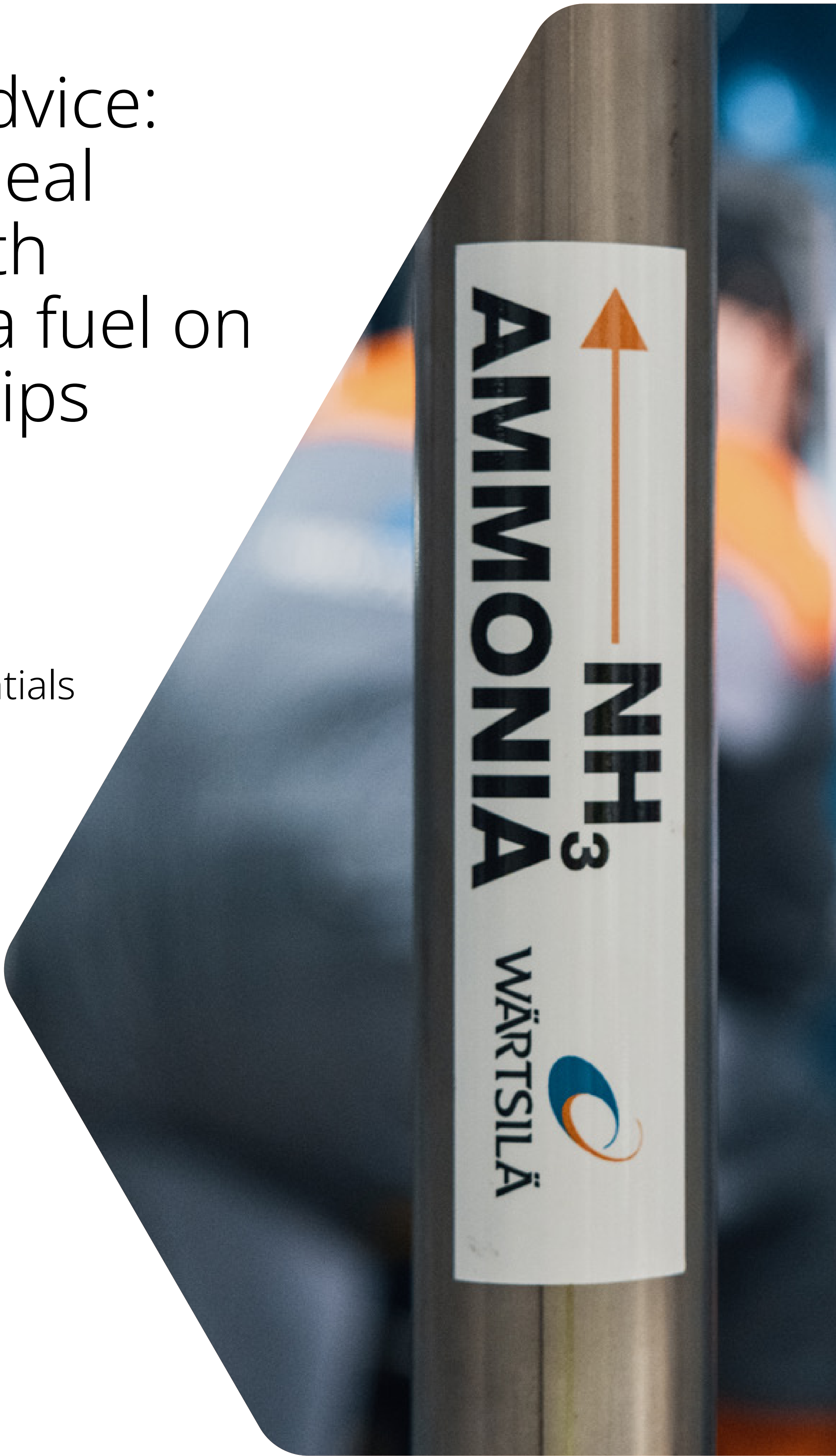
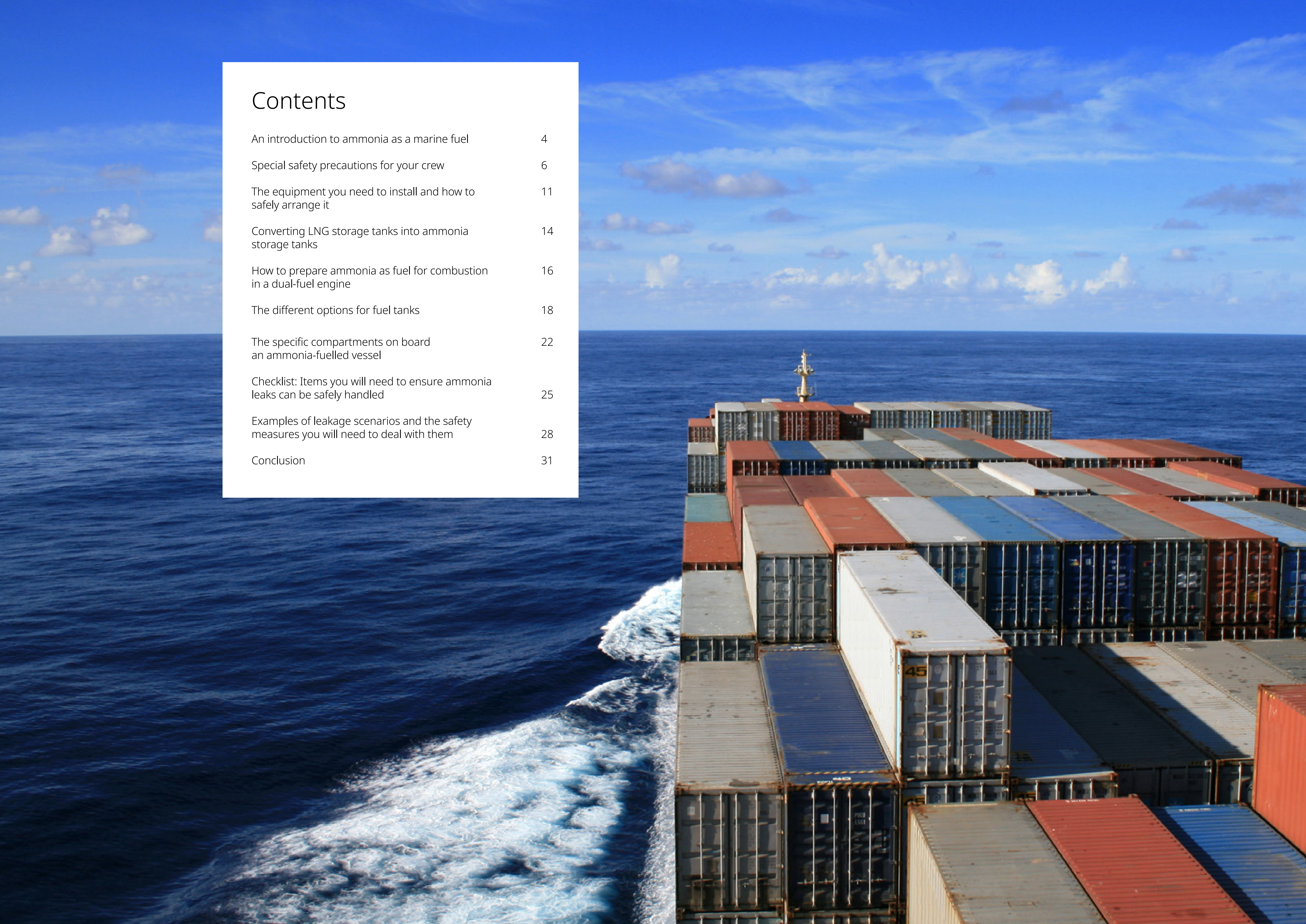
Expert advice: How to deal safely with ammonia fuel on board ships

A safety essentials eGuide





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An introduction to ammonia as a marine fuel

Ammonia has emerged as a promising alternative as the shipping industry looks for more sustainable fuel options because it does not produce carbon dioxide, sulphur or particulate emissions when combusted. Ammonia produced using fully renewable sources like solar or wind power will bring significant environmental benefits because it is completely carbon-free from well to wake.

There is an existing supply chain and infrastructure for other applications. Ammonia is already used in a huge variety of applications including cleaning products, refrigeration systems and fertilisers. It is typically transported by sea in LPG tankers, so there is a well-established storage and handling infrastructure in place.

Ammonia can be stored under pressure at atmospheric temperature or in a refrigerated state. This means that bunkering vessels and ships using ammonia as fuel can carry different combinations of fully refrigerated, semi-refrigerated or pressurised ammonia. To ensure safe operations you will need to fit your ship with specialised equipment and your crews need to be properly trained in how to handle ammonia as fuel.

Key facts about ammonia

- A compound of nitrogen and hydrogen (NH_3).
- In nature, it is produced by bacteria in soil and through the decomposition of organic matter.
- A colourless, strong-smelling gas at room temperature; becomes a liquid when cooled to -33 degrees Celsius.
- Releases no carbon dioxide, sulphur or particulates when combusted.
- Potential to be CO_2-free when produced using renewable energy (green ammonia)
- Toxic and corrosive, requiring careful handling and storage.

This safety essentials eGuide combines key findings from Wärtsilä's extensive experience of ammonia fuel with recommendations and requirements from classification societies. The guide covers the following topics:

- Special safety precautions for your crew
- The equipment you need to install on board your ship and how to safely arrange it
- Converting LNG storage tanks into ammonia storage tanks
- How to prepare ammonia as fuel for combustion
- The different options for fuel tanks
- The different compartments you need to have on board and their safety requirements
- Examples of leakage scenarios

Special safety precautions for your crew

To protect crew members from the toxic and corrosive nature of ammonia, there are several personal safety considerations that must be addressed.

1 Training and operational procedures:

- Crew members must be thoroughly trained in the handling of ammonia and emergency procedures related to its use. This includes understanding the properties of ammonia, how to use PPE and how to respond to leaks or spills.
- Regular emergency drills should be conducted to ensure the crew is prepared to respond effectively to ammonia-related incidents.
- Crew members must strictly adhere to established operational procedures for handling ammonia, including bunkering, purging and maintenance activities.
- Ammonia systems must be continuously monitored and any anomalies or potential issues reported immediately.

2 Ventilation and gas detection:

- Continuous ventilation systems must be in place to prevent the accumulation of ammonia gas in enclosed spaces. Ventilation inlets and outlets should be located at sufficient height above the deck to avoid the need for closing appliances.
- Permanently installed gas detection systems to monitor for ammonia leaks must be in place at the bunkering station, in machinery spaces and in other critical areas.
- Crew members must ensure that ventilation and gas detection systems are operational at all times and conduct regular checks and maintenance.

3 Communication and signage:

- Effective communication is essential, especially during bunkering operations and emergency situations. Crew members must use clear and concise communication to coordinate actions and ensure safety.
- Areas where ammonia is used or stored should be clearly marked with appropriate hazard signs and safety instructions.
- Effective communication systems should be in place to alert crew members in the event of an ammonia leak or emergency.
- Coordination with shore personnel and emergency responders is necessary for safe handling and response to ammonia-related incidents.

4 Access control:

- Access to areas where ammonia is stored or handled should be restricted to trained personnel only. Gas-tight doors and air locks should be used to prevent the spread of ammonia gas to other parts of the ship.

5 Emergency response procedures and equipment:

- In the event of an ammonia leak, crew members must take immediate action according to the emergency response plan, including moving to the closest safe haven, putting on appropriate PPE and using decontamination showers and eyewash stations if exposed to ammonia.
- Ammonia spill kits should be readily available in areas where ammonia may be present in liquid form. These kits should include absorbent materials, neutralising agents and tools for containing and cleaning up spills.
- First aid kits should be equipped with supplies specifically for treating ammonia exposure, such as eye wash solutions and burn treatments.
- Crew members must be familiar with evacuation protocols and muster points in case of a significant ammonia release.

6 Personal protective equipment (PPE):

When the design meets safe engine room principles, the crew can operate in the space without any additional PPE. However, during maintenance and bunkering procedures:

  - Crew members must wear coveralls made of chemical-resistant material to ensure no part of the body is exposed to ammonia, special gloves with long sleeves, and suitable footwear.
  - Face shields and appropriate respiratory protection, such as gas masks, are necessary to protect against inhalation and contact with ammonia.

- PPE must be properly fitted and regularly inspected and maintained to ensure its effectiveness.

7 Decontamination facilities:

- Suitably marked decontamination showers and eyewash stations must be available in the engine room and other critical areas to handle accidental exposure to ammonia.

Safety at the core of the Wärtsilä 25 Ammonia solution

Safety has been the first priority when designing the Wärtsilä 25 Ammonia solution. The solution employs safety strategies to help reduce and mitigate risks.

These strategies include, but are not limited to:

- ammonia sensors
- double-walled piping
- ammonia-compatible materials
- engine-room ventilation systems
- an ammonia release mitigation system (ARMS).

The equipment you need to install and how to safely arrange it

To use ammonia as fuel on your vessel safely and efficiently you will need to install the following equipment and take the following key considerations into account. Safely arranging the equipment is done through a holistic design process that takes into consideration all aspects of crew safety and operational procedures.

1. The materials used in the ammonia system must be carefully selected and be able to withstand the chemical's corrosiveness. Naturally, when you choose an ammonia solution from Wärtsilä this is taken care of. It is important to remember that special requirements also apply to the ammonia fuel storage tanks. It is particularly important to avoid materials like copper, brass and bronze, which are susceptible to ammonia corrosion.

2. The ammonia fuel lines connecting the tank connection space (TCS) and the engine must be protected by a secondary enclosure. This enclosure should be able to contain leakages and enable effective detection and mitigation of leakages.

3. The ammonia release mitigation system (ARMS) is an integral part of the fuel supply system. The ARMS must be in place to safely collect and handle all operational releases of ammonia from the ammonia engines, gas valve units and safety relief valves in the ammonia fuel supply system. It is also required to handle releases from most failure scenarios and emergency shutdowns (ESD) as well as purging and inerting of fuel pipes prior to maintenance. Treated discharges from the ARMS are led to a vent mast.

4. A dedicated ammonia vent mast to manage exhaust from the ARMS and releases from the tank safety valves.

5. A purging and gas-freeing system compatible with the ARMS, comprising:
   - the arrangement for purging and gas-freeing ammonia equipment and fuel lines
   - a nitrogen system with sufficient capacity to purge fuel bunkering, supply and return lines
   - a vent collection system that safely receives the purged ammonia-nitrogen mixture and feeds it to the ARMS.

6 A permanent gas detection system in all spaces where the ammonia fuel is handled. This includes the bunkering station, fuel preparation room TCS, ARMS room and engine room as well as the secondary containment systems.

7 The fuel supply control system must ensure that the system temperature remains high enough to prevent condensation from forming in the fuel pipes to the engines under any operating conditions.

8 The design of the engine and ammonia-related equipment in the machinery spaces must be according to (gas) safe engine room principles. This ensures that a single failure does not lead to the release of fuel into the machinery space. Engine room safety measures include a secondary enclosure with gas detection for the fuel supply piping and a decontamination shower and an eyewash station to mitigate any accidental exposure of personnel to ammonia.

9 Water screens are required for the entrances of enclosed bunkering stations, the fuel preparation room and the TCS. An emergency water spray system is required at the vent mast outlet and at other ventilation outlets from spaces containing ammonia fuel equipment. This system must be automatically activated if ammonia concentration exceeds a set threshold.

10 Due to the toxicity of ammonia, all air intakes, outlets and other openings into accommodation spaces, service spaces and control stations must be fitted with closing devices that can be operated from inside the space to prevent ammonia ingress.

11 Protective equipment for the crew, including respiratory and eye protection, and chemical protective suits, boots and gloves. Because ammonia is toxic, protective clothing and equipment must be worn in such a way that it covers all skin surfaces, ensuring no part of the body is left unprotected.

12 Good lifecycle management, which supports workplace safety and the safe handling of fuel. All aspects of lifecycle management have been taken into consideration in the design of the Wärtsilä 25 Ammonia solution.

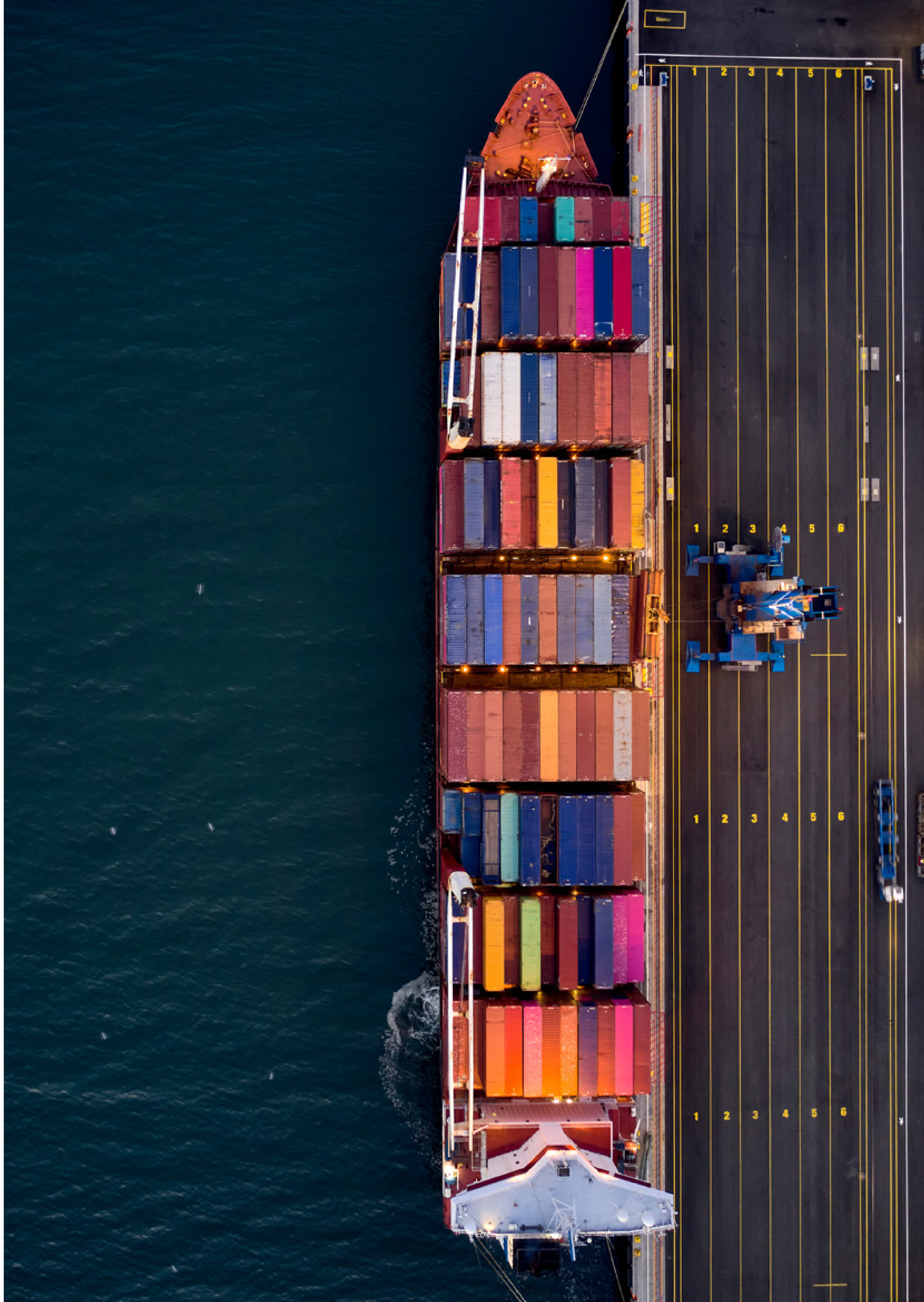
The Wärtsilä 25 Ammonia solution ticks all these boxes because safety has been the number one priority during the holistic design process. This process ensures that the equipment is safely arranged on board, taking into consideration all aspects of crew safety and operational procedures.

Converting LNG storage tanks into ammonia storage tanks

If you are converting a vessel that runs on LNG to use ammonia as fuel instead, you will need to verify that the vessel's fuel storage tanks and TCS are compatible with ammonia. Here is a checklist to help you:

1. The materials you use must be compatible with ammonia, which is highly corrosive, especially to materials like copper, brass and bronze.
2. Due to the higher density of ammonia compared to LNG, the supporting structures must be checked and, if necessary, modified to carry the additional weight of ammonia storage.
3. Fuel storage tanks must fulfill the criteria for ammonia, especially in terms of material. It is possible that tanks designed to store LNG may not be suitable.
4. Ventilation, leak detection and gas detection systems must be improved to meet ammonia requirements. These requirements are different to those of LNG because of ammonia's toxicity and lower flammability.

For more information about what is involved in converting a ship to ammonia operation, read this document from Breeze Ship Design:
What does it take to convert a ship to ammonia operation?



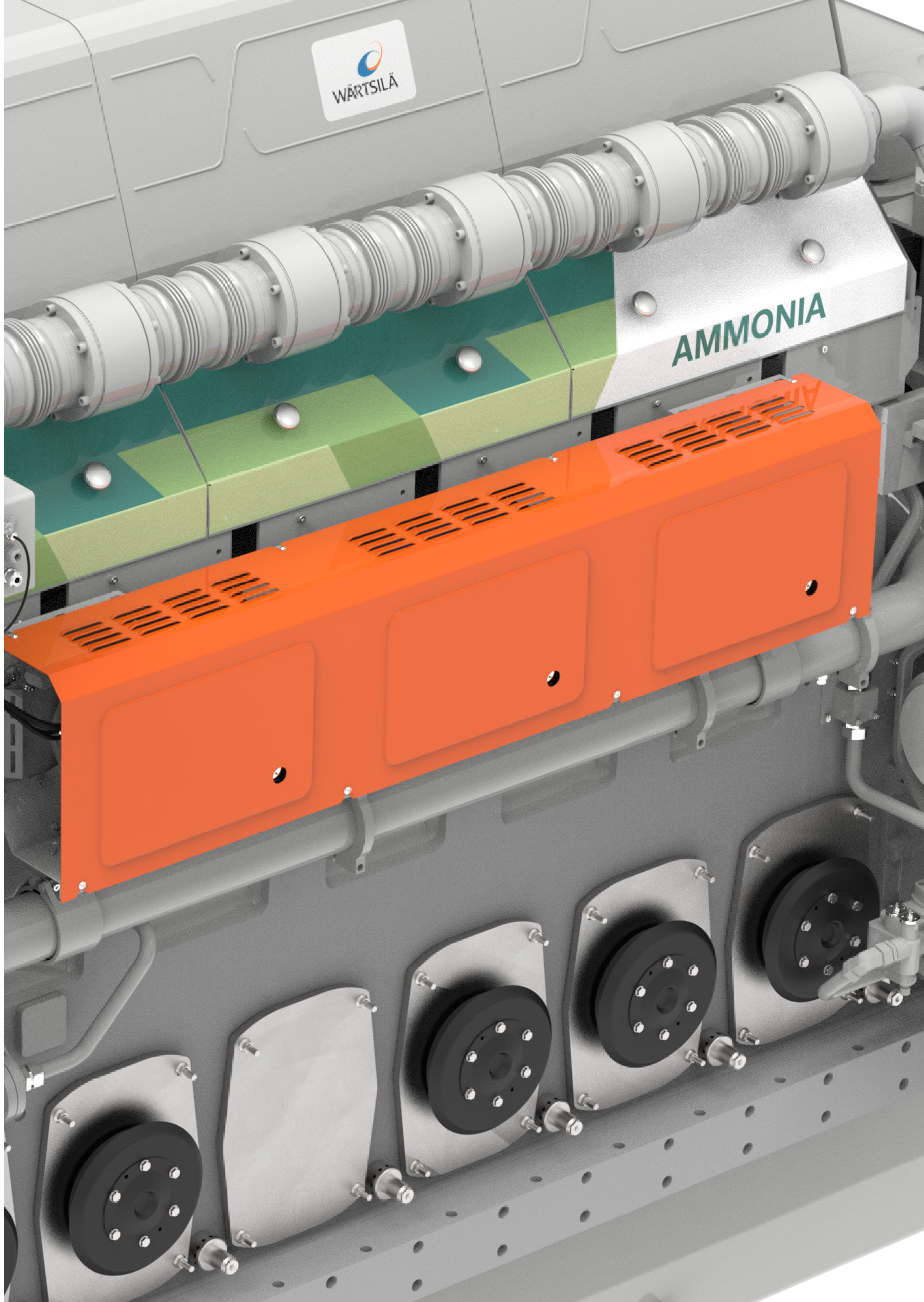
How to prepare ammonia as fuel for combustion in a dual-fuel engine

Ammonia stored as liquid needs to be gasified and heated to fulfil the requirements for fuel gas fed to the dual-fuel internal combustion engine. This process requires heat energy.

Most of the energy is used to gasify the fuel due to the high latent heat of ammonia vaporisation. The temperature of both the ammonia gas and the fuel gas piping must be kept at a sufficient level to prevent condensation.

It is recommended to use the ammonia engine's high-temperature water circuit as the heat source to ensure the requirements are met. The engine's exhaust gas heat recovery can also be a viable option as a heat source to gasify the ammonia. Another option is to use electric heaters as an additional or alternative source of heat to ensure that the ammonia reaches the required temperature for gasification.

You can also install a heat-recovery system to capture heat from other processes onboard your vessel for use as an energy source in the ammonia vaporisation process.

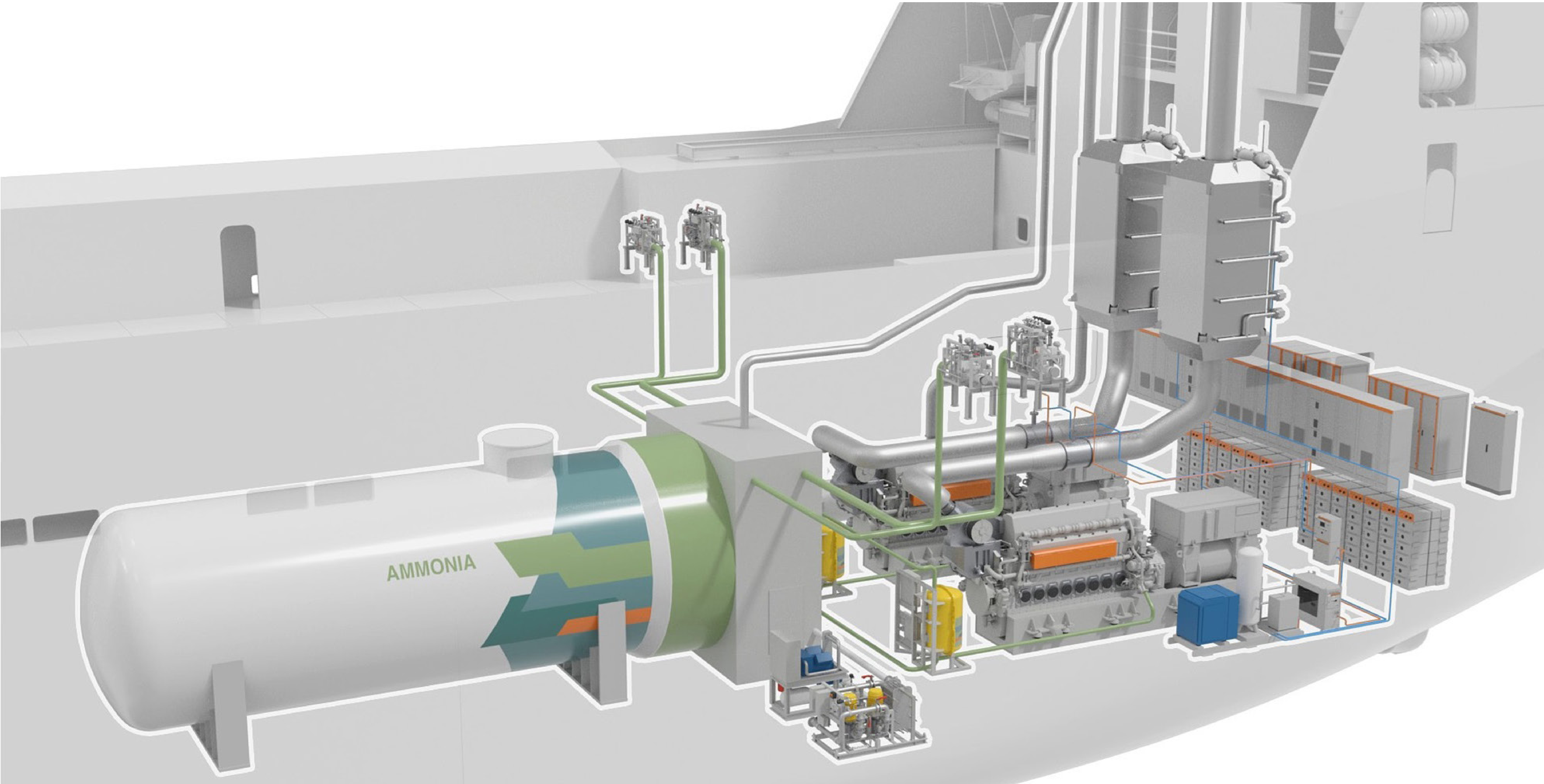


The different options for fuel tanks

There are different options for fuel tanks and fuel lines, and each has its own advantages and disadvantages.

Ammonia fuel tanks are either fully refrigerated, semi-refrigerated or fully pressurised.

- **Fully refrigerated tanks** store ammonia at atmospheric pressure and at a temperature of approximately -33°C.
  - **Advantages:** Because they operate at atmospheric pressure there is less risk of high-pressure leaks. If there is a leak, refrigerated ammonia also releases less vapour compared to ammonia stored at higher temperatures.
  - **Disadvantages:** Fully refrigerated tanks require significant insulation and a comprehensive refrigeration system to maintain the low temperature, which can increase the complexity of the system. Also, only fully refrigerated ammonia can be bunkered to these tanks.



- **Semi-refrigerated tanks** store ammonia at intermediate temperatures and pressures, typically around 0°C and at pressures of 2 to 5 bar.
  - **Advantages:** The balance between pressure and temperature offers a compromise between the low temperature of fully refrigerated tanks and the high pressure of fully pressurised tanks. Semi-refrigerated tanks also require less insulation than fully refrigerated tanks and lower pressure containment than fully pressurised tanks. They also provide additional safety and flexibility in case of possible pressure accumulation in the tank due to a refrigeration system malfunction. Semi-refrigerated tanks can bunker both fully and semi-refrigerated ammonia.
  - **Disadvantages:** Semi-refrigerated tanks are more demanding to design due to the need to manage both temperature and pressure. They can also be more expensive due to the need for both insulation and refrigeration system; however, they are less demanding than fully refrigerated systems.

- **Fully pressurised tanks** store ammonia at ambient temperature and at high pressures, typically up to 22 bar.
  - **Advantages:** These types of tanks do not require refrigeration systems, which reduces the space needed for, and the energy consumption of, the fuel system. Because these tanks can bunker everything from fully refrigerated to warm ammonia, they also simplify the delivery logistics and infrastructure. Handling ammonia at ambient temperature is generally easier and less energy-intensive compared to handling it at the cryogenic temperatures required for fully refrigerated tanks. Since the tanks operate at ambient temperature, there is no need for extensive insulation, which makes it possible to maximise the tank size in the available tank hold space.
  - **Disadvantages:** You will need to install robust safety systems to mitigate the increased risk of high-pressure leaks. You will also need to take into consideration the worst-case release scenarios for the vessel and its operations and be sure to use materials and construction methods that can withstand high pressures. This can increase the weight, cost and complexity of the fuel system.

The specific compartments on board an ammonia-fuelled vessel

An ammonia-fuelled vessel must have specific compartments to ensure safe storage, handling and use of the fuel. These compartments include:

1 | Tank connection space (TCS):

- The TCS is designed to safely contain ammonia leakages from tank connections and process systems. It must have a separate ventilation system to prevent the spread of ammonia gas to other spaces.
- The TCS should be arranged with gas-tight doors and an air lock separating it from any other compartment to ensure containment of any leaks.

2 | Engine room:

- A suitably marked decontamination shower and eyewash station must be available in the engine room.
- The design of the engine and ammonia-related equipment in the machinery spaces must be according to (gas) safe engine room principles, with all ammonia fuel system leakage sources protected by a secondary enclosure to prevent fuel release into the machinery space.

3 | Bunkering station:

- The bunkering station is recommended to be of an enclosed or semi-enclosed design to safely manage ammonia leakages.
- It must have a permanently installed gas detection system to monitor for ammonia leaks during bunkering operations and a separate ventilation system to prevent the spread of ammonia gas to other spaces and be continuously ventilated.
- Control of bunkering operations must be possible from a safe location, with monitoring of tank pressure, tank level and overfill alarms.

Checklist: Items you will need to ensure ammonia leaks can be safely handled

To ensure the safety of your crew and vessel in the case of an ammonia leak, you will need to install several different safety systems to detect, contain and mitigate the leak. Internal leakages from the ammonia system are managed by the ARMS. All the other compartments need to be arranged according to regulatory safety requirements.

Here is a list of items that are particularly important to ensure the safety of an ammonia-fuelled vessel:

1. Permanently installed gas detection systems in critical compartments such as the TCS, engine room and bunkering station to continuously monitor for ammonia concentrations and trigger alarms if levels exceed safe thresholds.
2. Safety measures such as water spray systems that are automatically activated if an ammonia concentration exceeding a threshold is detected.
3. Continuous ventilation in spaces containing ammonia systems to prevent the accumulation of ammonia gas.
4. Ventilation inlets and outlets located at sufficient height above the deck to avoid the need for closing appliances.
5. A water spray system for fuel-system compartments. This system is automatically activated if an ammonia concentration exceeding predefined levels is detected.
6. Water screens at the entrances of the TCS and bunkering station to limit the spread of toxic vapours, activated from a safe location outside the toxic zone.
7. Water distribution systems fitted over bulkhead openings for shore connections to provide a low-pressure water curtain for protection of the hull steel and the ship's side structure.

8 Ammonia fuel piping between the TCS and the engine safeguarded by a secondary enclosure to contain and detect leaks effectively, and to direct any leaked content to the open air.

9 Suitably marked decontamination showers and eyewash stations available in the engine room and other critical areas to handle accidental exposure to ammonia.

10 An emergency shutdown system that automatically shuts down the ammonia fuel supply if a set ppm threshold is reached.

11 A system capable of safely handling ammonia and purge gas (N_2 + NH_3) resulting from gas freeing. Proper consideration on how to handle purging after the emergency shutdown when the tank valve is closed and the ammonia fuel supply is cut.

12 Appropriate PPE for crew members including:

- large aprons
- special gloves with long sleeves
- suitable footwear
- coveralls of chemical-resistant material
- face shields
- respiratory protection

Working with an experienced provider like Wärtsilä will ensure your vessel benefits from a holistically designed solution for ammonia with safety as the core design principle.

Examples of leakage scenarios and the safety measures you will need to deal with them

It is crucial that crew members understand potential ammonia leakage scenarios so that they are well prepared to prevent any potential leakages.

Here are the key leakage scenarios and the associated safety considerations for crew members:

1 Tank pressure relief valve opening due to fire load:

- Scenario: In the event of a fire, the tank pressure relief valves may open to release pressure, resulting in the release of ammonia gas.
- Safety measures:
    - Crew members must evacuate the area immediately and move to a safe location.
    - Water spray systems should be activated to limit the spread of toxic vapours.
    - Crew members must put on appropriate PPE, including gas masks and protective clothing, before attempting any emergency response.

2 A major leakage in the TCS:

- Scenario: A significant leak occurs within the TCS, potentially due to a failure in piping, valves or other equipment.
- Safety measures:
    - The gas detection system will trigger alarms, prompting immediate action, and the safety system will automatically activate a shutdown of the fuel supply system to isolate the leak.
    - Continuous ventilation systems will help disperse the ammonia gas.

3 A major leakage in bunkering station:

- Scenario: A leak occurs during the bunkering process, potentially due to hose failure or connection issues.
- Safety measures:
    - The bunkering operation is automatically stopped thanks to the gas and leakage detection systems.
    - Water screens and spray systems should be activated to contain and dilute the ammonia vapours.
    - Crew members must evacuate the area and use appropriate PPE before re-entering the affected zone after the leakage has been contained and the area has been declared safe.

4 Minor leaks in piping or valves:

- Scenario: Small leaks occur in the ammonia piping or valves, potentially due to wear and tear or minor mechanical failures.
- Safety measures:
    - Routine inspections and maintenance can help identify and address minor leaks before they become significant.
    - Continuous monitoring by gas detection systems will alert crew members to the presence of ammonia.
    - Crew members must respond promptly to alarms, using PPE and following established procedures to isolate and repair the leak.

5 Leakage during maintenance activities:

- Scenario: Ammonia leaks occur during maintenance activities, such as valve replacements or pipe repairs.
- Safety measures:
    - Ammonia lines must be purged and gas-free before starting maintenance.
    - Maintenance personnel must wear appropriate PPE, including respiratory protection.
    - Clear emergency procedures must be in place, including the use of decontamination facilities and evacuation routes.

6 Leakage in enclosed spaces:

- Scenario: Ammonia leaks into enclosed spaces, such as the engine room.
- Safety measures:
    - Gas detection alarms must activate immediately to alert crew members.
    - Ventilation systems must be operational to disperse the gas.
    - The affected area must be evacuated and isolated to prevent the spread of ammonia.

Conclusion

Ammonia is a promising marine fuel because it produces no carbon emissions when it is combusted, which significantly reduces greenhouse gas emissions. Ammonia is also widely available and can be produced from renewable sources. It also has a high energy density, making it an efficient choice for long voyages. Furthermore, the infrastructure needed to support the adoption of ammonia as a marine fuel already exists, facilitating a smoother transition to low and eventually zero-carbon operations.

It is vital to remember that safety is paramount when handling ammonia, so any ammonia solution must be designed according to a stringent set of safety principles. Crew members must be properly trained in handling procedures and emergency responses, with regular drills and continuous system monitoring. Proper personal protective equipment – including chemical-resistant clothing and respiratory protection for those who work in critical areas – is essential. Continuous ventilation and gas detection systems are needed to prevent ammonia accumulation. In case of an incident, immediate action according to the emergency response plan is vital, and decontamination facilities and first-aid supplies must be readily available. Proper equipment installation, effective communication and restricting access to ammonia-handling areas help to ensure safety.

If you are considering ammonia but are unsure about where to start, a feasibility study carried out with Wärtsilä will give you the information you need to make an informed decision. When you are ready to take the next step, Wärtsilä has a complete three-element solution for vessels that will use ammonia as fuel, including training and lifecycle services for the whole system. The system is engineered as one holistic solution and comprises:

- the fuel-flexible Wärtsilä 25 Ammonia engine with a fully integrated exhaust after-treatment system to minimise emissions
- the fully automated Wärtsilä AmmoniaPac fuel supply system including the bunkering station skids, storage tanks and main process equipment
- the Wärtsilä Ammonia Release Mitigation System (which has received Approval in Principle from leading classification society DNV) to mitigate ammonia releases using staged and controlled combustion.

Get in touch to arrange a meeting with one of our experts. Through a feasibility study, we can help you take the first step towards safely adopting ammonia as fuel for your ships.

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Work with Wärtsilä to navigate decarbonisation with confidence.

Build your success on Wärtsilä's broad portfolio of engines, propulsion systems, hybrid technology, exhaust treatment, shaft line solutions and digital technologies, as well as integrated powertrain systems. These building blocks offer you efficiency, reliability, safety and world-class environmental performance.

The offering includes performance-based agreements, lifecycle solutions and an unrivalled global network of maritime expertise.

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