Concept design of a 15,000 TEU ammonia-fueled container vessel

Identifying the opportunities and challenges of designing a large ammonia-fueled container vessel

Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping

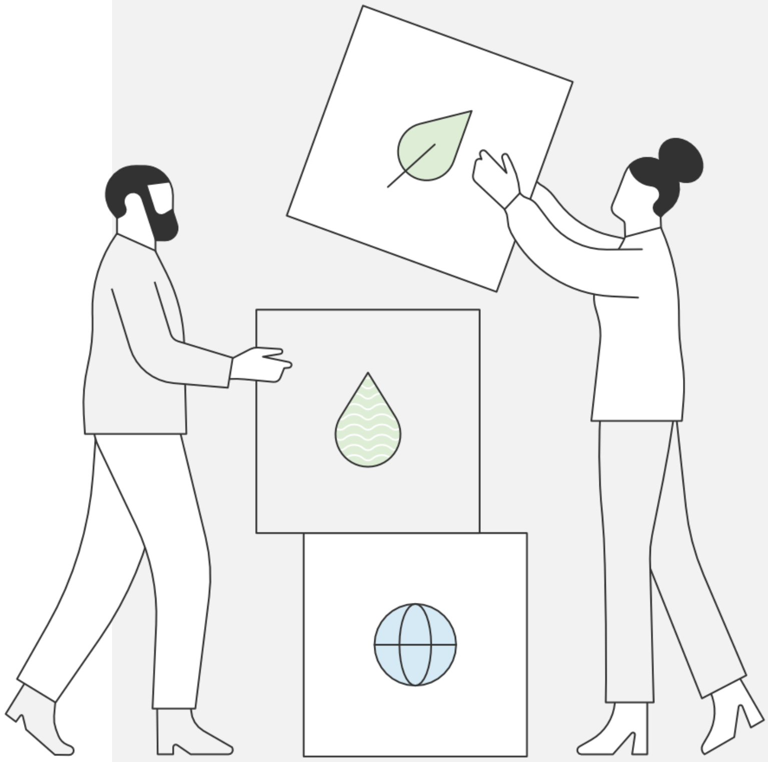
seaspan

Executive summary

As the shipping industry moves towards decarbonization, ammonia has emerged as a promising low-carbon alternative to conventional fossil-based marine fuels. However, considerable work is still needed to make widespread implementation of ammonia-fueled shipping a reality. Development of safe and efficient ammonia-fueled vessel designs is a major part of this ongoing work. To date, most ammonia-fueled vessel design projects have specifically focused on small or gas carrier vessels. As a result, their findings may not directly translate to large deep-sea oceangoing vessels such as container vessels. To address this gap, this project initiated by Seaspan and the Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping (MMMCZCS) set out to develop a design for a large ammonia-fueled container vessel.

Working closely with ship designer Foreship and classification society American Bureau of Shipping (ABS), we have jointly developed a concept design for a 15,000 twenty-foot equivalent unit (TEU) container vessel. This marks a significant milestone towards the potential commercialization of the ship design for Seaspan Corporation.

The following report outlines our concept design, encompassing initial design requirements, insights gathered from a hazard identification (HAZID) workshop, and specific details regarding the vessel's arrangement, systems, and performance.



During our design development, we have identified both opportunities and challenges, which can serve as a foundation for future ammonia-fueled vessel designs. Opportunities include:

– Achieving safety benefits through fully refrigerated ammonia storage.

– Optimizing the location and volumes of ammonia storage tanks to minimize container slot loss and reduce the risk of tank penetrations while ensuring the vessel's endurance.

– Providing sufficient space for defined hazardous zones, separate spaces for ammonia-related equipment, and multiple access/egress points.

Certain challenges and uncertainties are already identified and must be approached with careful consideration during the upcoming design stage, as outlined in the table below.

Challenge	Recommendation
Understanding impacts of ammonia leakage and release scenarios to minimize risks to crew onboard.	- All ammonia-fueled vessel designs currently being developed should conduct gas dispersion analysis for multiple scenarios to inform design decisions. - Use of quantitative risk assessment analysis in the next design phase to assess risks and potential mitigation measures in detail.
Understanding actual emission profiles, pilot fuel requirements, and safety implications of ammonia dual-fuel engines and associated equipment. Ammonia-related greenhouse gas emissions risks include ammonia slip, nitrogen oxides, and nitrous oxide.	- Monitor the development and testing of ammonia dual-fuel engines and associated equipment to better understand emissions risks and how to mitigate any identified risks. - Incorporate relevant technologies and information into future ammonia-fueled vessel designs.
While ammonia dual-fuel engines get the most attention, many other onboard systems also require development and proper and safe design integration. These systems include boil-off gas (BOG) management solutions, ventilation concepts of spaces with ammonia-containing equipment, fuel supply system including ammonia recovery and knock out drum usage, and ammonia water solution storage and treatment.	- Further development of auxiliary and supporting ammonia-related technologies for application on board vessels.
Not all risk mitigation measures could be incorporated into the concept design due to its early stage of development.	- Follow up and further develop the risk mitigation measures identified in HAZID reviews and, for our project, documented in the ABS approval in principle letter that are relevant for the more detailed design stage.
While the focus of the development has been on ammonia as a fuel, due to the expected price premium relative to conventional fuels, ammonia fuel consumption and associated operational expenses should be minimized.	- Optimize the vessel's energy efficiency including hullform optimization and the effects of incorporating a windshield, air lubrication system, shaft generator, and wind-assisted propulsion.

The project's completion of the vessel concept design development confirms the technical feasibility of large ammonia-fueled container vessels and their ability to achieve acceptable preliminary safety concepts. This has been convincingly demonstrated during the HAZID workshop and risk mitigation process, resulting in an Approval in Principle (AiP) awarded by ABS. Such a milestone boosts confidence in the advancement of the ammonia fuel pathway, unlocking its potential as a viable and eco-friendly option for maritime decarbonization. Nonetheless, despite these promising results, the next design stage demands careful consideration to effectively address the various known challenges and uncertainties that lie ahead, including the importance of human factors and change management in addition to technical safeguards.

For those interested in demonstrating the viability of the ammonia pathway, our concept design can provide an example of what is possible. For those designing ammonia-fueled vessels, we would like to highlight that while a high-level concept design is an important first step, the design and operational details will ultimately deliver a safe vessel. The MMMCZCS has recently published a report describing the results of a multi-disciplinary quantitative risk assessment study that suggests detailed safeguards to mitigate vessel design risks to tolerable levels.[1] While some of these safeguards are clear, other details require further joint industry development and collaboration.

1 Recommendations for Design and Operation of Ammonia-Fueled Vessels Based on Multi-disciplinary Risk Analysis, MMMCZCS and Lloyd's Register, 2023.

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01 Introduction

Ammonia-powered shipping can make a credible contribution to the long-term decarbonization of the shipping sector.[2] While most initial ammonia-fueled vessel design developments have been at small scale[3] or within the gas carrier segment,[4] it is also important to understand application of ammonia as a fuel for large deep-sea oceangoing container vessels.

Using ammonia as a fuel brings challenges, hazards, and opportunities that must be considered during the ship design process. Hazards include the properties of ammonia and its effects on human health (toxicity) and the environment, flammability, explosiveness, and corrosion. The main opportunities and challenges of using ammonia as a marine fuel have been outlined in recent publications from the Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping (MMMCZCS).[5]

In 2022, Seaspan and the MMMCZCS jointly initiated a project to better understand the challenges and opportunities of designing a large ammonia-fueled container vessel. A concept design for a 15,000 twenty-foot equivalent unit (TEU) container vessel was developed in close collaboration with ship designer Foreship and classification society American Bureau of Shipping (ABS). The project included defining the safety objective, assessing the impact of ammonia as a fuel on vessel performance, completion of a hazard identification (HAZID) qualitative risk assessment workshop, and development of a concept design.

The project is connected to the Singapore Ammonia Bunkering Feasibility Study (SABRE) consortium, focusing on developing and demonstrating an ammonia supply chain in Singapore. Phase 1 of SABRE performed an end-to-end technical and commercial feasibility study of ammonia bunkering in Singapore along with a preliminary ammonia bunkering vessel design. Phase 2 is investigating how to mature the commercial feasibility so that contractual terms across the supply chain are prepared and can be executed to establish an ammonia bunkering operation in Singapore.

The 15,000 TEU vessel was designed as a potential receiver of ammonia fuel in Singapore from bunker vessels currently under design and development.

This report presents the results and findings from the concept design development. It covers the design objectives and requirements, including relevant regulations, as well as the development of and decisions made for the general configuration of the design, including power and propulsion, ammonia fuel storage, bunker stations, fuel preparation and vent mast and ventilation. It also discusses the outcome and conclusion of a HAZID workshop, provides fuel consumption and emissions estimates, and calculates preliminary energy efficiency regulatory compliance.

The scope of our project was limited to the vessel design and systems related to ammonia as a fuel. Systems common to conventional container ship designs were omitted. One of the key qualifiers for successful adoption of ammonia as a fuel is application of sound human factors change management.[5] Due to the early stage of the design development, human factors were not directly addressed in detail; however, this will be an important aspect of the next design phase.

The concept design has been developed as a collaboration between the MMMCZCS, strategic partners Seaspan and ABS, and project partner Foreship.

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2 Maritime Decarbonization Strategy 2022: A decade of change, MMMCZCS, 2022.
3 Njovu, G., Amogy's ammonia-powered tug to hit the water in late 2023, Ammonia Energy Association, 2023.
4 Concept Design for Ammonia-Fuel Ready LNG-Fueled Vessel Completed, NYK Group, 2022.
5 Recommendations for Design and Operation of Ammonia-Fueled Vessels Based on Multi-disciplinary Risk Analysis, MMMCZCS and Lloyd's Register, 2023. Nordic Green Ammonia Powered Ships (NoGAPS): Feasibility assessment of an ammonia-fueled gas carrier design, MMMCZCS, 2023. Managing Emissions from Ammonia-Fueled Vessels, MMMCZCS, 2023.

02 Design objectives and requirements

The objective of the project was to assess and analyze the technical, regulatory, and environmental considerations for a 15,000 TEU ammonia-fueled container vessel design. The project scope did not include economic consequences.

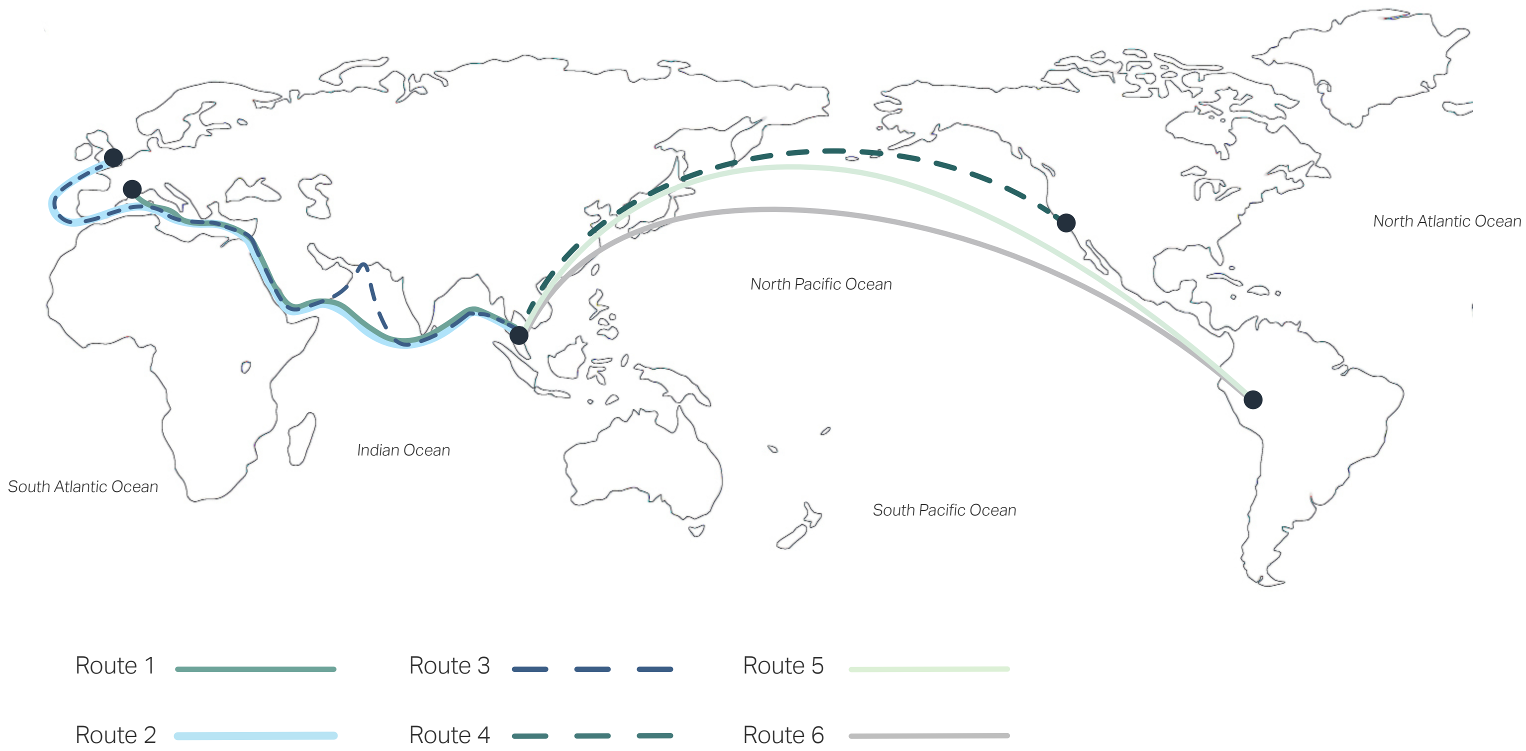
The principal dimensions, tank configuration, and general arrangement of the 15,000 TEU ammonia-fueled container vessel design drew on the experience and knowledge used to develop Seaspan's 23 modern 15,000 TEU vessels from three different series (Figure 1). Two of the series are conventional-fueled designs incorporating the latest hull optimization and energy-saving devices, and one design is Seaspan's first industry-leading liquified natural gas (LNG) dual-fuel design, providing an excellent basis for the ammonia-fueled design development. The first LNG dual-fuel design, ZIM SAMMY OFER, was delivered in April 2023, setting an important milestone in demonstrating Seaspan's commitment to ESG principles, carbon reduction, and developing the fleet through increasingly environmentally friendly technologies.

Figure 1: Seaspan's modern 15,000 TEU conatiner ship designs (source: Seaspan).

Combining the knowledge and experience of the project partners, the following design requirements were defined:

- Capacity: 15,000 TEU (minimum)
- Length between perpendiculars (LBP): approx. 350 m
- Design draft: 15.5 m
- Scantling draft: 17 m
- Design speed: 20 knots (kn)
- Operating speed: 15 kn
- Operational speed profile at scantling draft: 14-16 kn
- Refrigerated container slots: approx. 1,500 (1,000 on deck and 500 in holds)
- Main engine: Dual-fuel (ammonia + low-sulfur fuel oil (LSFO))
- Diesel generators: Dual-fuel (ammonia + LSFO)

Figure 2: Trading routes (source: Seaspan).



The desired range and design and operating speeds of the container vessel have a significant impact on the ammonia-fueled design. These factors determine the basic requirements for the fuel storage tank size, which, in turn, impacts the tank location.

The desired range depends on the specific trade routes the vessel is intended to be used on. Trading patterns were analyzed by Seaspan Corporation based on their knowledge of market volumes (Figure 2), which identified potential trade routes and distances for both single and return voyages with a suitable margin.

Table 1: Endurance analysis for the selected trading routes.

Route	Name	One-way (nm) + 10% margin	Roundtrip (nm) + 10% margin
1	Asia to Mediterranean	7, 758	15,516
2	Asia to Northern Europe	9,327	18,654
3	Asia to Northern Europe + Middle East	11,234	22,468
4	Transpacific	8,831	17,662
5	Transpacific + North and South America	14,549	29,097
6	Asia to South America	13,986	27,972

Based on the selected trading routes, we determined the endurance of the vessel (nautical miles (NM) to be traveled). The intended endurance also considers the availability of ammonia bunkering options for a single journey, assuming ammonia bunkering at both the route origin and destination, and a return journey which assumes ammonia bunkering only at the route origin. Table 1 summarizes the endurance for the six trading routes analyzed.

The trading routes and associated endurance values impact the ammonia storage tank size and, by extension, the tank location options within the vessel's general arrangement. Based on input from the SABRE consortium focused on trade in and out of Singapore, two specific routes out of the original six trading routes analyzed (Table 1) were selected to optimize the vessel design:

– Asia to Northern Europe + Middle East

– Transpacific (west coast of North America or west coast of South America)

Based on the two trading routes selected, we selected a one-way target endurance of 12,000 NM using ammonia and an additional endurance of 12,000 NM using LSFO. The one-way endurance on ammonia was selected to minimize the impact on cargo while assuming an increased availability of ammonia in the future. A higher percentage of LSFO PO could be consumed to increase flexibility and meet extended endurance requirements needed for a period when there is limited global availability of ammonia as a fuel, all whilst remaining compliant with regulatory requirements. An extended 18,500 NM endurance option using ammonia was also developed to allow a roundtrip endurance for the Asia to Mediterranean and Northern Europe routes. Roundtrip endurance can simplify ammonia bunkering operations at one preferred port indefinitely.

03 Rules and regulations

The International Code of Safety for Ships Using Gases or Other Low-flashpoint Fuels (IGF Code) does not currently provide prescriptive requirements for use of ammonia as a fuel. It does, however, provide a mechanism to approve alternative design arrangements for the use of low-flashpoint fuels. The International Maritime Organization (IMO) is currently developing preliminary guidelines and standards to allow ammonia as a fuel while considering the unique risk profile of ammonia, including its toxicity and corrosiveness. Various classification societies have also developed guidelines for using ammonia as a fuel to assist in the alternative design process as outlined in the IGF Code, including ABS.[6]

Recognizing the obvious regulatory gap, the project team adopted compliance in general with industry-leading ammonia guidelines, rules, and industry reports during the execution of the concept design.

The following industry-leading sources were used to provide a suitable guidance framework for the vessel development, ensuring the concept design would be able to obtain an Approval in Principle (AiP) and a sufficiently safe technical design arrangement:

– ABS Requirements for Ammonia-Fueled Vessels (September 2021)

– ABS Rules for Building and Classing Marine Vessels (Marine Vessel Rules) – Part 5C

– Lloyd's Register (LR) Rule proposal No. 2022/CLS005 Specific Requirements for Ships Using Ammonia as Fuel

– IMO IGF Code

As part of the overall design objectives, three main safety objectives were defined based on various requirements for ammonia-fueled vessels. The safety objectives are intended to provide a baseline assumption or initial position from which to assess and verify whether the concept design satisfies the intent of all goals and functional requirements for using ammonia as a fuel. These safety objectives are:

– Restrict ammonia-toxic areas and hazardous areas and minimize exposure time of crew working in these areas to minimize the potential risks that might affect the safety of the persons on board, the vessel, and equipment.

– Arrange for safe and suitable ammonia fuel supply, storage, and bunkering arrangements capable of receiving and containing the fuel in the required state without leakage.

– Design to prevent ammonia venting under all normal and abnormal operating conditions, including idle periods. Venting is only to be conducted in emergency conditions.

6 Requirements for Ammonia Fueled Vessels, ABS, 2022.

04 Risk assessment

The concept design was developed based on partner collaboration and a qualitative HAZID risk assessment workshop. The HAZID workshop was facilitated by ABS and attended by experts from the partner organizations. The aim of the workshop was to improve the concept design of the vessel by identifying potential major safety threats and hazards. This review is an important step in ensuring that the safety concept is acceptable with sufficient time remaining in the design process to incorporate needed design changes. Further details on the scope and process of the HAZID assessment can be found in Appendix A.1.

Pipe rupture of the fuel line from the tank connection space (TCS) to the fuel preparation room (FPR), vessel collision penetrating the storage tank, and damage of ammonia fuel line due to grounding have the most severe consequences and highest risk ratings. These catastrophic events are rare, but the consequences can be severe. The vessel arrangement was carefully considered to mitigate these consequences.

Additional key findings and recommendations from the HAZID workshop included:

– As demonstrated in a recent MMMCZCS report,[7] safety risks associated with leakages or releases are reduced when storing ammonia fully refrigerated as the ammonia leak will form a pool that will evaporate slowly compared to one from pressurized storage.

– The worst credible release volume resulting from rupture of ammonia lines is to be calculated to verify the adequacy of the safeguards once the detailed design has been developed. Pipe design specification must consider abnormal pressure.

– Slow leakage of ammonia is hard to detect and should be considered when designing emergency shutdown systems (ESD) and positioning safety equipment for the crew.

– The risk of ammonia storage tank rupture due to collision or impact can be reduced by positioning the tank under the accommodation and positioned 11.7m (B/5) off the ship's side in accordance with prescriptive rules from the IGF Code, and by adding increased structural steel in this region.

– Ammonia fuel supply line rupture risk due to collision or damage is high if located under the hatch coaming, and risk can be reduced by repositioning the supply line to the pipe duct in the keel.

– The FPR is one of the highest-risk onboard spaces for crew to be present in and requires risk mitigation measures. Separate FPRs outside of the engine room, one for the main engine and one for the auxiliary engines and boiler, can reduce the amount of high-risk equipment in a space to mitigate the risk for crew when in the FPR. High-pressure ammonia equipment is to be segregated and include spray guards to protect crew.

– Hazardous zones, including the FPR and TCS, should have at least two access points to the upper deck and should be well ventilated and equipped with safety equipment.

– Include knockout drum on vent line to ensure liquid ammonia is removed before release from mast.

– Ensure accommodation can remain a safe space for crew in the event of ammonia release.

– Regular crew and personnel training.[7]

– Development of robust and clear procedures.

– Regular audits ensuring systems are in place, understood, and adhered to.

Based on a review of these findings and recommendations, we identified suitable design improvements to ensure the safety of the crew and the vessel. Recommendations were either incorporated into the final concept design or added to a list to be considered in the next design stage. We will also identify and incorporate additional findings and recommendations following ammonia dual-fuel engine development and testing.

7 Recommendations for Design and Operation of Ammonia-Fueled Vessels Based on Multi-disciplinary Risk Analysis, MMMCZCS and Lloyd's Register, 2023.

05 Concept design

This section provides an overview of the main aspects of the concept design and general arrangement unique to using ammonia as a fuel. We present the design's power and propulsion concept, including the planned emissions management approach.
This is followed by a detailed description and analysis of fuel storage tank size and location and other considerations including the location, type, and technologies associated with the TCS, boil-off gas management, bunker stations, fuel preparation, vent mast, and ventilation systems.

5.1 Power and propulsion

The vessel's power and propulsion concept is based on an ammonia dual-fuel two-stroke main engine with a mechanically driven shaft and propeller.
The main engine considered is based on the MAN 7G90ME-C10.5 or WinGD 8X92DF-2.0 engines. Four ammonia dual-fuel auxiliary generator sets (gensets) manage the electrical load onboard: specifically, two 4.1 MW gensets and two 2.7 MW gensets. The auxiliary engines considered are based on the Himsen DF H35DF engine. The concept design will also have an ammonia-fueled auxiliary boiler for onboard heat demand and boil-off gas management.

A key consideration for the ammonia-fueled concept design's regulatory and environmental performance is the expected percentage of pilot fuel needed for the ammonia dual-fuel engines due to ammonia's poor combustion characteristics. The energy content of the pilot fuel, assumed to be LSFO for our analysis, relative to the ammonia energy content used for this analysis was 8% for the main engine and 20% for the auxiliary gensets. As ammonia dual-fuel engines are still under development, pilot fuel requirements are estimated based on engine maker targets and experience from liquified petroleum gas (LPG) dual-fuel engines. Further analysis is recommended, as use of biofuels as pilot fuel could further reduce emissions and improve the regulatory performance of ammonia-fueled vessels.

To minimize fuel consumption and emissions while at sea, a 3 MW shaft generator was studied. Based on a 16-knot speed, the installation of a shaft generator would improve the total efficiency of the vessel and reduce ammonia consumption by around two tonnes/day. However, the associated additional CapEx would need to be considered before including the shaft generator in the design.

A 7.5 MV high-voltage shore connection capability was also included as an option. Shore connection allows connection of the vessel to suitably rated shore power, enabling the shutdown of auxiliary engines and resulting in zero emissions when in port.

5.2 Fuel storage and boil-off gas management

Ammonia as a fuel requires a larger storage tank volume than fuel oil for the same endurance (typically more than three times net volume). Combined with different storage requirements compared to traditional or other alternative fuels, ammonia fuel storage presents unique challenges that were addressed during the concept design study.

The ammonia storage tank solution selected is an insulated IMO Type B tank. An ammonia storage tank size of 11,500 m^3 is required to meet the 12,000 NM endurance requirement including unpumpables, fill-limits, and a safety margin.

Container slot cost (propulsion power per TEU (kW/TEU)) due to fuel storage requirements was used as the main metric for evaluating the suitability of the design arrangement. As part of the assessment, we varied the location of the forward accommodation area to determine if an optimal accommodation-storage tank combination could be achieved.

Moving the accommodation forward meant fewer container slots were lost, while also ensuring that the lifeboats could be safely raised and lowered and that the relative location of the bunker station provided sufficient parallel body line for the bunker vessel.

The location of the storage tank was subjected to multiple iterations, with two principal locations considered and analyzed (Figure 3A):

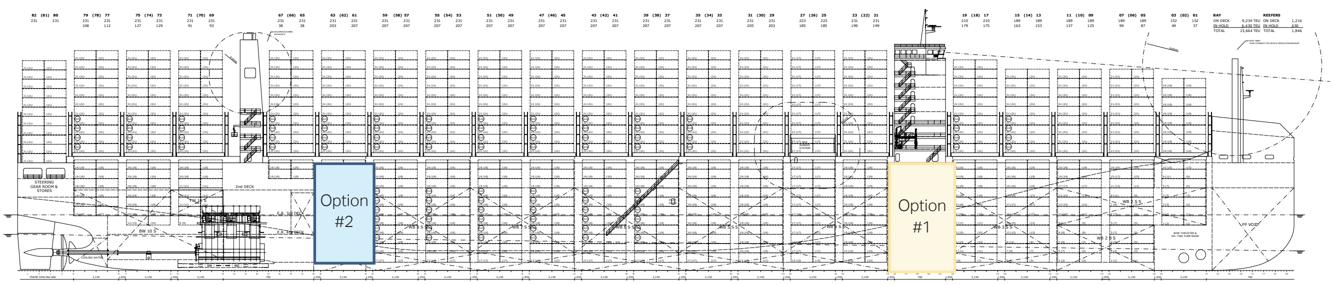
- Option #1 – Under the accommodation
- Option #2 – Forward of the engine room

Option #1 was ultimately selected, as it yielded the optimal nominal TEU capacity and the accommodation provided better protection against tank penetration. The accommodation length was adjusted to ensure sufficient volume was available for the tank.

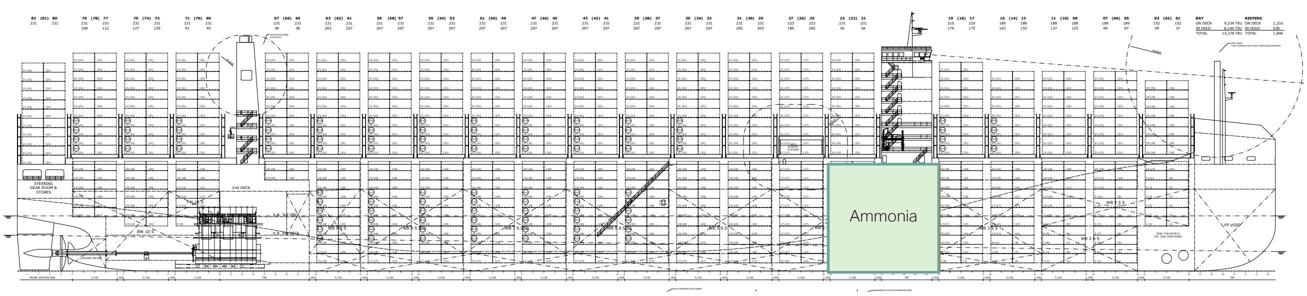
The extended endurance option with 18,500 NM endurance results in a larger storage tank size of 21,000 m^3 that is extended into the container bay aft of the accommodation (Figure 3B).

Figure 3: Ammonia storage tank options and arrangements for (A) baseline and (B) extended endurance.

Baseline endurance storage tank options (A)



Extended endurance storage tank arrangement (B)



The tank geometries and configurations were also analyzed. We initially used a probabilistic approach based on maximizing the storage tank width. The alternative is to design the tank geometry to be more than a 5th of the vessel beam off the ship's side (B/5 criteria) in accordance with prescriptive rules from the IGF Code.

Maintaining the B/5 prescriptive requirement was an important recommendation from the HAZID workshop, which identified that a breach of the ammonia storage tank due to collision or impact is critical and required suitable mitigation. While this tank geometry requires a slightly longer tank, it is still possible to locate the tank entirely under the accommodation without the loss of any additional container slots. Furthermore, the space outboard of the ammonia storage tank is used for LSFO storage tanks, which ensures that all main fuel storage tanks are located under the accommodation. Finally, a cofferdam is included around the ammonia storage tanks. Figure 4 provides a section view of the fuel storage tank area below the forward accommodation area, with further details on the tank geometries and configuration.

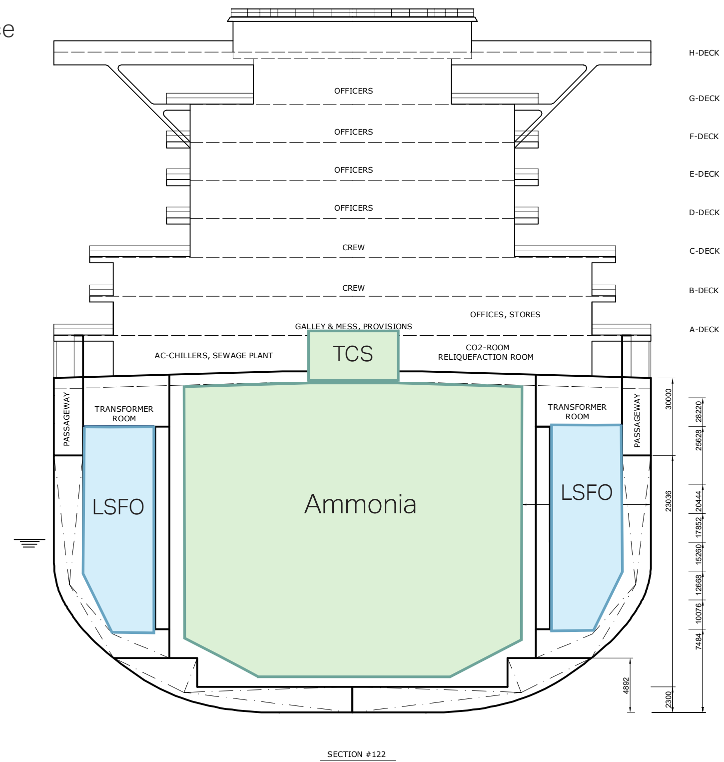
The ammonia storage tank is equipped with two deep well pumps (one for backup), which transfer the liquid ammonia to the fuel supply system in the FPR for both the main and auxiliary engines.

The TCS is the space surrounding the ammonia storage tank connections and tank valves from the bunker lines, fuel supply lines, and tank ventilation lines. The TCS also contains the electric motors for the deep well fuel pumps, along with a dedicated area to facilitate the extraction of the deep well pump head for maintenance and repair.

The TCS, which is located directly above the ammonia tank, is categorized as a hazardous area and is normally unmanned (see Figure 4 and Figure 5). The TCS is gas- and liquid-tight to contain potential liquid and gas ammonia leaks. The TCS is accessible via an air lock from the open deck aft of the accommodation and provided with suitable means of escape.

Figure 4: Section view showing ammonia and LSFO storage tank arrangement.

TCS - tank connection space
LSFO - low-sulfur fuel oil



As a safety measure, a water screen shall be provided at the access to the TCS. The TCS will also be provided with:

- Fixed fire and gas detection
- Fixed drip trays under all skids
- Dedicated mechanical ventilation
- ESD system (manual and automatic)
- Audible and visible alarms
- Safety shower and eye wash

According to the IGF Code, storing ammonia in tanks that are not fully pressurized requires two independent means of managing the boil-off gas (BOG) to provide a redundant solution. BOG caused by the heat penetration from the IMO Type B tank during operation is inevitable. The fuel tank pressure should be effectively managed by maintaining low temperatures. The amounts of BOG generated during voyages are determined based on evaporation losses, which can also play a vital role in the economics of ammonia-fueled vessels.

Ammonia BOG management techniques and technologies are either already commercially available, such as reliquification, or under development. These technologies are typically based on existing maritime concepts that are adapted to ammonia as a fuel, including gas combustion units (GCUs), catalysts, and water catchers/chemical absorbers.

Given the low maturity of many technical solutions for ammonia BOG management, the project completed a qualitative assessment of the following BOG management technologies:

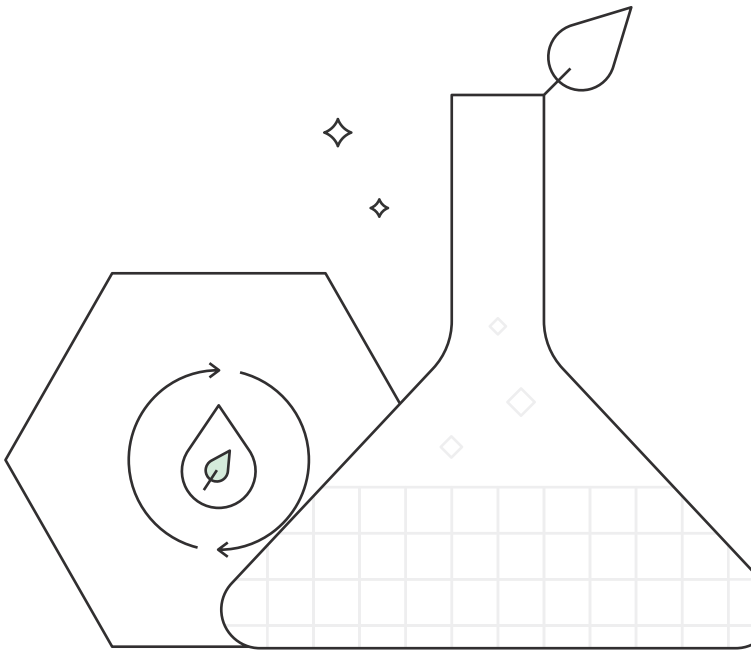
1. Reliquification plant
2. GCUs
3. DF auxiliary boiler

Reliquification is a proven technology currently used on gas carriers that carry ammonia as cargo. As a closed system, reliquification ensures that the ammonia BOG is recaptured and put back into the storage tank without any other emissions. Recapturing the ammonia BOG also mitigates the potential fiscal impact of ammonia fuel losses. Reliquification plants, however, have high capital and operational expenditures (CapEx and OpEx), high maintenance demand, and a large footprint.

GCUs are simple units that manage ammonia BOG by combusting it. They have low CapEx and OpEx and limited maintenance demand. However, pilot fuel might be required to improve combustion, and GCUs will have their own associated GHG emissions, potentially including CO_2 from the pilot fuel as well as ammonia and ammonia combustion byproducts such as NO_X or N_2O. Aftertreatment may be required, and challenges associated with toxicity, corrosiveness, slow ignition, and GHG emissions would need to be resolved.

To capture the waste heat from burning the BOG, a DF auxiliary boiler could be used in place of the GCU. However, the BOG supply might result in an inadequately sized boiler or generation of heat when it is not needed.

Our qualitative assessment of these solutions consisted of assigning scores to the various combinations for BOG management based on CapEx, OpEx, environmental impact, and level of future-proofing. The recommended BOG management solutions based on the assessment were to have one reliquification plant and a connection to the auxiliary boiler. The proposed reliquification system adopts the vapor compression cycle with the ammonia refrigerant. The reliquification plant has been placed in a separate room with dedicated ventilation located adjacent to the TCS.



5.3 Bunker stations

The ammonia bunker stations are located two bays aft of the accommodation (Figure 5), arranged at port and starboard sides and ensuring that the parallel body line is sufficient to ensure proper contact with a bunker vessel. This arrangement provides the shortest possible bunker line while still maintaining the required hazardous zone separation from the accommodation entrances and air inlets.

The bunker station is designed as a semi-enclosed type with the open side towards the bunker vessel. The bunker station location results in the loss of one container row in the hold due to the width of the station. The bunker station deckhead shall be reinforced to provide protection from dropped objects, which in the worst-case scenario could be a fully laden container.

The bunker station, including fuel bunkering and transfer systems, is designed to be compatible with the following bunker vessel interface:

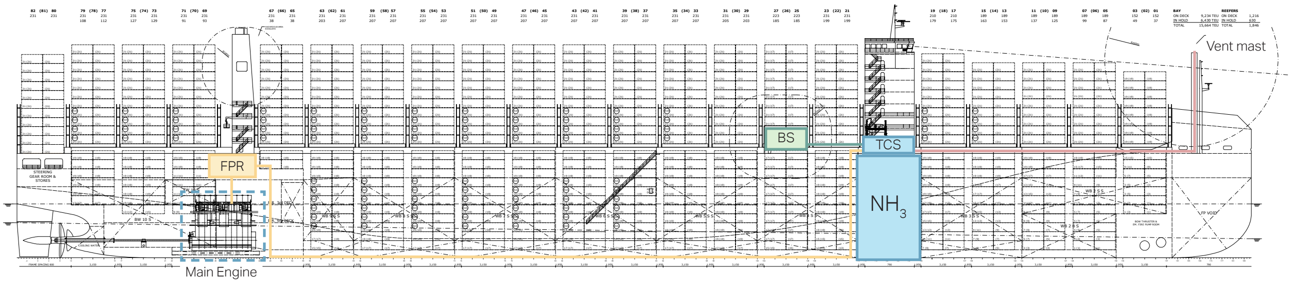
- Maximum 8-inch hose connections
- Three 8-inch supply connections
- One 8-inch vapor return
- Bunker capacity: 2,000 m^3/hour (subject to future safety review)

Each bunker station will also be provided with:

- Safety shower with eye wash
- Fixed fire and gas detection
- Fixed drip trays under all bunker line skids
- Dedicated fixed drain tank and system, designed to contain scrubbing water and spills from drip trays
- ESD system
- Closed-circuit television (CCTV) system
- Audible and visual alarms
- Two means of escape
- Dedicated mechanical ventilation
- Water curtain system

The water curtain system is provided to limit dispersion of ammonia gas or liquid due to major leaks and incidents. The water curtain system shall be capable of being activated manually or automatically based on ammonia leak detection.

Figure 5: General arrangement of the baseline endurance vessel.



NH_3 - Ammonia
TCS - Tank connection space
BS - Bunker station
FPR - Fuel preparation room

The fuel bunkering and transfer system is broadly based on proven systems for LPG/LNG fuel systems. The fuel bunkering and transfer system shall be equipped with all mandatory and applicable control and instrumentation functions including level, flow, pressure, temperature monitoring, alarm, and operational safety. These instrumentation devices are subject to further detailed design.

In addition, automatic shutdown of the bunker manifold ESD valves shall be activated via any of the applicable monitoring and safety functions, such as gas detection at the bunker station.

The bunkering manifold interface is designed as a quick connect/disconnect liquid- and pressure-tight dry break coupling. The couplings shall have a valve arrangement that shuts down the ammonia liquid flow prior to the disconnection of the male and female couplings. The couplings cannot be disconnected while under flow condition.

A vapor return line is included in the design, and it is required for the bunker vessel to provide this. Further work is needed to better understand whether:

- The BOG management system installed is rated sufficiently to manage bunker vapor.

- The vessel has the ability via other means to manage the vapor pressure created by the BOG.

- Ammonia is supplied in such a way that BOG is cooled down with the generated vapor.

Bunker lines are provided with the ability to be pressure-tested to ensure that all lines are free from damage or potential leakage points. Bunker lines are arranged for inerting and gas freeing.

5.4 Fuel preparation room

The FPR contains all the relevant equipment for fuel preparation and supply purposes, including fuel pumps, fuel valve trains, heat exchangers, filters, knock out drums, and ammonia release mitigation systems. The FPR is located as close as possible to the main and auxiliary engines to reduce the route length of ammonia piping.

All ammonia pipework not contained in secondary enclosures designed to safely manage ammonia leaks shall be of double-walled type, with leak detection provided for the inner pipe. The solution chosen for this concept design is to allow for the space between the inner and outer pipe to be continuously ventilated and provided with gas detection to detect any traces of ammonia.

The longest route of double-walled piping will be from the forward ammonia storage tank and TCS to the aft FPR. This route will be installed inside the existing duct in the double bottom. The FPR is located directly above the engine room, and the fuel piping from the TCS passes through the engine room.

The FPR is split into two separate spaces: main engine FPR and auxiliary engine and boiler FPR. Each space is accessed from air locks accessible from the open deck. The FPRs are considered hazardous spaces and are normally unmanned. The FPRs are separated by gas-tight bulkheads and decks and the ventilation systems are designed to maintain the space at an under pressure relative to surrounding spaces.

The FPR is designed to contain a leak of liquid or gaseous ammonia. The FPR spaces are provided with an independent bilge system leading to independent holding tanks to enable safe processing and disposal of leaked ammonia once ashore. The FPRs are additionally provided with two widely separated means of access and escape, with water screens provided above access doors.

Each FPR will also be provided with:

- Safety shower with eye wash
- Fixed fire and gas detection
- Fixed drip trays under all equipment skids
- ESD system
- Audible and visual alarms
- Dedicated mechanical ventilation (normal and emergency)
- Low oxygen level detection and alarms
- CCTV system

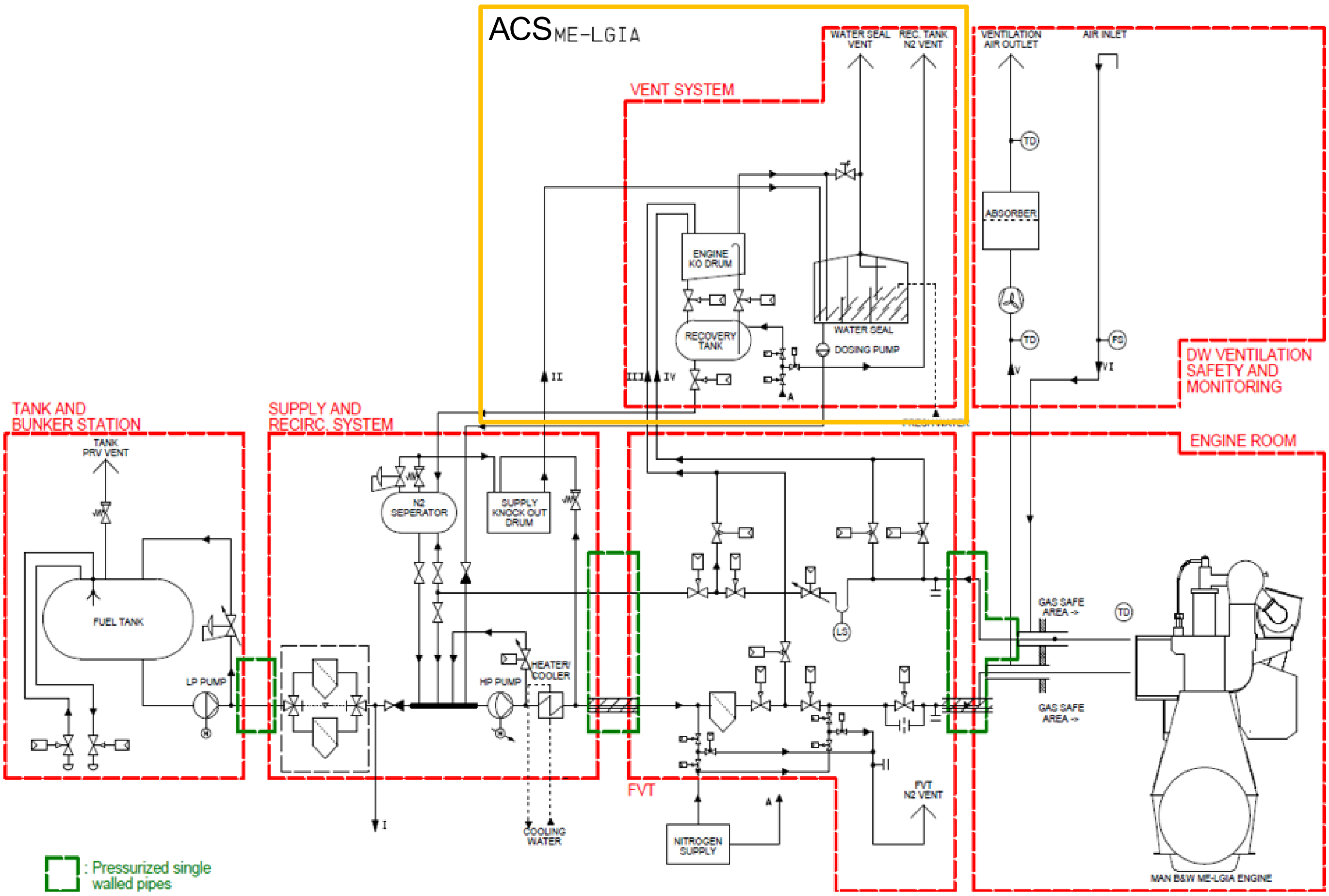
The main components of the fuel supply system (FSS) for the main and auxiliary engines and boiler are in the FPRs. The FSS will resemble the proven systems for LPG/LNG fuel supply systems. The FSS for the main engine is based on available published literature for the MAN B&W two-stroke engine designed to operate on ammonia[8] (see Figure 6).

The FSS contains the equipment necessary to ensure that ammonia fuel is delivered to the engine(s) at the required temperature, pressure, and quality. FSS equipment includes a recirculation system, a fuel valve train (FVT) system, a nitrogen system, a ventilation system, and an ammonia catch system (knock out drum). The FSS is separated into one low-pressure side and one high-pressure side. The low-pressure side comprises the fuel storage tank, TCS, and fuel supply pumps. The high-pressure side is designed to supply liquid ammonia to the engine(s).

During ammonia engine operation, the ammonia fuel supply comes from the storage tanks via the FSS. To maintain the required fuel conditions, a small portion of the ammonia fuel continuously recirculates within the FSS via the recirculation system.

8 Engineering the future two-stroke green-ammonia engine, MAN Energy Solutions, 2019.

Figure 6: MAN B&W ammonia fuel supply system (source: MAN Energy Solutions).



The FVT is the interface between the engine and the FSS auxiliary systems. The FVT ensures safe isolation of the engine during shutdown and maintenance and provides a nitrogen purging functionality to neutralize the system after shutdown.

The ammonia catch system is provided to prevent release of ammonia to the environment. Ammonia water catchers/chemical absorbers can treat ammonia emissions from fuel systems. This is an important feature due to the ammonia safety concerns onboard vessels.

Water catchers can treat ammonia releases resulting from purging and venting operations, emergency operations, and shutdowns. As an additional safety measure, double-walled piping is used inside the engine room between the FSS and engine.

The FSS for the auxiliary engines and boiler is based on the same concept as the main engine ammonia FSS. The pressure requirements will be confirmed by the auxiliary engine designers.

5.5 Vent mast and ventilation systems

Effective mechanical ventilation and venting arrangements of the spaces where ammonia is used and stored are necessary to ensure that the safety objectives are met. For this project, the vent systems are designed to minimize the gas released to open space and facilitate dispersion into the open atmosphere. Primary concerns when venting ammonia include toxicity levels, flammability levels, and ensuring acceptable distance from the vent mast riser and riser location.

In this concept design, we propose that the vent mast shall be located at the front of the vessel and arranged at least 25 meters from the nearest air intake, outlet, or opening to accommodation spaces. All accommodation windows facing the vent mast location shall be fixed type (non-opening).

Additionally, two independent vent lines are provided, one routed port side and one routed starboard side, under the hatch cover to the vent riser location at the front of the vessel. The vent mast will also be provided with fixed ammonia gas detection to detect an ammonia venting occurrence.

In terms of ventilation, we considered three main situations:

– Emergency release of ammonia: In case of fire, or any other operational malfunctions, and where the pressure inside the ammonia storage tank increases and exceeds the set safety pressure, the overpressure should be released through the vent mast.

– Operational releases: Releases from handling ammonia onboard must be appropriately managed to ensure that ammonia concentrations in the air are below acceptable limits.

– Mechanical/forced ventilation of spaces containing ammonia equipment: All spaces containing ammonia-handling equipment, and where there is an increased risk of potential leakages (e.g. valves, joints, seals), shall be continuously ventilated via dedicated independent mechanical ventilation systems. As there are spaces that require forced ventilation both forward (TCS, reliquification) and aft (FPR, engine room) of the vessel, it is desirable to have a combined ventilation exhaust for all the equipment. This simplifies the number of hazard zones on the vessel.

06 Fuel consumption and emissions

As part of the concept design development, we assessed the emission risks of ammonia dual-fueled vessels and defined an approach to manage the resulting emission risks of our concept design. We also estimated the vessel's fuel consumption and associated GHG emissions, as well as calculated preliminary estimates of the vessel's ratings under the energy efficiency regulations Energy Efficiency Design Index (EEDI) and Carbon Intensity Indicator (CII). These estimates are helpful for understanding fuel needs and potential fuel-related OpEx, as well as the vessel's expected environmental impact and regulatory compliance.

6.1 Emission risks

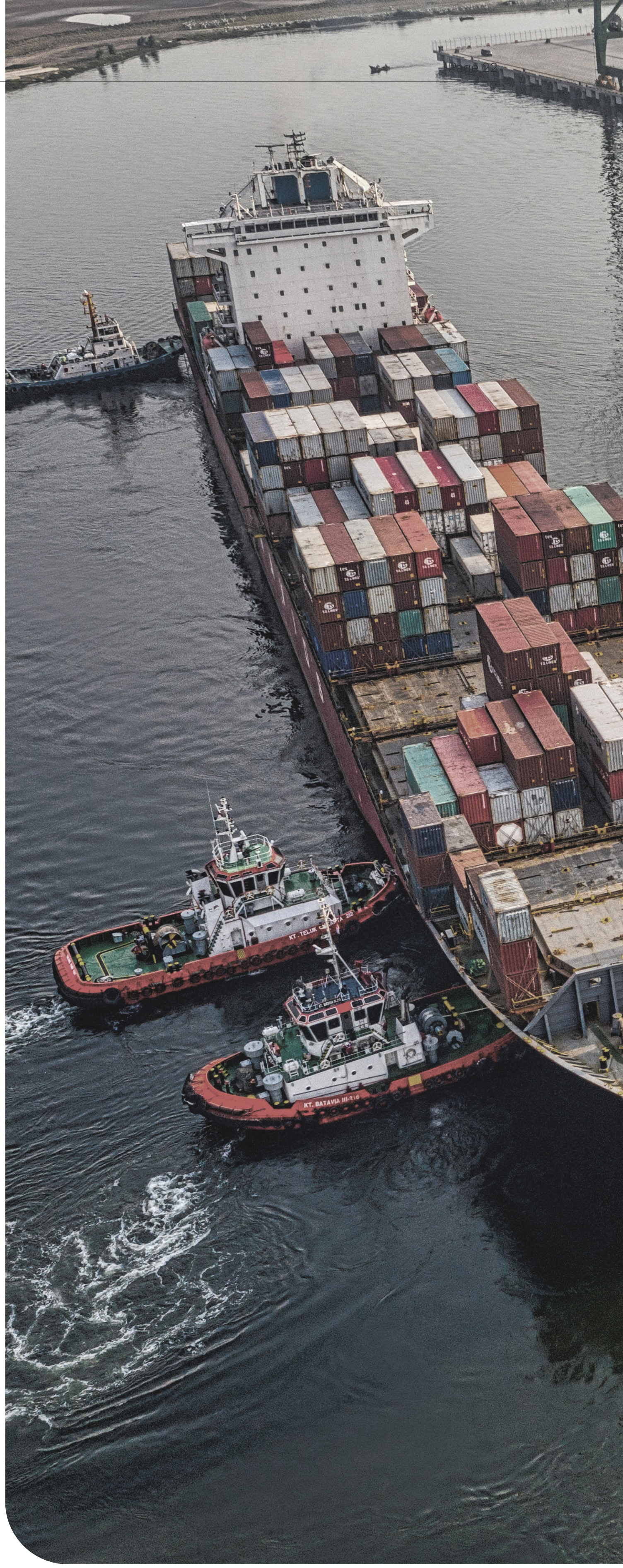
Specific GHG and air pollutant emission levels from ammonia-fueled vessels, including combustion consumers, are still largely unknown. However, particular attention needs to be paid to the potential presence of ammonia slip as well as nitrous oxide (N_2O) and nitrogen oxides (NO_X) emissions resulting from the imperfect combustion of ammonia and the use of pilot fuels. If present, these emissions will need to be kept as low as possible, and any progress regarding this goal will only be confirmed after further development of ammonia dual-fuel engines.

Ammonia slip, N_2O, and NO_X emissions can be generated from the main engine, auxiliary engines, and boiler. These emissions may require reduction using suitable technologies, which are available with varying levels of maturity and outlined in a recent MMMCZCS publication.[9]

Owing to the lack of technical maturity, a space allowance has been made in the concept design for future development of suitable emissions management technologies. It is assumed that existing selective catalytic reduction (SCR) technology can reduce NO_X emissions to compliant levels, and that ongoing engine and treatment technology development will find solutions to manage N_2O emissions.[9] Any ammonia slip from the engine is also expected to be utilized within the SCR as a NO_X reducing agent.

In addition to emissions to air, ammonia liquid solutions can result when ammonia meets water. Hazardous zones are to have a dedicated ammonia drain tank to capture ammonia spillages and aqueous ammonia. Ammonia solutions are expected to be consumed in the main engine, where possible, or consumed in a GCU when the concentration becomes critical.

9 Managing emissions from ammonia-fueled vessels, MMMCZCS, 2023.



6.2 Fuel consumption and emissions calculations

For the fuel consumption and emissions calculations, we defined three operating scenarios:

1. At sea, no refrigerated containers

2. At sea, 50% of refrigerated containers onboard (750 containers)

3. At sea, 100% of refrigerated containers onboard (1,500 containers)

For each operating scenario, we calculated the propulsion power required, refrigerated container electrical load, base electrical load, and resultant total energy required at multiple speeds. In addition to at-sea calculations, we calculated fuel consumption for maneuvering and in-port scenarios based on the vessel's expected hours at sea, maneuvering, and in port.

The electrical load associated with refrigerated containers has a significant impact on the load balance and power demand. Refrigerated containers are placed in the hold and on deck as follows:

– In-hold: maximum 500 containers, 6kW load including in-hold cooling fans, three conditions are considered as mentioned above

– On-deck: maximum 1,000 containers, 4.5kW load, three conditions are considered as mentioned above

The resultant total energy required is equal to the specific fuel oil consumption of the main and auxiliary engines. The engine performance and emissions data were based on available published engine maker literature and other DF engine characteristics.

Table 2 provides the preliminary estimated fuel consumption for the ammonia dual-fuel concept design based on the baseline endurance of 12,000 NM, as well as the fuel consumption for the vessel operating in monofuel mode using LSFO.

Table 2: Preliminary fuel consumption (tonne) for 12,000 NM baseline endurance.

Operating scenario	Dual-fuel: ammonia (NH_3) + LSFO (tonne)							
	15 kn		16 kn		18 kn		20 kn	
	NH_3	LSFO	NH_3	LSFO	NH_3	LSFO	NH_3	LSFO
At sea, no refrigerated containers	5,250	240	5,840	260	7,260	310	9,050	370
At sea, 50% of refrigerated containers onboard	6,580	360	7,100	380	8,370	410	10,870	460
At sea, 100% of refrigerated containers onboard	7,680	470	8,120	470	9,280	500	10,870	540

Operating scenario	Monofuel: LSFO (tonne)			
	15 kn	16 kn	18 kn	20 kn
At sea, no refrigerated containers	2,670	2,960	3,660	4,560
At sea, 50% of refrigerated containers onboard	3,410	3,660	4,280	5,110
At sea, 100% of refrigerated containers onboard	4,020	4,230	4,790	5,570

Table 3 summarizes the preliminary estimated fuel consumption for the ammonia dual-fuel concept design based on the extended endurance of 18,500 NM.

Table 3: Preliminary fuel consumption (tonne) for the 18,500 NM extended endurance design.

Operating scenario	Dual-fuel: ammonia (NH_3) + LSFO (tonne)							
	15 kn		16 kn		18 kn		20 kn	
	NH_3	LSFO	NH_3	LSFO	NH_3	LSFO	NH_3	LSFO
At sea, no refrigerated containers	8,090	370	9,000	400	11,190	470	13,950	570
At sea, 50% of refrigerated containers onboard	10,150	560	10,940	580	12,900	630	15,500	710
At sea, 100% of refrigerated containers onboard	11,830	720	12,520	720	14,310	760	16,760	830

The vessel's greenhouse gas (GHG) emissions can subsequently be calculated based on its fuel consumption. Quantification of the vessel's GHG emissions are required for several regulations, including emissions reporting as well as demonstration of EEDI and CII compliance. There is currently no explicit provision for the direct use of an ammonia emissions factor in EEDI and CII calculations; however, this is expected to change as these regulations are updated. For our analysis of EEDI and CII compliance, the emissions factor for ammonia was assumed to be zero. We also assumed that the vessel generates no methane or N_2O emissions. Actual emission levels will be better understood after engine development is complete.

The preliminary EEDI rating for the ammonia dual-fuel vessel is 4.68, which is about 44% lower than the required Phase 3 level that is currently in force for container ships. This result indicates that if the current EEDI calculation formula is maintained, allowing for the primary fuel to be used to impact the attained rating, ammonia dual-fuel vessels will likely comply with EEDI requirements for Phase 3 and potentially also future phases. For reference, the EEDI rating when using only LSFO would be around 7.2, which is also below the Phase 3 level indicating an efficient baseline ship design.

To obtain the CII value for the different operating modes and ship speeds, we calculated total annual CO_2 emissions. CII is calculated by dividing the total annual CO_2 emissions by the vessel's transport work (vessel capacity multiplied by total distance traveled). Table 4 provides the preliminary CII calculation for the dual-fuel operating scenarios and four operating speeds.

If operating using only LSFO, the CII rating would be C or lower depending on the operating scenario and speed. Ratings below C would require improvement actions such as the use of energy effiicency initiatives or the introduction of alternative fuel use.

The 2023 CII rating for all operating scenarios and ship speeds is A, which is the highest possible rating. This rating is achieved since ammonia generates zero CO_2 emissions, and therefore the vessel's only remaining CO_2 emissions are from combustion of pilot fuel used in the main and auxiliary engines. If N_2O emissions are not able to be eliminated, they should be incorporated into CO_2-equivalent emissions calculations.

While enforcement of CII compliance is still evolving, owners of vessels with good CII ratings are expected to gain some market benefits including:

- Better charter rates from sustainability-conscious companies
- Preference for inclusion in green and sustainable investment portfolios
- Better financing conditions than vessels with worse ratings
- Being a preferred option for long-term charters
- Potentially a better capability to demonstrate higher speed and flexibility

With an A rating achieved using ammonia as a fuel, the concept design minimizes regulatory compliance risks while also presenting business opportunities for the vessel owner.

Table 4: Preliminary CII calculation and 2023 rating (ammonia).

Operating scenario	Dual-fuel: ammonia + LSFO CO_2 emissions (tonne) and CII value							
	15 kn		16 kn		18 kn		20 kn	
	CO_2	CII	CO_2	CII	CO_2	CII	CO_2	CII
At sea, no refrigerated containers	9,140	0.673	9,847	0.680	11,629	0.714	14,046	0.776
At sea, 50% of refrigerated containers onboard	11,544	0.741	12,251	0.744	14,033	0.771	16,450	0.827
At sea, 100% of refrigerated containers onboard	13,511	0.778	14,218	0.778	16,000	0.801	18,417	0.854

07 Conclusions and future work

The vessel concept design development completed during this project demonstrates that large ammonia-fueled container vessels are technically feasible and can achieve acceptable preliminary safety concepts. This has been supported throughout the HAZID workshop and risk mitigation process, culminating in an AiP awarded by ABS.

The project has also identified opportunities and challenges associated with designing a large ammonia-fueled container vessel. Opportunities include:

– Reduced risk associated with leakages or releases when storing ammonia fully refrigerated. Safety should be increased.

– Optimization of ammonia storage tank location, volumes, and the vessel's endurance to minimize container slot loss and risk of tank penetrations.

– Sufficient space for defined hazardous zones, separate spaces for ammonia-related equipment, and multiple access/egress points.

Known challenges and unknowns remain and require careful consideration as part of the next design stage, as summarized in Table 5.

Table 5: Known challenges and recommendations for future design of large ammonia-fueled vessels.

Challenge	Recommendation
Understanding impacts of ammonia leakage and release scenarios to minimize risks to crew onboard.	- All ammonia-fueled vessel designs currently being developed should conduct gas dispersion analysis for multiple scenarios to inform design decisions. - Use of quantitative risk assessment analysis in the next design phase to assess risks and potential mitigation measures in detail.
Understanding actual emission profiles, pilot fuel requirements, and safety implications of ammonia dual-fuel engines and associated equipment. Ammonia-related greenhouse gas emissions risks include ammonia slip, nitrogen oxides, and nitrous oxide.	- Monitor the development and testing of ammonia dual-fuel engines and associated equipment to better understand emissions risks and how to mitigate any identified risks. - Incorporate relevant technologies and information into future ammonia-fueled vessel designs.
While ammonia dual-fuel engines get the most attention, many other onboard systems also require development and proper and safe design integration. These systems include boil-off gas (BOG) management solutions, ventilation concepts of spaces with ammonia-containing equipment, fuel supply system including ammonia recovery and knock out drum usage, and ammonia water solution storage and treatment.	- Further development of auxiliary and supporting ammonia-related technologies for application on board vessels.
Not all risk mitigation measures could be incorporated into the concept design due to its early stage of development.	- Follow up and further develop the risk mitigation measures identified in HAZID reviews and, for our project, documented in the ABS approval in principle letter that are relevant for the more detailed design stage.
While the focus of the development has been on ammonia as a fuel, due to the expected price premium relative to conventional fuels, ammonia fuel consumption and associated operational expenses should be minimized.	- Optimize the vessel's energy efficiency including hullform optimization and the effects of incorporating a windshield, air lubrication system, shaft generator, and wind-assisted propulsion.

In addition to purely design-related considerations, initial stages of ammonia-fueled vessel development projects should also include an assessment of bunkering and port operations. Compatibility with a potential bunker vessel needs to be understood, including the vessel interface and bunkering equipment. Societal risk from bunkering operations within populated port areas also needs to be considered, and implications of this could lead to ship design changes. The ability to conduct simultaneous bunkering and cargo operations will also impact how ammonia-fueled vessels can operate, at least in the initial stages of their introduction.

The project team will continue to engage with the SABRE consortium and other projects to ensure bunkering and port operations are addressed from an early stage of the vessel design process, to minimize operational risks once the vessel is introduced.

The completion of our concept design development and awarding of an AiP demonstrates that large ammonia-fueled container vessels are technically feasible and can achieve acceptable preliminary safety concepts. This demonstration increases confidence in the maturation of the ammonia fuel pathway to unlock ammonia as a viable fuel that can contribute to maritime decarbonization. While our results are promising, careful consideration is required as part of the next design stage to manage the identified multiple known challenges and unknowns.

Profile cutaway - baseline endurance

Profile cutaway - extended endurance

Project team

This report was prepared by Seaspan and the MMMCZCS based on a Foreship report and with assistance from our partners.

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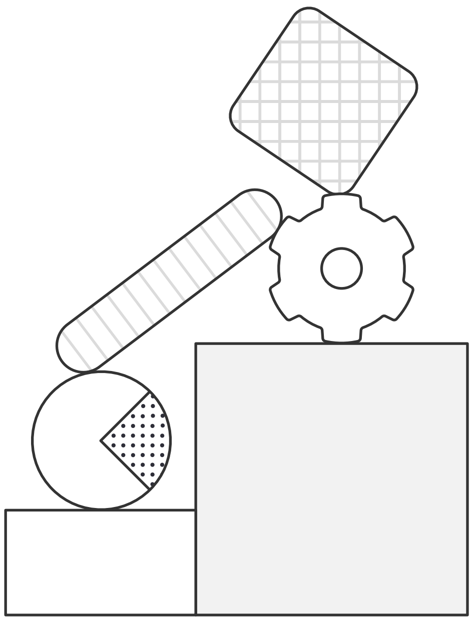


Abbreviations

ABS	American Bureau of Shipping
BOG	Boil-off gas
CII	Carbon Intensity Indicator
CO_2	Carbon dioxide
EEDI	Energy Efficiency Design Index
ESD	Emergency shutdown system
FPR	Fuel preparation room
FSS	Fuel supply system
FVT	Fuel valve train
FWD	Forward
GCU	Gas combustion unit
GHG	Greenhouse gas
IEC	International Electrotechnical Commission
IGF Code	International Code of Safety for Ships Using Gases or Other Low-flashpoint Fuels
kn	Knots
kW	Kilowatts
LBP	Length between perpendiculars
LNG	Liquified natural gas
LPG	Liquified petroleum gas
LSFO	Low-sulfur fuel oil
MW	Megawatt
NH_3	Ammonia
NM	Nautical mile
NO_X	Nitrogen oxides
SO_X	Sulfur oxides
TCS	Tank connection space
TEU	Twenty-foot equivalent unit

Appendix

A.1 HAZID Workshop

The HAZID workshop for this project was facilitated by ABS and attended by experts from the partner organizations. A preliminary concept design was deemed sufficiently mature to be used as a basis for the assessment. The HAZID workshop evaluated the risks, defined risk composition, and identified dominant risk contributors, providing a basis and groundwork for further research, risk studies, engineering analyses, and rules development activities. The review also allowed for experience and knowledge to be shared between the main partners in the project.

The critical nodes, or systems, related to the ammonia-fueled aspects of the vessel design were selected for the HAZID assessment. Systems common to conventional container ship designs were omitted.

The HAZID nodes (Figure 7) included:

- Bunkering station(s) arrangement
- Fuel storage tank
- Fuel system/preparation
- Fuel reliquification/vapor handling
- Engine room arrangement/safety concept
- Vent/vent lines/vent mast
- Safety systems: fire and gas detection, firefighting, water mist

Focus areas of each HAZID node are also provided in Figure 7.

Figure 7: HAZID nodes and focus areas.

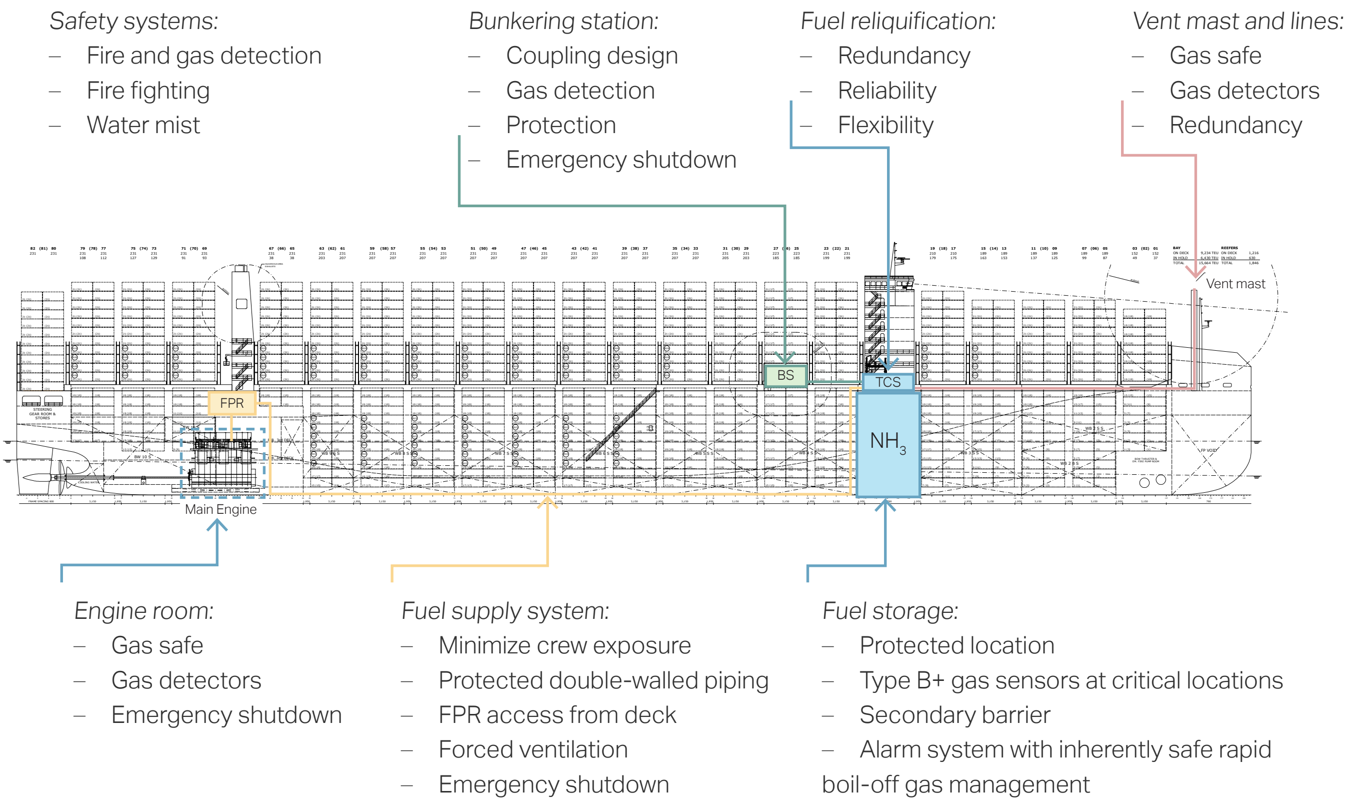
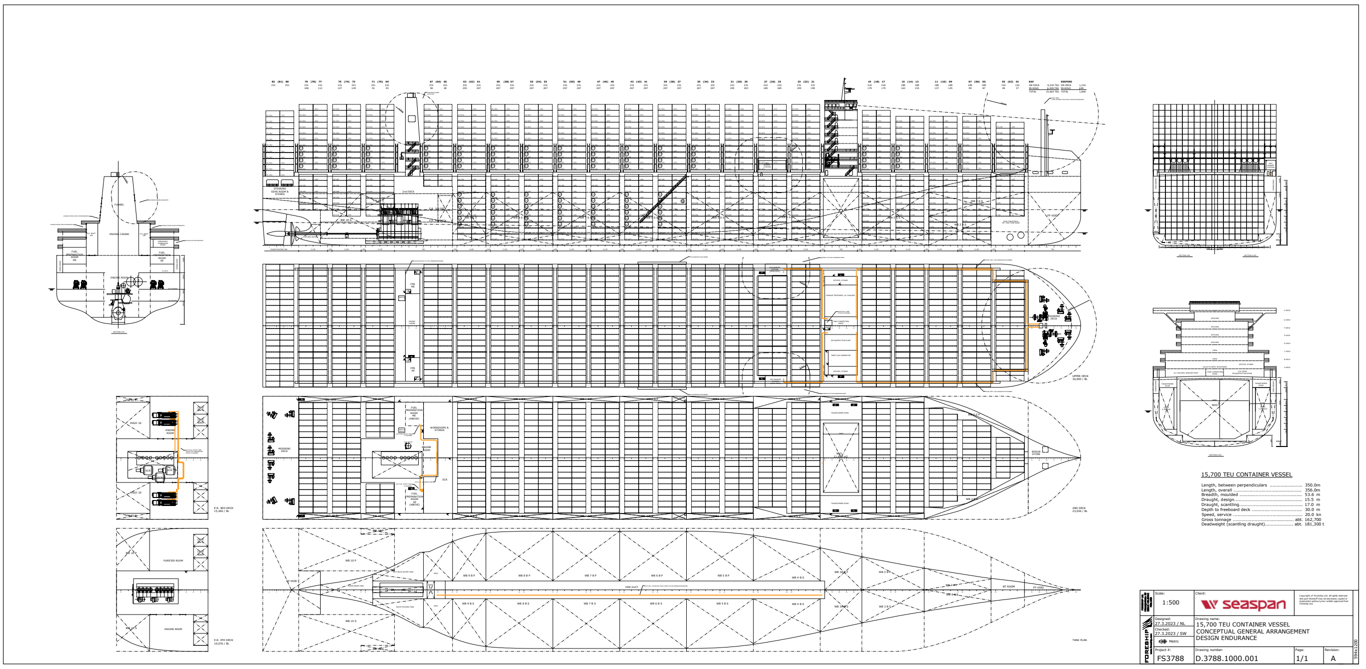


Table 6 provides the risk matrix used, provided by ABS, and an overview of the distribution of risks based on their probability and consequence ratings from the HAZID workshop. The number within the 5x5 matrix indicates the number of risks with that rating.

Table 6: Summary of HAZID risk ratings.

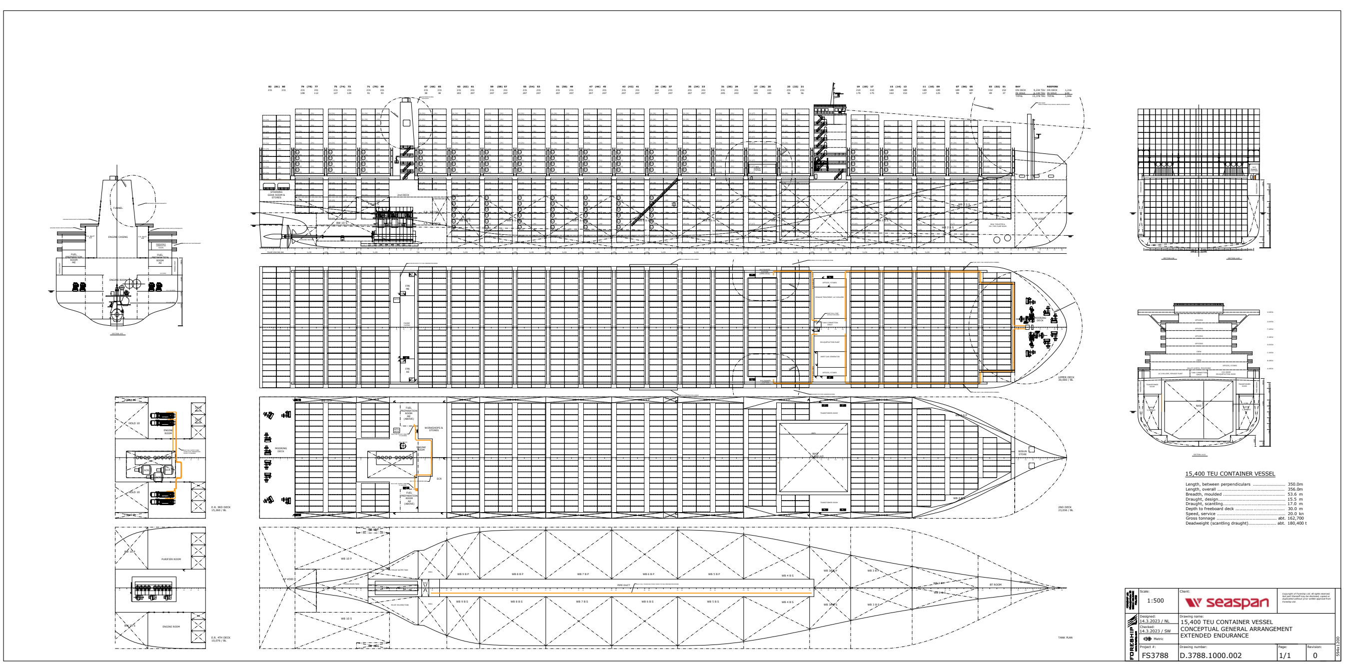
Category				Consequence				
Asset				No shutdown, costs less than $10,000 to repair	No shutdown, costs less than $100,000 to repair	Operations shutdown, loss of day rate for 1-7 days and/or repair costs of up to $1,000,000	Operations shutdown, loss of day rate for 7-28 days and/or repair costs of up to $10,000,000	Operations shutdown, loss of day rate for more than 28 days and/or repair more than $10,000,000
Environment				No lasting effect. Low level impacts on biological or physical environment. Limited damage to minimal area of low significance.	Minor effects on biological or physical environment. Minor short-term damage to small area of limited significance.	Moderate effects on biological or physical environment but not affecting ecosystem function. Moderate short-medium term widespread impacts e.g., oil spill causing impacts on shoreline.	Serious environmental effects with some impairment of ecosystem function e.g., displacement of species. Relatively widespread medium-long term impacts.	Very serious effects with impairment of ecosystem function. Long term widespread effects on significant environment e.g., unique habitat, national park.
Community/Government/Media/Reputation				Public concern restricted to local complaints. Ongoing scrutiny/ attention from regulator.	Minor, adverse local public or media attention and complaints. Significant hardship from regulator. Reputation is adversely affected with a small number of site focused people.	Attention from media and/ or heightened concern by local community. Criticism by NGOs. Significant difficulties in gaining approvals. Environmental credentials moderately affected.	Significant adverse national media/ public/ NGO attention. May lose license to operate or not gain approval. Environment/ management credentials are significantly tarnished.	Serious public or media outcry (international coverage). Damaging NGO campaign. License to operate threatened. Reputation severely tarnished. Share price may be affected.
Injury and disease				Low level short-term subjective inconvenience or symptoms. No measurable physical effects. No medical treatment required.	Objective but reversible disability/impairment and/ or medical treatment, injuries requiring hospitalisation.	Moderate irreversible disability or impairment (<30%) to one or more persons.	Single fatality and/ or severe irreversible disability or impairment (>30%) to one or more persons.	Short- or long-term health effects leading to multiple fatalities, or significant irreversible health effects to >50 persons.
				Low	Minor	Moderate	Major	Critical
				1	2	3	4	5
Likelihood	Occurs 1 or more times a year	Almost certain	E	0	0	0	0	0
	Occurs once every 1-10 years	Likely	D	1	1	1	0	0
	Occurs once every 10 -100 years	Possible	C	17	11	9	0	0
	Occurs once every 100 - 1,000 years	Unlikely	B	17	19	23	12	0
	Occurs once every 1,000 - 10,000 years	Rare	A	1	13	26	13	4
Action key	Low			No action is required, unless change in circumstances				
	Moderate			No additional controls are required, monitoring is required to ensure no changes in circumstances				
	High			Risk is high and additional control is required to manage risk				
	Extreme			Intolerable risk, mitigation is required				

A.2 General arrangement (baseline endurance)



Orange lines represent ammonia-related fuel and vent systems.

A.3 General arrangement (extended endurance)

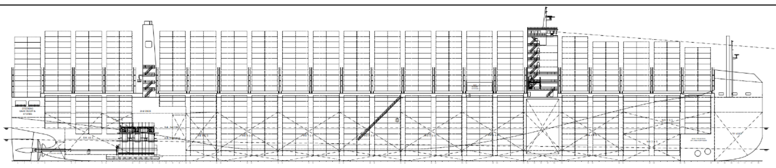


Orange lines represent ammonia-related fuel and vent systems.

A.4 Pocket plan

15,700 TEU AMMONIA FUELED CONTAINER SHIP

seaspan



MAIN PARTICULARS

Length, o.a.	approx.	356.0 m
Length, b.p.		350.0 m
Breadth		53.6 m
Depth		30.0 m
Draught, design		15.5 m
Draught, scantling		17.0 m
Air draft	less than	60.0 m
Deadweight, scantling	approx.	181,300 t
Service speed	approx.	20 kn

CLASS: ABS A1, Container Carrier, AMS, ACCU, CPS, BWT, CLP-V, CRC(I), CSC, NBLES, RRDA, TCM, UWILD, LFFS(DFD-Ammonia), RELIQ

TANK CAPACITIES

Ammonia (Type B)	11,600 m^3
VLSFO/ULSFO	4,600 m^3
Ballast Water Storage	57,000 m^3
Fresh Water	530 m^3
Lubricating Oil	430 m^3

ENERGY EFFICIENCY

Rudder:	Full spade, twisted leading edge
ESD:	Rudder bulb, pre-swirl stator
VFD:	ER fans and SW cooling pumps
Lighting:	LED
Coating:	High performance
Attained EEDI:	(gas mode) 4.37
CII:	(gas mode) A-Rating

MACHINERY

Main engine	MAN 7G90ME-C10.5 or WinGD 8X92DF-2.0
Tier III (SCR), Dual-Fuel	
NMCR	39,000 kW @ 75 rpm
Bow Thrusters	2 x 3,500 kW
BOG Management	1 x Reliquification Plant
Fuel Preparation	ME & AE
BWTS	1 x USCG Approved
Propeller	FPP

POWER SUPPLY

Diesel Generators	2 x 4,147 kW
Tier III (SCR), Dual-Fuel	2 x 2,764 kW
Emergency Generator	1 x 350kW
Cold Ironing System (AMP)	Fixed Type, PS & STB
Power	440Vac, 3ph
Lighting	230Vac, 1ph

GAS FUEL CONSUMPTION

At design draft, 16 kn:	
Service, no reefers	267 DGC (t/day)
Service, all reefers	374 DGC (t/day)
Service, 50% reefers	326 DGC (t/day)

OIL FUEL CONSUMPTION

At design draft, 16 kn:	
Service, no reefers	87 DFC (t/day)
Service, all reefers	122 DFC (t/day)
Service, 50% reefers	106 DFC (t/day)

COMPLEMENT

Crew	31 P + 6 Suez

CARGO LOADING

Hatch covers:	Steel pontoon type
90 t/20 ft & 200 t/40 ft & mixed stowage 275 t/stack	
Cargo hold:	270 t/20 ft & 336 t/40 ft
IMDG Cargo:	Hold. No 1/2 & upper deck

CONTAINER CAPACITIES

Containers intake IMO visibility guidance

	ISO 8'6'' high
On deck	9,234 TEU
In Hold	6,430 TEU
TOTAL	15,664 TEU
Rows max. in holds/on hatches	19 / 21 Rows
Tiers max. in holds/on hatches	11 / 11 Tiers
Lashing bridge on deck	3 tiers + 2 MM
Max. Reefer Container Plugs	
On deck (4.5 kW/plug)	1,200 FEU
In holds (6.0 kW/plug)	600 FEU
Total	1,800 FEU

Homogeneous loading:
10 t/TEU / 14 t/TEU: 13,900 / 11,686
(based on VCG as 45% of 8'6'', 100% bunkering)
Hull Strength as 20% over IACS

NAVIGATION EQUIPMENT

1 - Auto Pilot, 2 - Gyro Compass, 2 - ECDIS + conning , 3 - Radar Plant (ARPA, ECDIS), 1 - Echo Sounder, 2 - Speed Log, 2 - DGPS, 1 - VDR, 1 - AIS, 1 - LRIT, 1 - SSAS, 1 - GMDSS A3, 3 - VHF, 2 - INMARSAT C, 1 - CCTV (16 cameras), 2 - VSAT, 1 - FB system, 1 - LTE

FS3788
28.3.2023

All values are approximate.

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