

Risk Focus: Ammonia Bunkering and Handling

A Guide to Safe Ammonia Bunkering Practices



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Image of an LPG-powered VLGC convertible to ammonia fuel

A Guide to Safe LNG Ammonia Bunkering and Handling

The IMO's enhanced GHG strategy and new EU regulations are driving shipping toward net-zero emissions by 2050, and ammonia is a carbon-free options in the fuel transition.

Ammonia has been transported by sea since the early 20th century, primarily as a key raw material for fertilisers. This long-standing practice has established a robust global shipping network, facilitating the movement of ammonia from production facilities to agricultural hubs worldwide. However, in recent years, ammonia has garnered attention as a potential zero-emission fuel for the maritime industry, offering a pathway to decarbonise shipping. The International Maritime Organization (IMO) has set an ambitious goal to achieve net-zero greenhouse gas emissions from international shipping by 2050, underscoring the need for sustainable fuel alternatives.

As of early 2025, approximately 130 ammonia-fuelled vessels and 225 ammonia-ready vessels have been ordered or announced. These vessels represent a significant step toward integrating ammonia into maritime propulsion systems. The Fortescue Green Pioneer, a Singapore-flagged vessel, conducted the world's first ammonia fuel trial in March 2024, using a blend of

ammonia and diesel. This trial, supported by the Maritime and Port Authority of Singapore (MPA), marked a significant milestone in ammonia-powered maritime operations. Additionally, NYK's tugboat, Sakigake, has been operating on ammonia. These developments signal a growing interest in ammonia as a marine fuel, prompting the need for corresponding bunkering infrastructure.

The development of ammonia bunkering infrastructure is crucial to support the adoption of ammonia as a marine fuel. This includes establishing ammonia storage facilities, bunkering terminals, and transportation networks. The Port of Rotterdam is actively involved in ammonia bunkering initiatives, collaborating with various stakeholders to develop the necessary infrastructure. Additionally, the U.S. East Coast is exploring ammonia bunkering opportunities, with projects underway in ports such as Savannah, Georgia. These efforts aim to establish a robust supply chain for ammonia as a marine fuel, facilitating its adoption across global shipping routes.

Ammonia can be produced through various methods, categorised as blue and green ammonia. Blue ammonia is produced by reforming natural gas and capturing the resulting CO₂ emissions, while green ammonia is produced using renewable energy sources to electrolyse water into hydrogen, which is then combined with nitrogen. Green ammonia is considered more sustainable due to its lower carbon footprint but currently faces challenges related to high production costs and limited availability. For instance, TotalEnergies is exploring a project in Morocco to produce 200,000 metric tons of green ammonia annually using renewable energy. These initiatives highlight the potential of ammonia as a clean fuel alternative, contingent on advancements in production technologies and infrastructure development.

Despite its promise, ammonia faces several challenges as a marine fuel:

- Combustion of ammonia can produce nitrogen oxides (NO_x) and nitrous oxide (N₂O), potent greenhouse gases with a global warming potential nearly 300 times that of CO₂ over a 100-year period.

- Additionally, ammonia is toxic and corrosive, posing safety risks during bunkering and operation. Infrastructure requirements for ammonia bunkering are substantial, necessitating investments in pipelines, storage facilities, and specialised equipment.
- Economically, green ammonia is currently two to four times more expensive than conventional fuels, primarily due to limited supply and lower energy density.

While ammonia holds promise, its widespread adoption will require addressing these environmental, safety, infrastructural, and economic challenges through technological advancements, regulatory frameworks, and strategic investments.

Ammonia presents a viable option for reducing greenhouse gas emissions in the maritime industry. However, its widespread adoption will require addressing technical, economic, and infrastructural challenges. Through continued research, investment, and collaboration among industry stakeholders, ammonia can play a significant role in the future of sustainable shipping.

Introduction

Ammonia bunkering is a critical operation. The process entails the safe transfer of ammonia—typically in its liquid state under pressure or refrigerated—from a bunkering source, such as a bunker vessel or shore terminal, to the receiving ship’s dedicated fuel tanks. Although ammonia does not require cryogenic temperatures under all conditions, the operation still demands meticulous planning and strict adherence to handling protocols due to ammonia’s toxic and corrosive nature.

A fundamental step in ammonia bunkering is assessing the containment system on board the receiving vessel. Ammonia is not highly flammable under standard marine storage conditions. Nevertheless, proper tank conditioning remains essential. This includes cleaning and drying the tanks to remove any contaminants or moisture, followed by checks for pressure integrity and, depending on the system, pre-cooling or controlled pressurization to prepare the tanks for safe loading.



Image of ammonia bunkering at sea

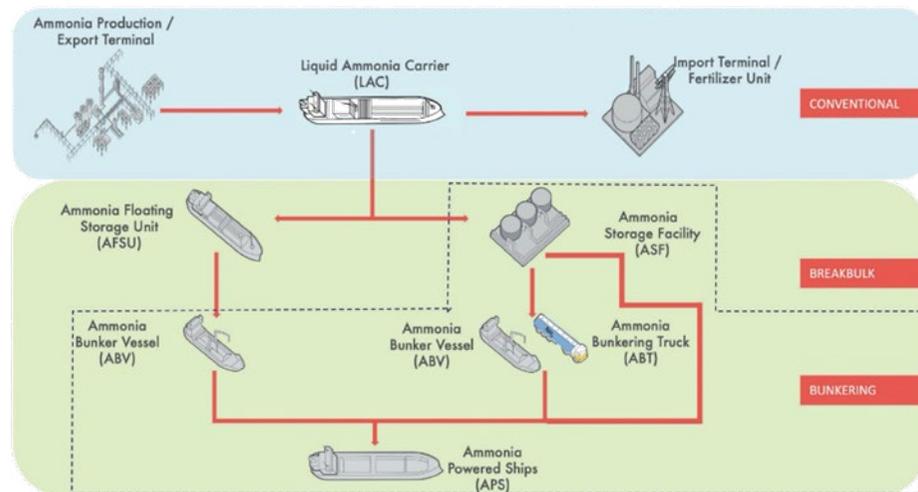


Image Source: Manifold Times

The transfer process requires careful control of both temperature and pressure. When refrigerated ammonia is used, pre-cooling helps prevent thermal shock and vapour generation during loading. Continuous monitoring ensures that the tanks remain within safe operating limits, protecting structural integrity and preventing leaks or over pressurization.

Vapour management is a critical aspect of ammonia bunkering. Due to the hazardous nature of ammonia vapours, the system must include gas-tight transfer lines, vapour return systems, and appropriate treatment or containment solutions. Unlike fuels with flammable boil-off gases, ammonia vapours cannot be vented freely and must be handled with equipment designed to mitigate health and environmental risks.

Safe ammonia bunkering also depends on robust safety protocols, including gas detection systems, emergency shutdown mechanisms, and the use of proper Personal Protective Equipment (PPE) by all personnel involved. As ammonia continues to gain traction as an alternative marine fuel, the development of standardised procedures and purpose-built infrastructure will be essential to ensure the safe and efficient expansion of its use in maritime operations.

Physical Properties of Ammonia

Composition

Ammonia (NH₃) is a colourless gas with a sharp, pungent odour. It is composed of nitrogen and hydrogen, and is commonly used in liquid form for industrial applications such as refrigeration, fertilisers, and increasingly, as a potential marine fuel. It is highly soluble in water, forming ammonium hydroxide (NH₄OH), a corrosive solution.

Boiling Point

Ammonia has a boiling point of approximately -33°C at atmospheric pressure, which allows it to be transported as a liquid under moderate pressure or refrigeration.

Freezing Point

The freezing point of ammonia is around -78°C , significantly lower than many other industrial gases.

Vapour Pressure

At its boiling point, ammonia exhibits a vapour pressure of approximately 8.5 atmospheres, highlighting its tendency to rapidly vaporise when released.

Vapour Density

Ammonia gas has a vapour density of 0.6 (air = 1), making it lighter than air. However, in humid conditions, ammonia vapours can absorb moisture, becoming denser and settling near the ground—posing inhalation risks at low elevations.

Specific Gravity

The specific gravity of liquid ammonia at -33°C is approximately 0.6818, making it less dense than water.

Expansion Ratio

One cubic foot of liquid ammonia can expand to about 850 cubic feet of gas at standard temperature and pressure. This high expansion ratio increases the hazard in case of accidental releases.

Flammability

Ammonia is flammable within a relatively narrow concentration range of 15% to 28% by volume in air. While not classified as a highly flammable gas, under certain conditions, particularly in confined spaces, it can form explosive mixtures.

Autoignition Temperature The autoignition temperature of ammonia is 651°C , indicating the temperature at which it can ignite without an external spark or flame.

Odour Threshold

Ammonia has a strong and easily detectable odour at concentrations as low as 5 ppm, acting as an early warning in case of leaks.

Toxicity and Exposure Limits

Ammonia is a highly toxic, and its handling is governed by strict occupational exposure limits to ensure the safety of personnel.

The National Institute for Occupational Safety and Health (NIOSH) recommends a limit, with a Recommended Exposure Limit (REL) of 25 ppm TWA and a Short-Term Exposure Limit (STEL) of 35 ppm for exposures not exceeding 15 minutes.

Ammonia is considered Immediately Dangerous to Life or Health (IDLH) at concentrations of 300 ppm or higher, at which point immediate evacuation and the use of protective breathing apparatus are necessary.

Emergency Response Planning Guidelines (ERPG) further classify exposure values into three tiers:

- 25 ppm for ERPG-1 (mild, reversible effects).
- 150 ppm for ERPG-2 (serious, irreversible effects).
- 1,500 ppm for ERPG-3 (life-threatening conditions).

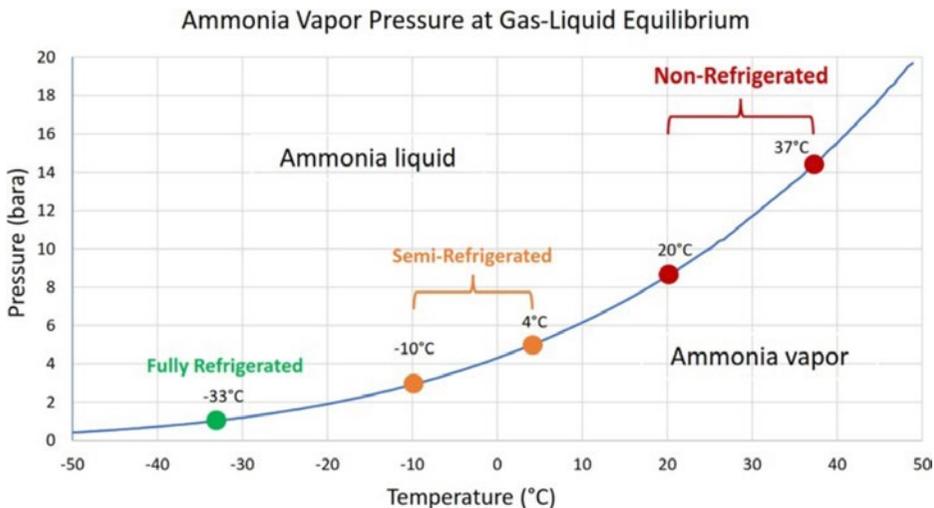


Image Source: The Engineering Toolbox

Health Hazards and First Aid Measures

Inhalation

Ammonia vapour can rapidly reach harmful levels, especially in confined spaces. Prolonged or high-level exposure can result in chronic respiratory issues or fatal pulmonary damage.

- *Low Concentrations:* Irritation of the nose, throat, and eyes.
- *High Concentrations:* May cause coughing, and potentially fatal respiratory distress.

First Aid: Remove to fresh air immediately; seek urgent medical attention.

Skin Contact

Liquid ammonia is extremely corrosive to skin, eyes, and mucous membranes. Full-body PPE, including chemical-resistant gloves and face shields, is essential during handling.

- Liquid ammonia can cause frostbite and chemical burns.

First Aid: Flush affected area with lukewarm water for at least 15 minutes. Do not use hot water. Remove contaminated clothing and seek immediate medical help.

Eye Contact

- Causes severe irritation and can lead to permanent eye damage or blindness.

First Aid: Rinse eyes with water continuously for at least 15 minutes. Immediate medical evaluation is necessary.

Personal Protective Equipment (PPE)

The use of Personal Protective Equipment (PPE) is essential in managing ammonia exposure. The selection of PPE is based on airborne ammonia concentrations and is governed by the IGC Code, SOLAS.

Additionally, guidelines from the Australian Occupational Exposure Standards, National Institute for Occupational Safety and Health (NIOSH), and American Industrial Hygiene Association (AIHA) inform the trigger levels for wearing specific PPE.

Concentration Range	PPE Required
< 25 ppm (TWA)	Full-face respirator.
25–300 ppm (STEL–IDLH)	Chemical splash suit + SCBA or full-face respirator with ammonia-rated filters.
> 300 ppm (IDLH)	Fully encapsulated chemical-resistant suit + SCBA to prevent chemical burns and inhalation.

TWA: Time-Weighted Average

STEL: Short-Term Exposure Limit

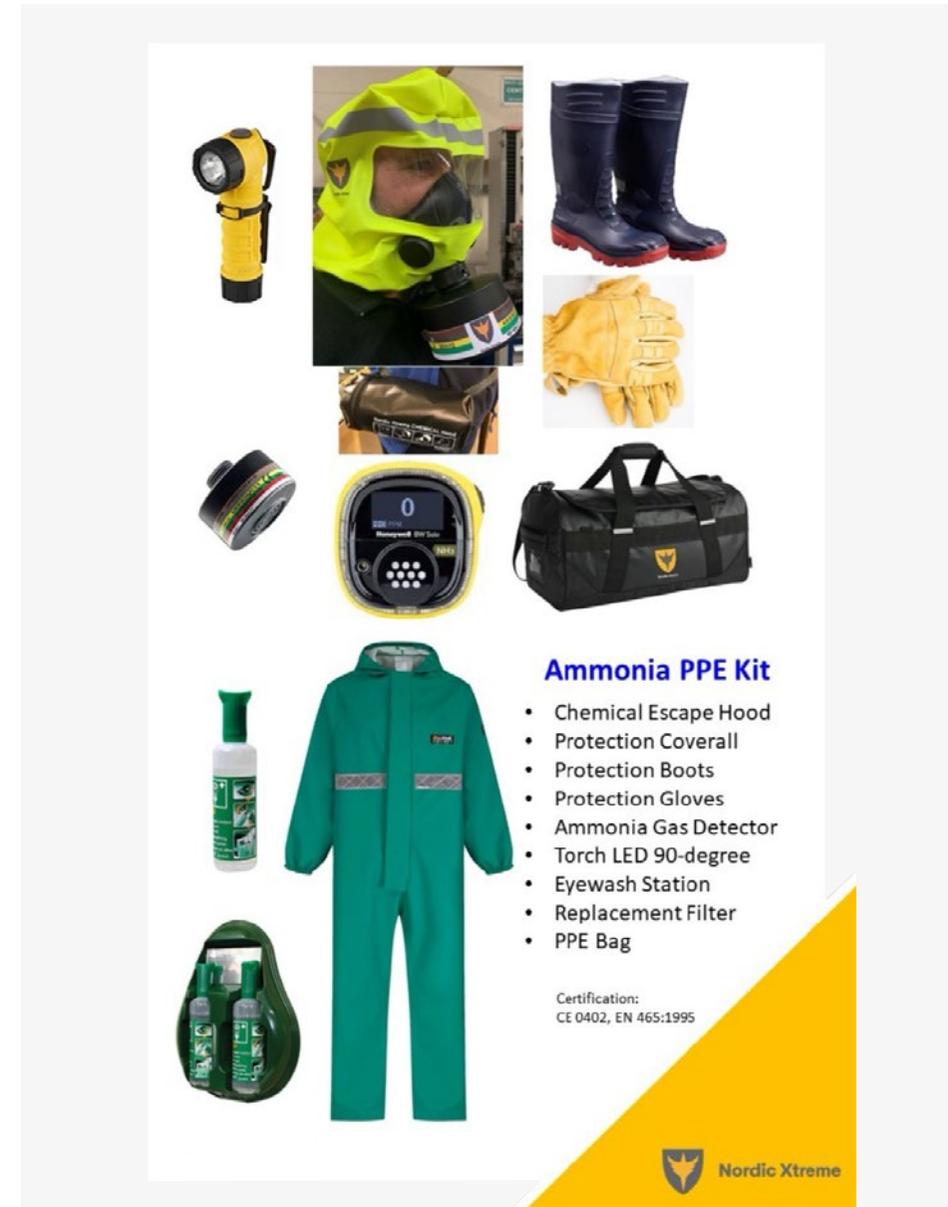
IDLH: Immediately Dangerous to Life or Health

SCBA: Self-Contained Breathing Apparatus

PPE on board must include:

- Chemical-resistant gloves and boots.
- Chemical Escape Hood or EEBD (Emergency Escape Breathing Devices) for each crew member on board and additional sets as per the Fire Plan.
- Encapsulated chemical-resistant suits for high-risk response.
- Eyewash stations and decontamination safety showers are to be provided, the location and number of these eyewash stations and safety showers are to be derived from the detailed installation arrangements. As a minimum, the following stations are to be provided:
 1. Fuel Preparation and Pump Locations (like FGSS rooms and similar).
 2. Bunkering Stations.
 3. Ammonia Exposure Risk Areas and Operation Conditions—such as system openings, filling or drainage points, or components requiring periodic maintenance.
- All vessels need to be provided with at least two sets of portable ammonia gas detectors that meet an acceptable national or international standard.

Routine inspection of PPE, maintenance of breathing equipment, and crew training are mandatory components of the ship's Safety Management System (SMS).



Contingency Planning and Emergency Response Procedures

In case of an ammonia release, structured and code-compliant emergency procedures must be executed swiftly. These include immediate gas detection, shutdown of systems, activation of emergency isolation valves, and protection of personnel. According to the International Code of the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IGC Code) Chapter 18 and the International Code of Safety for Ships Using Gases or Other Low-flashpoint Fuels (IGF Code) Section 5.8, emergency shutdown and ventilation systems must be remotely operable.

Key actions include:

- Remote isolation of fuel systems using Emergency Shutdown Devices (ESDs).
- Forced ventilation to reduce ammonia concentrations below 25 ppm before re-entry.
- Fire suppression, avoiding unnecessary water use to limit toxic runoff.
- Rescue procedures for personnel in contaminated areas, using Self-Contained Breathing Apparatus (SCBA) and encapsulated suits.
- Evacuation protocols based on wind direction and predicted gas dispersion.
- Communication with port authorities and emergency services.

Emergency drills simulating these scenarios must be conducted at least once every three months, including leak management, rescue, and full system shutdown.



Community Protection Measures

Ammonia releases may extend beyond the vessel, potentially affecting nearby communities, especially during port operations. Community protection planning must be based on internationally recognised exposure guidelines such as the Emergency Response Planning Guidelines (ERPG), which provide concentration thresholds to inform public safety actions.

Planning should include:

- Identification of at-risk populations and neighbours.
- Evacuation zones based on dispersion modelling.
- Emergency communication protocols.
- Coordination with local disaster management authorities.

Dispersion modelling software such as Areal Locations of Hazardous Atmospheres (ALOHA) and Process Hazard Analysis Software Tool (PHAST) should be used to simulate ammonia cloud behaviour based on wind speed, temperature, topography, and release volume.

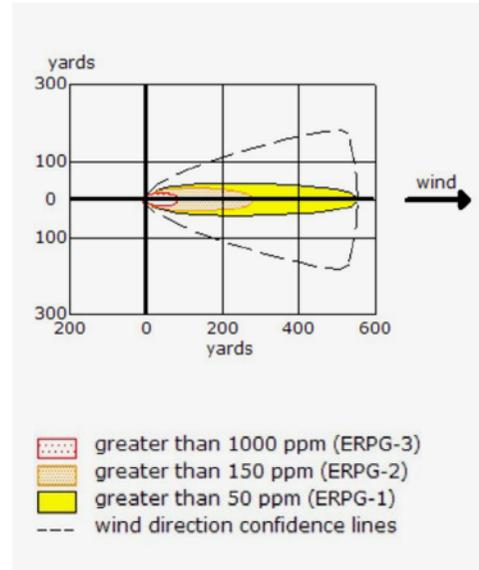


Image Source: United States Environmental Protection Agency

Environmental Considerations

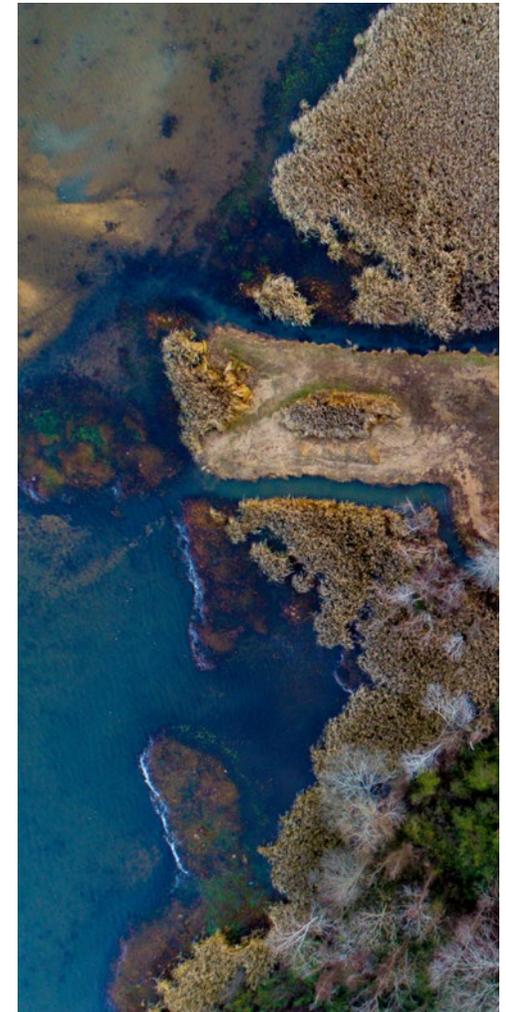
Ammonia-contaminated water generated during firefighting or vapour suppression is highly toxic to aquatic ecosystems.

Emergency plans must include provisions for controlling and containing such waste to prevent environmental damage.

Response measures include:

- Diverting runoff to catchment ponds, bunds, or sealed containment zones.
- Preventing ammonia discharge into storm drains or waterways.
- Use of wet scrubbers on emergency ventilation ducts in densely populated areas.
- Monitoring and disposal of contaminated water per MARPOL Annex V and local environmental regulations.

Environmental risk assessments must be part of the overall emergency plan, and post-incident reviews must evaluate pollution levels and recommend remediation if necessary.



Types of Ammonia Bunker Containment Systems

While the International Maritime Organization (IMO) has not yet established specific containment system categories for ammonia, industry practice is largely based on technologies developed for transporting liquefied petroleum gas (LPG), particularly through Medium Gas Carriers (MGCs) and Very Large Gas Carriers (VLGCs).

IMO Type A and Type B Tanks

Type A and Type B containment systems are not typically used for ammonia fuel tanks. Type A tanks are non-pressurised prismatic tanks requiring a full secondary barrier and extensive insulation, while Type B tanks are either spherical or prismatic and rely on partial secondary barriers supported by advanced structural analysis. These designs are intended for low-pressure cryogenic fuels and are integrated into the ship's hull. However, because ammonia is carried under pressure rather than at deep cryogenic temperatures, these systems are considered technically and economically unsuitable for ammonia service. In addition, the toxic and reactive nature of ammonia demands rapid leak containment and specialised ventilation, which are not inherent features of Type A or B systems. As such, these containment types are not currently adopted in ammonia shipping or bunkering practice.

Type C Tanks

Type C tanks are the most widely used and practically applicable containment systems for ammonia bunkering. These tanks are self-supporting and pressurised, typically featuring cylindrical or spherical geometries. Constructed from ammonia-resistant materials such as specific grades of stainless or nickel steel, Type C tanks are designed to store ammonia at pressures ranging from 4 to 10 barg. This pressurised environment allows ammonia to be stored in liquid form at ambient temperatures, eliminating the need for refrigeration systems. Owing to their long-standing use in LPG shipping, Type C tanks have a strong safety record and are well understood by industry and regulatory authorities. Their modular design and straightforward integration make them suitable for ammonia-fuelled vessels, particularly in smaller bunkering ships, offshore supply vessels, and coastal ferries.

In the context of ammonia as fuel, additional safety modifications are typically required in Type C tank systems. These may include double-walled piping, inert gas padding, continuous ammonia gas monitoring systems, and emergency shutoff valves. These features are critical in addressing the toxicity and corrosive properties of ammonia and ensuring that any accidental release can be detected and contained quickly and safely.

Pressurised Storage Systems

Pressurised storage systems, of which Type C tanks are a major example, represent the preferred containment approach for ammonia in maritime applications. These systems maintain ammonia in liquid form by keeping it at pressures typically between 4 and 10 barg at ambient temperature. Ammonia does not require cryogenic insulation or complex reliquefaction systems, which simplifies the containment system and reduces overall energy requirements. Pressurised storage systems are especially suited for small to medium vessels where compactness and system efficiency are important. Their construction requires careful material selection to ensure corrosion resistance, and they are always equipped with standard safety features such as pressure relief valves, gas detection systems, ventilation fans, and fire suppression systems.

Double-walled tank

Support guide

Outer tank

Inner tank

Saddle

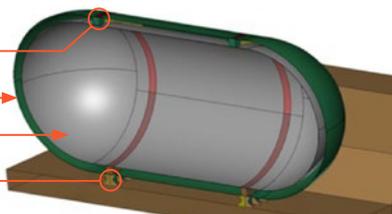


Image: IMO Type C tanks

Commercial— Quality and Quantity Agreement

In anticipation of ammonia-fuelled vessels entering service, industry stakeholders have begun drafting technical frameworks and safety standards. In line with this development, contractual clauses are required to address the specific commercial, technical, and operational aspects of ammonia as a marine fuel.

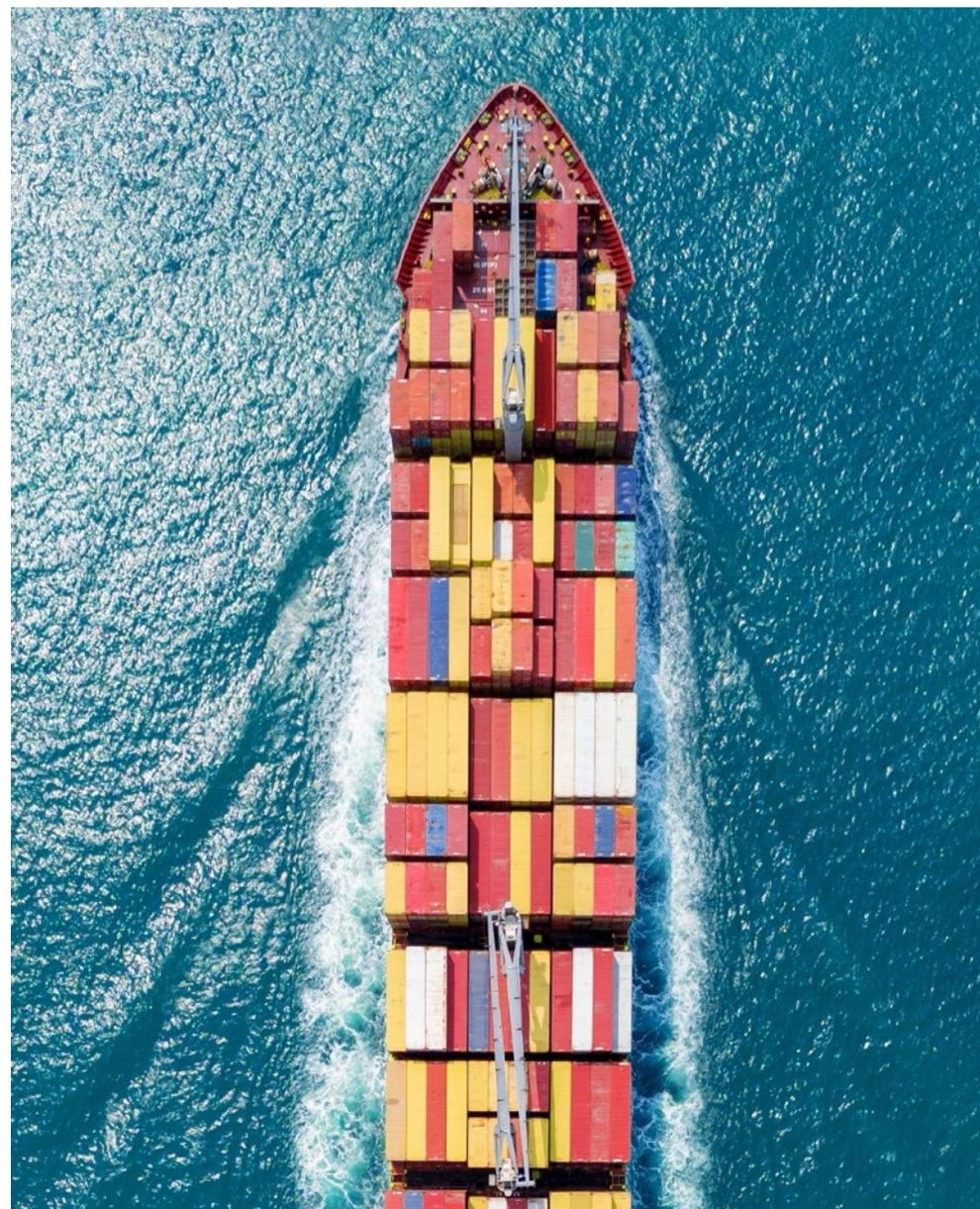
A future Ammonia Fuel Quality Clause is expected to define the specifications ammonia fuel must meet to ensure safe use, compatibility with engine systems, and environmental compliance. Key parameters under such a clause may require charterers to supply ammonia fuel that:

- Is free of foreign matter, including particulates and undissolved impurities.
- Complies with applicable ISO standards (such as ISO/TS 21343:2025—Oil and gas industries including lower carbon energy—Fuel ammonia—Requirements and guidance for boilers for power generation) or equivalent fuel-grade specifications specific to marine use.

- Meets defined limits for water content, oil contamination, and metallic impurities.
- Has a minimum purity threshold (typically 99.5% anhydrous ammonia).
- Contains less than a specified maximum concentration of NO_x precursors and other contaminants (e.g., CO₂, N₂O, hydrocarbons).
- Is chemically compatible with the vessel's fuel system and storage arrangements.

Additionally, charterers would be required to provide owners with a certified Bunker Delivery Note (BDN) and supporting documentation verifying compliance with the above standards. This documentation must also align with the International Code of Safety for Ships Using Gases or Other Low-flashpoint Fuels (IGF Code), and any future amendments that specifically address ammonia bunkering.

Failure to comply with the prescribed fuel quality would render the charterers liable for any resulting loss, damage, or operational impact on the vessel. To ensure compatibility, a comprehensive risk and safety compatibility assessment, typically involving both the supplier and the receiving vessel's technical team, would be mandated prior to the first bunkering operation.



Management of Change (MOC) for Ammonia-Fuelled Vessels

The adoption of vessels operating with dual-fuel engines capable of using both ammonia and conventional fuel oil requires more than just physical upgrades. It necessitates a holistic organizational shift involving new systems, revised work processes, enhanced safety protocols, and, critically, upskilling of the crew. The scale and depth of these modifications call for a formal MOC programme at both the management ashore and shipboard levels.

Key MOC considerations include:

- **Organizational and Procedural Changes:** The introduction of ammonia systems mandates updated operational procedures, maintenance schedules, and safety protocols. Existing documentation—including manuals, technical drawings, and databases—must be revised to reflect new risks, response strategies, and technical specifications.
- **Training and Competency Development:** Officers and crew will require comprehensive training to address ammonia-specific hazards and operations, with training programs needing to align with the STCW Convention, IGF Code, and guidance from organizations such as SGMF and SIGTTO. This should include ammonia handling, bunkering procedures, emergency response (e.g., spill containment and mustering), and dual-fuel engine management. Personnel must understand the toxicological profile of ammonia and the necessary Personal Protective Equipment (PPE) to mitigate exposure risks.
- **Human Factors and Crew Structure:** The shift to ammonia may influence onboard crew composition and responsibilities. New or modified roles may emerge, particularly related to bunkering and emergency preparedness. In some cases, increased automation may reduce manual tasks but simultaneously demand more technical oversight and analytical skills for data interpretation and control system management.
- **Technology and Automation:** Ammonia operations will introduce or expand digital systems on board, such as Human-Machine Interfaces (HMI), Distributed Control Systems (DCS), and enhanced monitoring tools. Displays and alarms in the Engine Control Room (ECR), bridge, and local panels will be updated to integrate ammonia-related data (e.g., from SCRs, detox units, gas detectors). Personnel must be trained in interpreting and responding to this information effectively.
- **Equipment and Safety System Updates:** Vessels will require new ammonia-compatible systems and retrofitting of new equipment. These should include fire detection/suppression, ventilation, and emergency life-saving appliances. For instance, lifeboats may need upgrading to those used on chemical tankers, and corrosion resistance of materials in ammonia-handling areas must be evaluated. Multi-gas detectors will also need calibration or replacement to ensure compatibility with ammonia vapours.
- **Comprehensive MOC Framework:** Given the complexity of transitioning to ammonia, it is essential to develop a tailored MOC framework that addresses organizational readiness, identifies change drivers, assesses risk impacts, and establishes governance for change implementation. This framework should span shore-based management systems and shipboard operations to ensure cohesive and resilient fuel integration.

Simultaneous Operations (SIMOPS)

In ports where bunkering is conducted alongside other maritime activities such as cargo handling, maintenance, or provisioning, the complexity increases due to the interaction between operations. A SIMOPS assessment is necessary to identify any risk interfaces between ammonia transfer and concurrent operations. This includes evaluating the potential for ignition sources, unauthorised personnel access, or conflicting resource allocation. Where necessary, conflicting activities must be isolated or temporarily ceased, and a SIMOPS coordinator (who could be the Vessel Manager or the Master) should be appointed to manage real-time safety alignment.

Mooring Analysis

The physical stability of both vessels during ammonia bunkering is maintained through carefully planned mooring arrangements, particularly important due to differences in vessel size, freeboard height, and motion responses. The mooring strategy should prioritise balanced restraint across the vessel's longitudinal and lateral axes while accounting for local metocean conditions such as surge, swell, and wind forces.

Pneumatic fenders certified under ISO 17357 must be deployed as primary shock absorbers, supplemented by foam-filled fenders to prevent contact with superstructures. Mooring lines must follow the Mooring Equipment Guidelines, Fourth Edition (MEG4) standards, using high-modulus synthetic ropes with certified tails to ensure elasticity and resistance to load spikes. Enclosed fairleads should guide mooring lines to avoid chafing, while the overall line configuration must be capable of holding the vessels in position under dynamic conditions and allow for rapid release in emergencies. A full mooring analysis—preferably using software modelling based on local data—should be conducted prior to each operation.

Risk Assessment and HAZOP Integration

Given the high-risk profile of ammonia as a toxic, corrosive, and cryogenic chemical, a comprehensive and operation-specific risk assessment is imperative for each bunkering operation.

The risk profile should not only consider traditional ship-to-ship hazards such as hose rupture, overfilling, and power failure but must also integrate ammonia-specific threats including vapour cloud formation, toxic inhalation risks, and structural embrittlement due to low temperatures. These risks require a layered safety approach where operational planning, equipment reliability, and crew behaviour are all accounted for in detail.

At the core of this risk evaluation is the Hazard and Operability Study (HAZOP), a structured and methodical technique used to identify potential deviations from intended design or operational performance. During an ammonia bunkering HAZOP, a multidisciplinary team—typically consisting of engineers, safety officers, operational staff, and marine specialists—reviews each subsystem such as pipelines, valves, sensors, and tank venting arrangements.

Some notable ammonia-specific hazard scenarios identified through operational experience include:

- Venting of NH₃ vapours → Toxic release and asphyxiation risk.
- Sources of ignition near vapour areas → Fire/explosion hazard.
- Improper system line-up or valve operation → Mechanical damage, cargo escape.
- Material fatigue or equipment failure → Brittle fractures in cold conditions, leaks.
- Complacency, fatigue, or SIMOPS interference → Structural stress, cargo contamination, personnel injury.
- ESD or valve hydraulic failure → Delayed response to emergencies, uncontrolled spillage.

These scenarios emphasise the need for a dynamic and frequently updated RA-HAZOP process, especially when considering changing environmental conditions, vessel configurations, or simultaneous operations (SIMOPS).

Safety Measures and Emergency Planning

Ensuring operational safety requires multiple layers of precaution. All personnel involved must wear appropriate Personal Protective Equipment (PPE), including chemical-resistant suits, gloves, face shields, and Self-Contained Breathing Apparatus (SCBA). Fixed gas detectors should be installed at key points along the transfer line, supplemented by portable detectors for crew use. The Emergency Shutdown System (ESD) should be fully functional, integrated across both vessels, and tested for interoperability. Environmental monitoring must be continuous, especially for changes in wind direction that could influence vapour dispersion. A safety zone should be established around the transfer area, restricting access to trained and authorised personnel only. An ammonia-specific Shipboard Oil Pollution Emergency Plan (SOPEP) should be on board, along with a medical response protocol that includes nearest hospital access and medevac logistics.

Emergency response drills—including rapid disconnection and unmooring—must be rehearsed before transfer begins.



Hazard Identification (HAZID)

The adoption of ammonia as a marine fuel introduces new hazards and necessitates careful consideration of vessel ergonomics to ensure crew safety, efficiency, and system operability. A structured Hazard Identification (HAZID) approach is essential during the design and operational planning phases to anticipate and mitigate risks associated with toxicity, chemical exposure, high-pressure systems, and emergency response. These risks are compounded by the physical and cognitive demands placed on crew members operating in challenging environments, especially during tasks such as bunkering and maintenance.

Ergonomic design must be user-centric, accounting for the crew's physical capabilities and limitations in high-risk conditions. Deck and bunkering station layouts should minimise manual handling of heavy components such as hoses and reinforce protection against chemical exposure. Working in chemical protective gear can lead to fatigue and reduced mobility, so equipment and workflows must be adapted accordingly. Remote operation and monitoring capabilities should be prioritised to reduce crew exposure and enhance situational awareness during critical operations such as bunkering.

Crew Training and Competence for Ammonia-Fuelled Vessels

The transition to ammonia as a marine fuel introduces a unique set of operational, technical, and safety challenges, necessitating an evolution in the training and competence of seafarers. While current frameworks—such as the STCW Convention, IGF Code, IGC Code, and ISM Code—offer a solid foundation, it is ultimately the responsibility of ship operators to ensure their crews are adequately trained and certified to manage the specific hazards and systems associated with ammonia-fuelled operations.

Ammonia's distinctive properties—namely toxicity, corrosivity, flammability, and explosivity—require not only specialised technical knowledge but also strengthened non-technical skills. Crew members must be prepared to work with new and unfamiliar systems, such as detox scrubbers, ventilation units, and emissions reduction equipment such as SCR systems. In parallel, competencies such as hazard recognition, situational awareness, communication, and decision-making are critical in both routine and emergency situations.

As the roles and responsibilities of shipboard personnel evolve to accommodate ammonia as a fuel, new competencies must be developed to ensure safety, efficiency, and environmental compliance. Competence encompasses not just technical proficiency but the consistent application of knowledge, experience, and sound judgement in operational settings. This includes the ability to manage risk effectively and respond appropriately to dynamic and potentially hazardous scenarios.

Training must incorporate the operation and maintenance of ammonia fuel systems, covering aspects such as storage, transfer, emissions control, and leak detection. Regulatory compliance remains essential, with training programmes needing to align with the STCW Convention, IGF Code, and guidance from organizations such as SGMF and SIGTTO. The integration of safety practices into daily operations is also vital, reinforcing the use of PPE, hazard recognition, and emergency procedures as standard practice.

Safety Aspects

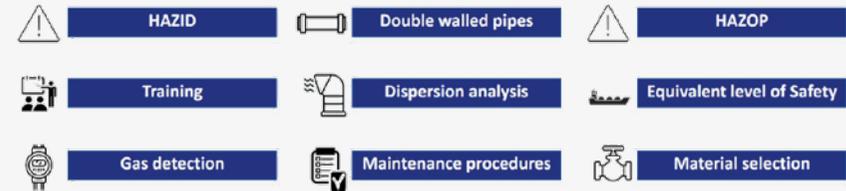


Image Source: Ammonia Energy Association

The STCW Convention, under Section A-V/3, outlines the minimum mandatory standards for seafarers on vessels using low-flashpoint fuels. All personnel involved in safety-related duties must hold a Certificate of Proficiency (COP) in Basic Training, as specified in Table A-V/3-1. This covers fuel properties, safety measures, hazard identification, and emergency response. Individuals already certified under Regulation V/1-2 for liquefied gas tanker operations may meet the basic training requirement.

Advanced training is required for Masters, engineers, and those directly responsible for fuel systems, following the standards in Table A-V/3-2. This involves completing an approved training course and obtaining at least one month of relevant sea service, including participation in three ammonia bunkering operations—two of which may be completed via simulator. Those certified under Section A-V/1-2 may also qualify if they meet these experience requirements and have completed the basic training component.

Competence Development for Ammonia Operations

To ensure safe ammonia-fuelled operations, all seafarers must have a fundamental understanding of ammonia's hazards, including its toxicity, flammability, corrosivity, and potential for explosive behaviour. Officers require deeper technical training to operate ammonia systems safely, respond to off-normal conditions, and navigate applicable regulatory requirements. Ratings and support staff must be trained to avoid exposure, use PPE properly, and fulfil defined roles during emergencies. Additionally, shipowners should ensure that contractors, visitors, pilots, and port personnel are informed about ammonia-related hazards and emergency protocols. Clear communication, safety awareness, and coordination with shore-based entities are essential to maintaining safety across all operational interfaces.

Ammonia Bunkering

Tank Preparation for Bunkering

Before ammonia can be bunkered, the tank on the receiving vessel must be prepared. This ensures that the tank is safe to accept the ammonia and prevents operational risks such as over-pressurisation, leaks, or the formation of dangerous compounds.

Drying

The drying process involves removing any residual moisture or water vapour from the tank. This is important as moisture can react with ammonia, potentially leading to hazardous situations.

- Dry air or nitrogen is introduced into the tank, displacing the atmospheric air. This process ensures that the dew point inside the tank is sufficiently low to prevent the formation of ice or ammonia-water mixtures.
- The drying continues until the dew point of the air inside the tank is lower than -45°C at the manifold sampling point.

Gassing-Up

Ammonia bunkering does not typically require inerting, although using pure nitrogen (N_2) as an inerting gas is acceptable, as it is chemically inert and does not react with ammonia under normal conditions. However, using inert flue gas or other inert gas mixtures containing carbon dioxide (CO_2) is not recommended, as CO_2 can react with ammonia to form ammonium carbamate, a compound that may solidify and create operational and safety issues. Additionally, if moisture is present, ammonium hydroxide can form, which is corrosive and poses further risks.

To avoid these reactions, ammonia vapour is introduced directly into the tank to displace existing dry air. This eliminates the need for inert gases and reduces the potential for dangerous chemical interactions.

In practice, ammonia vapour is introduced at the top of the tank. As the vapour fills the tank, it displaces atmospheric air through the vent mast, due to differences in vapour density. Tank pressure is maintained at atmospheric pressure throughout the operation. Sampling points are strategically positioned to continuously monitor ammonia concentrations, ensuring a safe and controlled transfer process.

The displacement method relies on the principle of replacing one gas with another based on their relative vapour densities. This allows for effective purging without mixing. To remember the increasing order of vapour density under standard temperature and pressure (STP), the mnemonic 'A NAIL' can be used:

- **A** → AMMONIA
- **N** → NITROGEN
- **A** → AIR
- **I** → INERT GAS
- **L** → LIQUEFIED PETROLEUM GAS (LPG)

This order shows that ammonia is the lightest, followed by nitrogen, air, inert gas, and finally LPG as the heaviest. By choosing a displacing gas that is either lighter or heavier than the target gas, efficient and directional purging can be achieved via the piston effect.

Cooling-Down

Given that the ammonia fuel tanks are pressurised, and the ammonia will be supplied at ambient temperature, a cooldown process may not be required.

During Ammonia Bunkering Supervision

- Qualified personnel must be present to supervise the ammonia bunkering operation. The operation must be continuously monitored for ammonia concentration, temperature, pressure, and transfer rate.
- No simultaneous operations should occur during bunkering to prevent distractions or the possibility of safety oversights.
- A continuous gas monitoring system should be in place to detect any ammonia leaks. High-level alarms should trigger at 50 ppm, and emergency shutdowns should be activated if ammonia concentrations exceed 300 ppm (IDLH).

Bunker Transfer Process

- Once the ammonia tank is properly prepared, the transfer process begins. The ammonia is transferred at a controlled rate to the receiving tank.
- Start at a slow transfer rate and gradually increase to the pre-agreed rate. The operation should be stopped immediately if any irregularities are detected.
- Continuous communication between the bunker vessel and receiving ship is essential to coordinate transfer and ensure safe bunkering.

Overview of a Typical Fuel Ammonia Plant On Board

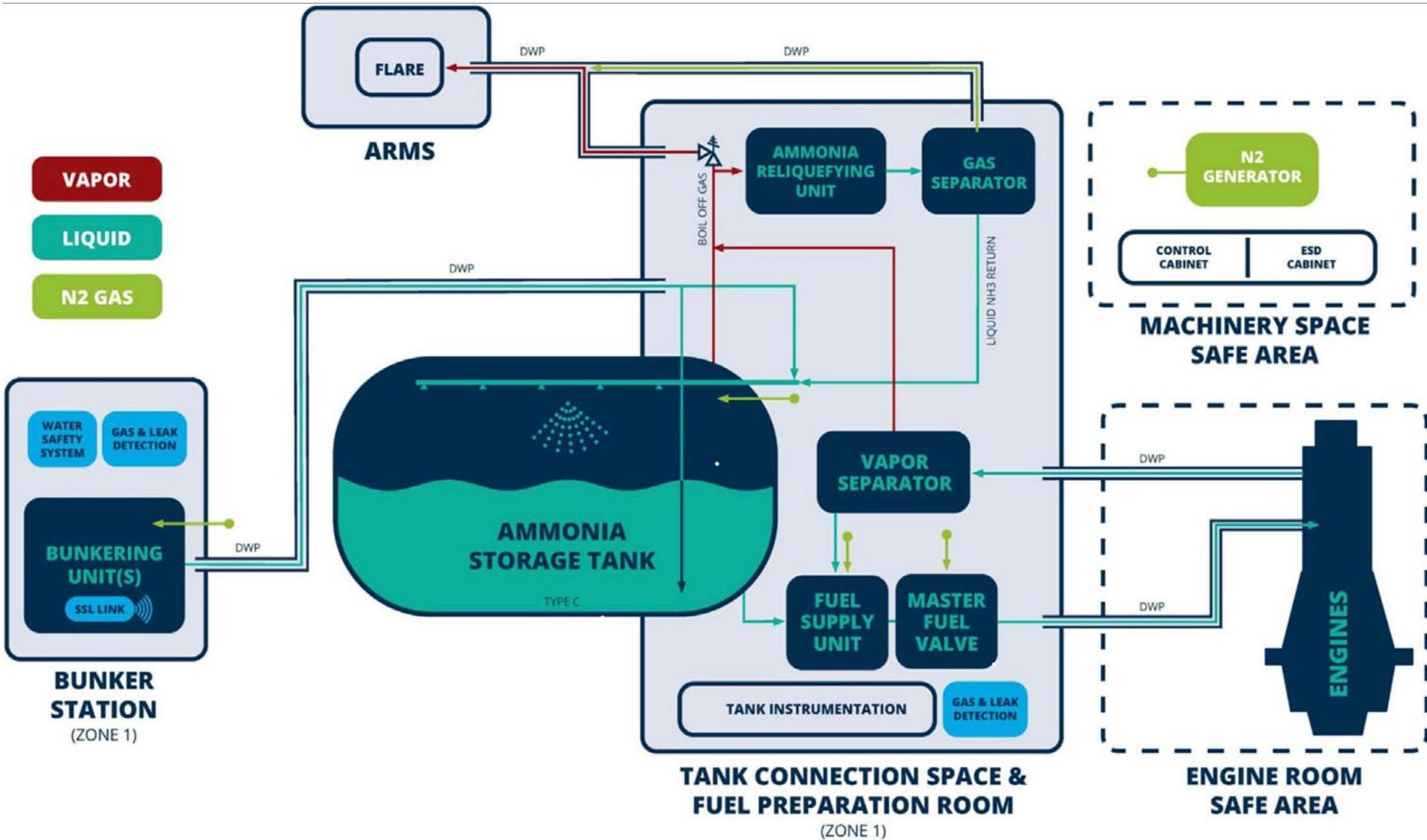


Image Source: Manifold Times

Topping-Off

- As the receiving tank nears capacity, the transfer rate should be reduced to avoid overfilling or excessive pressure build-up.
- During this phase, operators should be particularly careful to prevent any high-level alarms or pressure events from triggering emergency shutdowns.
- ESD System: Not to be used as a routine method for halting the bunkering operation at high levels.

Vapour Management

- Ammonia vapour must be carefully managed to prevent over-pressurisation of the receiving tank and to minimise the risk of leaks or venting.
- Vapour displaced during the bunkering process is returned through vapour return lines or scrubbers to prevent the ammonia from being released into the atmosphere.
- Pressure in the tank must be monitored, and any vapour return should be confirmed to be within safe limits.

After Bunkering

Once the bunkering operation is completed, the system must be securely shut down, and the tank must be sealed to ensure no ammonia leaks or risks are present.

Post-Transfer Checklist

A comprehensive post-transfer checklist must be completed by both the bunker supplier and the receiving vessel. This checklist ensures that all procedures were followed and that no further risks exist.

- Tank levels, pressure, and temperature should be recorded.
- The bunkering lines must be drained, purged, and checked for any residual ammonia.
- All personnel should confirm that the ammonia concentration in the bunkering area is below the acceptable threshold (25 ppm for routine operations, 50 ppm for emergency alarms).

Draining and Purging

- Residual ammonia in the bunkering lines should be safely drained back to the bunker tank or to a collection facility designed for ammonia waste.
- After draining, all lines and hoses should be purged with nitrogen to remove any remaining ammonia.
- Nitrogen purging ensures that no ammonia vapour remains in the system before disconnection.
- Purging should follow standard protocols to ensure ammonia is not released into the atmosphere.

Disconnection of Hoses or Arms

- Before disconnecting the ammonia bunkering hoses, ammonia concentrations in the lines should be checked. They should be below 25 ppm for safe disconnection.
- Once the ammonia vapour is confirmed to be cleared from the lines, the hoses or arms are disconnected and sealed to prevent the ingress of moisture or air.
- Disconnection points should be immediately capped, and all equipment should be checked for cold spots or potential leaks.

Post-Bunkering Activities

- After disconnection, the ammonia vapour detection systems should continue monitoring for any leaks in the area for at least 30–60 minutes to ensure no delayed leakage occurs.
- A final report of the bunkering operation should be completed, including all records, incidents (if any), and compliance checks.
- The receiving vessel should notify the relevant authorities that the bunkering operation is complete.

Storage Tank Arrangement

Ammonia is typically stored in double-walled or independent pressure vessels (Type C tanks). These tanks are usually installed below deck or within specially designated gas-safe zones. Key features include inert gas blanketing (using nitrogen), continuous pressure and temperature monitoring, leak detection sensors, and vent masts connected to overpressure and emergency release systems. The tanks are structurally reinforced and thermally insulated to maintain ammonia in liquid form during voyages.



Tank Connection Space

Beneath or adjacent to the tanks lies the Tank Connection Space (TCS)—a critical interface between storage and downstream systems. This enclosed space contains essential components such as transfer pumps, ESD valves, strainers, and flow meters. It is continuously ventilated and equipped with gas detection and drainage systems to quickly remove leaked ammonia or inert gas. All equipment within this zone is rated for hazardous environments and designed for rapid isolation in case of emergency. Access is restricted and tightly monitored due to the risk of gas accumulation and toxicity.

Fuel Preparation and Conditioning System (or Fuel Gas Supply System—FGSS)

The ammonia is transferred from the TCS to the Fuel Preparation Unit (FPU) or Fuel Conditioning System, which adjusts the fuel's phase, temperature, and pressure according to engine requirements. This unit includes heat exchangers (for vaporisation if gaseous ammonia is needed), chillers or heaters (to stabilise fuel temperature), pressure-reducing valves, and high-efficiency filters. Leak detection and purge lines (inert gas/N₂) are integrated to ensure safe handling. The conditioned ammonia is now ready for injection and is sent forward through high-pressure, double-walled pipelines to the engine room.

Engine Room Arrangement

Within the engine room, strict zoning and gas safety protocols are followed. The high-pressure ammonia fuel lines remain double-walled and routed through ventilated ducts with gas detection throughout. Key control systems, such as the main safety shutoff valves, flame arrestors, and ESD panels, are placed in easily accessible locations. The space is continuously monitored with hydrocarbon and ammonia gas sensors, and ventilation is interlocked with alarm and shutdown systems to maintain a gas-free environment. Personnel access is governed by strict PPE and safety protocols, especially during operations or maintenance involving the fuel system.

Main Engine—ME-LGIP

The ME-LGIP dual-fuel engine is the core of the propulsion system. It is a two-stroke engine that allows combustion of either conventional fuel oil or ammonia (with minimal pilot fuel for ignition). It uses a hydraulic-mechanical system for controlling fuel injection and exhaust valves. Each cylinder is equipped with a control block that manages injection timing via electronically controlled proportional valves. A hydraulic booster system, powered by control oil, injects ammonia and pilot fuel with high precision. The exhaust valves use two-stage hydraulic actuators and close via air springs. Lubricating oil serves as the medium for hydraulic control and is supplied by a dedicated power unit.

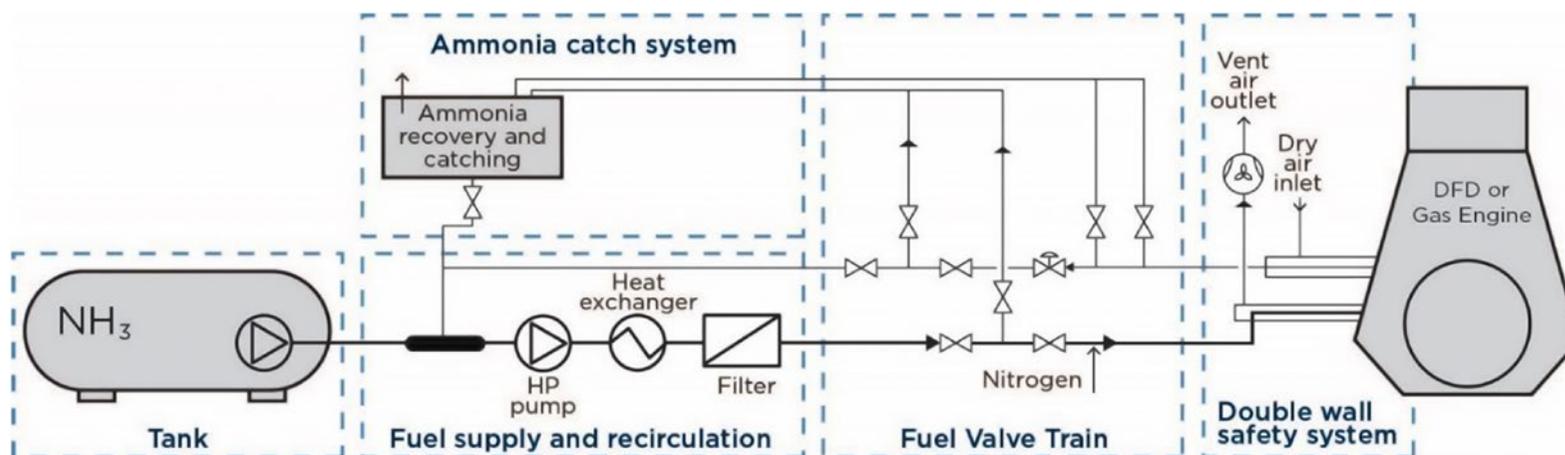


Image: Schematic of the Fuel Supply System of a Two-Stroke Diesel Cycle Ammonia Engine

The engine includes several key subsystems:

- Second fuel supply system: Delivers ammonia to each cylinder's control block.
- Sealing oil system: Prevents ammonia leakage into the hydraulic system.
- Ventilation system: Removes any leaked vapours from the cylinder area and discharges them to a safe location.
- Inert gas system: Used to purge second fuel systems during shutdowns or changeover operations.
- Control and Safety System: Monitors pressure, leakage, and fuel flow. Integrated hydrocarbon analysers and level switches detect abnormal conditions instantly.

Engine Operation Modes

The ME-LGIP engine operates in three distinct modes:

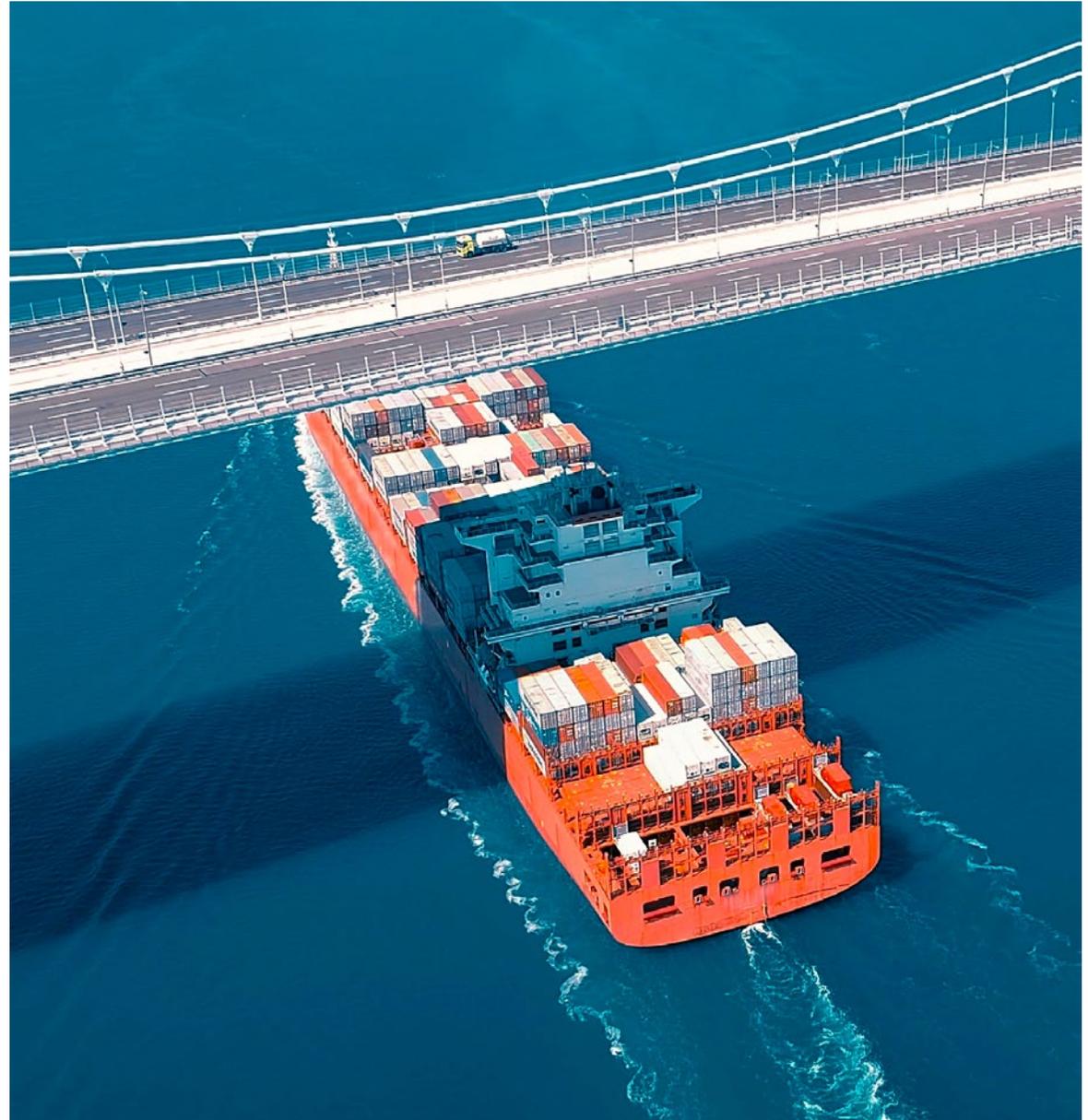
1. Second Fuel Mode—Ammonia is used as the primary fuel, with minimal pilot oil for ignition.
2. Dual-Fuel Mode (Flexible Mode)—A fixed quantity of ammonia is injected, with the remainder of energy demand met using fuel oil.
3. Fuel Oil-Only Mode—In this fallback or standby mode, only fuel oil is used. Ammonia systems remain in standby and can be monitored for leaks even while offline.

The transition between modes is automatic and seamless, controlled by the engine's electronic control system (ECS). In the event of a system failure, the engine instantly switches to fuel oil operation without any power loss. During this switchover, the ammonia supply lines are purged using nitrogen, ensuring the entire fuel system is cleared and safe.



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