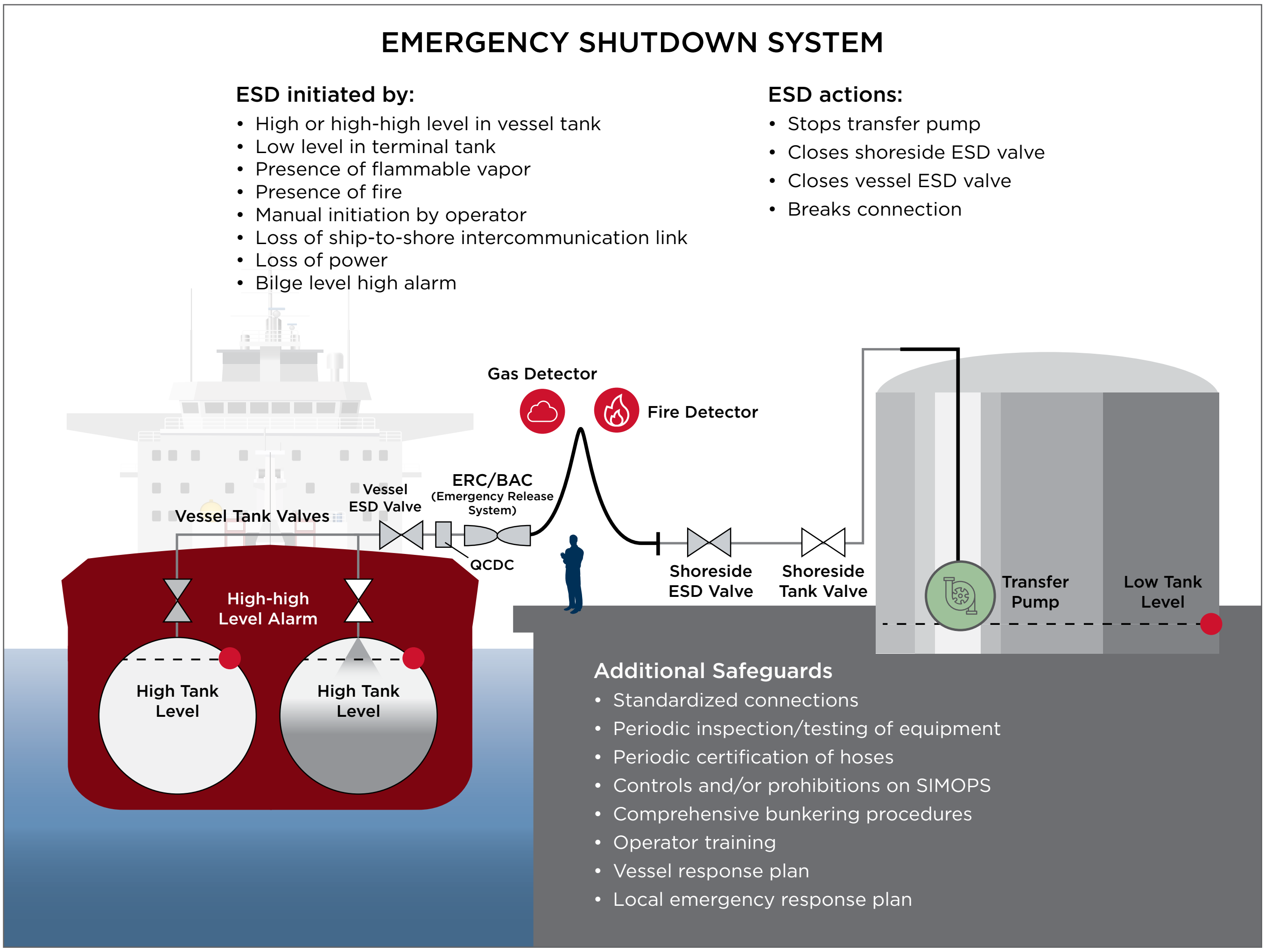


Figure 6: Safety guards and ESD for ammonia bunkering operations.

ACCIDENTAL LEAKAGE HANDLING – HEALTH AND ENVIRONMENTAL IMPACTS

Anhydrous ammonia is very soluble in water and forms ammonium hydroxide upon contact with moist surfaces. The corrosive and exothermic properties of ammonium hydroxide can immediately damage the eyes, skin, and mucous membranes of the oral cavity and respiratory tract. Ammonia has an NFPA rating of 3 for health, indicating that short exposure above a certain threshold concentration may cause serious temporary or permanent injury.

Examples of ammonia exposure guidance are shown in Tables 6.1 and 6.2 below.

Table 6.1: Effects of ammonia exposure concentration (Karabeyoglu A, Brian E., 2012).

Effect	Ammonia Concentration in Air (By Volume)
Readily detectable odor	20–50 ppm
No impairment of health for prolonged exposure	50–100 ppm
Severe irritation of eyes, ears, nose and throat. No lasting effect on short exposure	400–700 ppm
Dangerous, less than 30 minutes exposure may be fatal	2,000–3,000 ppm
Serious oedema, strangulation, asphyxia and rapidly fatal	5,000–10,000 ppm

Based on Acute Exposure Guideline Levels (AEGL) for airborne chemicals defined by the United States Environmental Protection Agency (US EPA), the limits to ammonia exposure can be identified as shown in Table 6.2.

Table 6.2: Acute exposure guideline levels (US EPA, 2016).

	10 Minutes	30 Minutes	60 Minutes	4 Hours	8 Hours
AEGL 1	30 ppm	30 ppm	30 ppm	30 ppm	30 ppm
AEGL 2	220 ppm	220 ppm	160 ppm	110 ppm	110 ppm
AEGL 2	2700 ppm	1600 ppm	1100 ppm	550 ppm	390 ppm

AEGL 1: Notable discomfort, irritation, or certain asymptomatic non-sensory effects. However, the effects are not disabling and are transient and reversible upon cessation of exposure.
AEGL 2: Irreversible or other serious, long-lasting adverse health effects or an impaired ability to escape.
AEGL 3: Life-threatening health effects or death

As a general guidance, the list below provides first aid measures to be taken in case of direct contact with ammonia:

Inhalation – Remove victims to fresh air and keep at rest in a position comfortable for breathing. If it is suspected that fumes are still present, the rescuer should wear an appropriate mask or self-contained breathing apparatus. If breathing of effected persons is irregular, labored, or if respiratory arrest occurs, trained personnel should provide artificial respiration or oxygen. Avoid mouth-to-mouth resuscitation as it may endanger the person providing aid. If unconscious, victims should be placed in recovery position, maintain an open airway, and loosen tight clothing such as a collar, tie, belt or waistband. Get medical attention immediately. In case of inhalation of decomposition products in a fire, symptoms may be delayed.

Skin Contact – In case of contact with skin, it is recommended to immediately use an emergency shower and flush the exposed areas with ample amounts of lukewarm water for at least 15 minutes. Note that ammonia can freeze the exposed clothing and the skin below it. This can result in extensive skin damage. Contaminated clothing and shoes must be removed and washed before reuse. Medical attention is required.

Eye Contact – In case of contact with eyes, the ammonia irritates or burns the eyes. Such contact can lead to permanent damage, including blindness. It is recommended to immediately flush the eyes with ample amounts of lukewarm water for at least 20 minutes. Medical attention is required.

Environmental Impact – Ammonia is classified as toxic to aquatic life with long lasting effects. The permissible discharge limit is defined as the maximum concentration of ammonia in the effluents. This limit depends on the international or local regulation limits. Normally effluents containing liquid or dissolved ammonia are not to be discharged overboard.

DRILLS, TRAINING AND CERTIFICATION

A combination of both training and operational experience is key to developing the required competencies for ammonia bunkering operations. The level of competency needed for each task depends on the role and responsibilities of the individual. Therefore, the training may vary from person to person.

Seafarers on board ships using ammonia fuel should have completed training to attain the abilities that are appropriate to the capacity to be filled, and duties and responsibilities to be taken up. The master, officers, ratings and other personnel on ships using ammonia fuel should be trained and qualified in accordance with regulation V/3 of the STCW Convention and section A-V/3 of the STCW Code, taking into account the specific hazards of ammonia used as fuel.

Ship-specific training is to be reviewed and approved by governing regulatory authorities. The IGF Code provides detailed training requirements for ships which use gases or other low-flashpoint fuels. Ships 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. Drills are to be conducted on board regularly per IGF Code Chapters 17 and 18.2.4 (5C-13-17 and 5C-13-18/2.4 of the ABS *Marine Vessel Rules*).

All crew personnel must be provided with and be made aware of the emergency procedures and must be trained in any roles and responsibilities they may have. Training, drills and exercises to prepare the crews for emergencies are to be provided. Lessons learned from past operations should be incorporated to improve the emergency procedures. Procedures should cover all scenarios specific to the ship, type of incident, equipment and associated areas.

APPENDIX: BUNKERING CHECKLISTS

The following checklists are guidelines for ammonia bunkering operations. They can be used as templates to develop specific checklists based on the actual ship, bunker supply and location.

BEFORE BUNKERING

Item	Check	Supplier (Truck/ Terminal/ Ship)	Receiving Ship	Remarks
PART I: PLANNED OPERATIONS CHECKLIST (To be completed within 48 hours prior to bunkering operation)				
1	Initiate communication with all involved parties including the port authorities with intent to bunker			
2	Supplier is authorized by relevant port authority to bunker ammonia with the confirmed bunker permit			
3	Bunkering location and schedule are agreed upon			
4	Firefighting and emergency response procedures, any applicable limitations and communication protocols are completed and agreed upon			
5	Bunker fuel specification and transfer quantity is agreed upon			
6	Perform mooring compatibility assessment prior to operations			
7	Rigging sequence and hose handling/ securing methods are agreed upon			
8	Perform compatibility assessment of ammonia transfer system arrangement			
9	Method of electrical bonding to earth has been agreed upon and electrical insulation is provided for the bunker			

Item	Check	Supplier (Truck/ Terminal/ Ship)	Receiving Ship	Remarks
10	Procedure and time period for testing, purging and blow through operations are established			
11	Nitrogen availability and supply for testing, purging and blow through process are established			
12	Tank vents are free of obstructions			
13	Sampling procedure and quantity of samples to be collected is agreed upon			
14	Sounding procedure is agreed upon			
15	ESD scenarios are established and agreed upon and ESD system tested			
16	Persons-in-charge of mooring and bunkering are designated			
17	Crew qualifications, training and records of fire and spill drills are available			
18	Fire control plans are available at readily accessible location			
19	Firefighting equipment (fixed and portable) is in good working order			
20	Requirements of local and/or national authorities are being observed			
21	Gas detectors and/or thermal cameras (fixed and portable) are in place, tested and in good working order			
22	PPE matrix for each stage of the operation is established			

Item	Check	Supplier (Truck/ Terminal/ Ship)	Receiving Ship	Remarks
23	Spill protection is available at the manifold			
24	Spill transfer arrangement (pump) is ready to use			
25	Review appropriate lighting is provided			
26	Review safety zones and security zones are established and in place			
27	Maintenance records and test certificates of fender and mooring equipment are available			
28	Limits of wind, weather and sea conditions have been agreed upon			
29	Provision to monitor lightning warnings is available			
30	Safe means of access are available between the ships and/or shore			
31	Provision for continuous monitoring of bunkering operation (physical presence/ CCTV) is in place for both the receiver and supplier			

Item	Check	Supplier (Truck/ Terminal/ Ship)	Receiving Ship	Remarks
PART II: PRE-BUNKERING CHECKLIST (To be completed before commencement of the bunkering operation)				
1	Part I of checklist is completed and operations specific requirements (if identified) are available			
2	Wind, weather and sea conditions are within the agreed upon limits			
3	Shore personnel/crew/onboard fixed or portable system is designated to monitor lightning warnings			
4	Permissions from authorities for ammonia bunkering (where applicable) have been received and notifications made			
5	Any simultaneous operation during bunkering is to be agreed upon between the supplier and receiver as necessary			
6	Primary and secondary means of communication is established			
7	Ship is securely moored with sufficient fendering			
8	Initial bunker gauging completed			
9	Receiving ship tank has sufficient volume to receive the specified bunker quantity and subsequent nitrogen blanketing			
10	Safe means to access between supplier and receiver is established			
11	Bunker manifold and operation areas are sufficiently illuminated			
12	Safety shower and eyewash are ready for use			
13	Scupper and save-alls are plugged			
14	Spill trays are empty and drain plugs are closed			

Item	Check	Supplier (Truck/ Terminal/ Ship)	Receiving Ship	Remarks
15	Unused bunker connections are blanked and secured			
16	Bunker hoses or transfer arms together with QCDC, DBC, SSL and ESD links are connected between the supplier's and receiving ship's manifolds			
17	Hoses are adequately supported			
18	Insulation and electrical grounding are set up			
19	Fixed and portable electrical components in the operations area are intrinsically safe			
20	Provision to prevent accidents from falling objects in place			
21	Signage is posted for safety zones and unauthorized access zones			
22	External doors, portholes and accommodation ventilation inlets are closed			
23	Positive pressure maintained inside accommodation			
24	Nitrogen supply for purging and leak testing the hoses is available			
25	Valves and instruments for purging and leak testing the hoses are identified and ready			
26	Crew notified of commencement of hose testing			
27	Ammonia and vapor return hoses are purged and leak tested satisfactorily			
28	Receiving ship has been notified facility is ready for transfer			
29	Supplier received confirmation to commence the transfer			

DURING BUNKERING

Item	Check	Supplier (Truck/ Terminal/ Ship)	Receiving Ship	Remarks
1	Pre-bunkering checklist Part I and II completed			
2	Bunkering commences to the specified transfer rate progressively			
3	Safety procedures and mitigation measures for simultaneous activities, as mentioned in the ship's approved operational documentation, are agreed upon and are observed by all parties involved			
4	Monitoring of tank levels, tank conditions (pressure and temperature), leaks and vapors, and pump transfer rates			
5	Monitor mooring lines and bunker hoses and transfer arms occasionally			
6	Quantity of ammonia discharged to the receiving ship (10%, 25%, 50%, etc.) is continuously relayed to receiving ship			
7	Monitor that the integrity of security and safety zones is maintained			
8	Monitor that weather and sea conditions remain within limits			

AFTER BUNKERING

Item	Check	Supplier (Truck/ Terminal/ Ship)	Receiving Ship	Remarks
1	Receiving ship has been informed that the ammonia transfer is completed			
2	Confirm all manifold valves are closed			
3	Nitrogen supply for purging and blow through operation is available			
4	Spill trays are located below the disconnecting flanges			
5	Ammonia and vapor return hoses are purged and blown through			
6	Bunker loading arm, hoses, monitoring, ESD and electrical isolation or bonding connections are disconnected from the receiving ship's manifold			
7	Remove all signs after the security zone and safety zone have been deactivated			
8	All parties involved, including the authorities, have been notified that operations have been completed			
9	Documentation and bunker samples are handed over			
10	Unmooring and cast off			
11	Disconnection of communication			
12	Report any near misses and/or incidents to the authorities			

LIST OF REFERENCES AND GUIDANCE DOCUMENTS

1. ABS *Methanol Bunkering: Technical and Operational Advisory* (2024)
2. ABS *Sustainability Whitepaper Ammonia as Marine Fuel* (October 2020)
3. ABS *Advisory on Gas and Other Low Flashpoint Fuels*
4. ABS *Bunkering of Liquefied Natural Gas-Fueled Marine Vessels in North America* (2nd Edition)
5. ABS *LNG Bunkering: Technical and Operational Advisory*
6. ABS *Requirements for Ammonia Fueled Vessels* (2023)
7. ABS *Requirements for Methanol and Ethanol Fueled Vessels* (2024)
8. ABS *Rules for Building and Classing Marine Vessels* (2024)
9. ABS *Guidance Notes on Risk Assessment Applications for the Marine and Offshore Industries*
10. ABS *Beyond the Horizon: View of the Emerging Energy Value Chains* (2023)
11. IMO International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IGC Code)
12. IMO International Code of Safety for Ships Using Gases or Other Low-Flashpoint Fuels (IGF Code)
13. IMO Sub-Committee on Carriage of Cargoes on Containers CCC 9/3/7 Amendments to the IGF Code and Development of Guideline for Alternative Fuels and Related Technologies; Proposed amendments to regulations 9.4.2, 13.4.1, and 13.6.1 of the Interim guidelines for the safety of ships using methyl/ethyl alcohol as fuel (MSC.1/Circ.1621), 19 July 2023.
14. IMO MARPOL Annex VI. Regulations for the Prevention of Air Pollution from Ships. Adopted by the Protocol of 1997, 15 to 26 September 1997.
15. IMO Resolution MSC.392(95). Amendments to the International Convention for the Safety of Life at Sea, 1974, as amended. Adopted 11 June 2015.
16. IMO Resolution MSC.285(86). Interim Guidelines on Safety for Natural Gas-Fueled Engine Installations in Ships. Adopted 1 June 2009.
17. IMO Resolution MEPC.377(80). 2023 IMO Strategy on Reduction of GHG Emissions from Ships. Adopted 07 July 2023.
18. IACS Unified Requirement H1 "Control of Ammonia Releases in Ammonia Fueled Vessels." Jan/2024.
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21. Safety and Operational Guidelines for Piloting Ammonia Bunkering in Singapore – Global Centre for Maritime Decarbonization (GCMD) (2023)
22. Ammonia as a Marine Fuel, An Introduction – Society for Gas as a Marine Fuel (SGMF) (2023)
23. Ammonia as a Marine Fuel Safety Handbook – Green Shipping Programme
24. MSC.1/Circ.1621. Interim Guidelines for the Safety of Ships Using Methyl/Ethyl Alcohol as Fuel.
25. ISO 5771:2024 "Rubber Hoses and Hoses Assemblies for Transferring Anhydrous Ammonia – Specification."
26. ISO 21593:2019 "Technical Requirements for Dry-Disconnect/Connect Couplings for Bunkering Liquefied Natural Gas".
27. ISO 7105: Liquefied Anhydrous Ammonia for Industrial Use – Determination of Water Content – Karl Fisher Method
28. ISO 7106: Liquefied Anhydrous Ammonia for Industrial Use – Determination of Oil Content – Gravimetric and Infra-Red Spectrometric Methods
29. Compressed Gas association – CGA G-2.2 Guideline Method for Determining Minimum of 0.2% Water in Anhydrous Ammonia (2016)

LIST OF ACRONYMS AND ABBREVIATIONS

ABS	American Bureau of Shipping
AEGL	Acute Exposure Guideline Levels
ATR	Autothermal Reforming
BAC	Breakaway Coupling
BDN	Bunker Delivery Note
BOG	Boil Off Gas
capex	Capital Expense
CCTV	Closed-Circuit Television; Video Surveillance
CGA	Compressed Gas Association
CO_2	Carbon Dioxide
EEBD	Emergency Escape Breathing Device
EPA	Environmental Protection Agency (US)
ERC	Emergency Release Coupling
ESD	Emergency Shutdown
FTIR	Fourier Transform Infrared Spectroscopy
GC	Gas Chromatography
GCV	Gross Calorific Value
GHG	Greenhouse Gas
HFO	Heavy Fuel Oil
IACS	International Association of Classification Societies
IAPP	International Air Pollution Prevention Certificate (MARPOL)
IGC Code	International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IMO)
IGF Code	International Code of Safety for Ships Using Gases or other Low-Flashpoint Fuels (IMO)
IMO	International Maritime Organization
ISO	International Organization for Standardization
LNG	Liquefied Natural Gas
MARPOL	International Convention for the Prevention of Pollution from Ships (IMO)
MEPC	Marine Environment Protection Committee (IMO)
MGO	Marine Gas Oil
MSC	Maritime Safety Committee (IMO)
MVR	ABS *Rules for Building and Classing Marine Vessels; Marine Vessel Rules*
N_2O	Nitrous Oxide
NFPA	National Fire Protection Association

NH_3	Ammonia
NOx	Nitrogen Oxides
opex	Operating Expense
OSHA	Occupational Safety and Health Administration
PAH	Polycyclic Aromatic Hydrocarbons
PIC	Person-in-Charge
PM	Particulate Matter
PPE	Personal Protection Equipment
PPM	Parts Per Million
QCDC	Quick Connect/Disconnect Coupling
Rec	Recommendations (IACS)
RO	Recognized Organization
SCBA	Self-Contained Breathing Apparatus
SGMF	Society for Gas as a Marine Fuel
SIGTTO	The Society of International Gas Tanker and Terminal Operators
SIMOPS	Simultaneous Operations
SMR	Steam Methane Reforming
SOLAS	International Convention for the Safety of Life at Sea (IMO)
SSL	Ship-Shore Link
STCW Code	International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (IMO)
UI	Unified Interpretation (IACS)
UR	Unified Requirements (IACS)

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