GRIEG STAR

Green Shipping Programme

# Ammonia powered bulk carrier

## Pilot report


IMO 9593907
STAR LIVORNO
BERGEN

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3O REANMER
JEAN B BALDOZA

# Content

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# Introduction

In 2022, the implications of climate change seemed to be more pronounced than ever. Throughout the year, four continents experienced droughts, with Europe facing its worst drought in over 500 years. The drought in the Horn of Africa could push more than 22 million people into starvation. Wildfires, floodings, typhoons and hurricanes wreaked havoc.

Shipping contributes approximately three per cent of the world's CO2 emissions. The shipping community has eight years to reach a 40% reduction of those emissions and meet IMO's expectations. How to get there is murky at best. But to us, sitting back and waiting for others to create solutions is not an option. Grieg Maritime Group has vowed to be a part of the solution. And to find that solution, we must contribute to ideating, prototyping, testing, and developing new solutions.

We see green ammonia as one of many possible fuels for shipping in the future. The vessels of tomorrow may have designs that make them more energy efficient and ready for multifuel propulsion. But is it sustainable to retrofit a ten-year-old ship to operate on green ammonia in a transatlantic trade right now? Is it technically feasible or financially sound? What do we need to make it sustainable? We have a fleet of 30 Open Hatch Supramax vessels in worldwide trade, and the answers to these questions are critical for us.

Facilitated by the Norwegian Green Shipping Program, a team of brilliant partners from all aspects of the business has spent the last year looking to find these answers. Based on a thorough understanding of technical solutions, availability of green ammonia, safety/rules/regulations, and the financial and operational implications, they give some insight with this report.

We are forever grateful for our partners' eagerness and willingness to share their knowledge and insights. A special thank you to the Green Shipping Program, their pilot coordinator, Hans-Christian Wintervoll, and all the workstream leads; Tessa Major (Yara), Therese Landås (NMA), John Garbiel Östling (GS), Henrik Bredesen (GMG), Henning Rebnord (G2O) and Torleif Frimannslund (GS).

Atle Sommer
**MANAGING DIRECTOR, GRIEG STAR**
Bergen, 18th of January, 2023

PHOTO: 3O JC TERUEL

> The main barrier today is the combination of high retrofit investment costs, lack of availability of competitively priced green ammonia and unclear effects of regulatory frameworks.

# Conclusion

The work on this pilot study has delivered a lot of insight. Elements we perceived as challenges have turned out not to be barriers or present major risks for moving forward with a retrofit project. The study has identified a concept for retrofitting the vessel to run on ammonia. Our regulations screening has found that modifications can be done within existing regulations. Still, there is no doubt that we must resolve significant barriers and risks regarding safety, local regulations, engine technology, emissions, availability, and financing before a viable investment case can become a reality.

More visibility on available funding, grants and subsidies is necessary. While this pilot and its calculations indicate a positive case for a retrofit, those calculations are based on several uncertainties and high-level assumptions. Also, it is worth noting that the financial model is limited to break-even calculation based on the availability of competitively priced green ammonia and does not include return on equity.

The main barrier today is the combination of high retrofit investment costs, lack of availability of competitively priced green ammonia and unclear effects of regulatory frameworks. The two latter items are the main governing factors for return on a retrofit investment. Without the stability of green ammonia availability/pricing for the maritime sector (potentially green corridors) and, even more importantly, stable framework conditions, financing such a venture is not viable, even with significant soft project funding.

The IMO CII regulations clearly have their shortcomings, being highlighted by many parties in the media, with regards to sub-optimization of transported goods vs emissions. The main challenge holding up major investments on both supply and demand is the lack of visibility on future effects and outcomes of the regulation. The consequences of non-compliance need to be clarified. The market reaction to such regulations is hugely complex to foresee. The horizon ends in 2026, after which the metrics may be altered.

Owners, banks, and other financing institutions depend on understanding the risks of delivering the financing. In our estimation, the framework conditions are currently not such that we can finance the required investments to remain compliant with the CII regulation through traditional channels.

# Main findings – answers to business case/pilot description

By the end of this decade, the deep-sea marine transport industry will have to have changed significantly. We must take significant steps towards utilizing alternative fuels, reducing emissions, and complying with the IMO CII regulation coming into force in 2023. Understanding the risks, barriers, and opportunities regarding using ammonia as an alternative fuel in the deep-sea marine transport sector is vital for moving the industry towards a zero-carbon future.

This study has narrowed the focus and evaluated a specific vessel (Grieg Star L-Class) in one particular trade (SA-ARA-GOM). Thus, we have eliminated some layers of complexity, enabling us to answer more directly the questions regarding the viability of such a venture. We have divided the study into five categories, focusing on green ammonia availability, relevant safety issues and regulations, potential onboard retrofit solutions, ESG/Finance, and operational impact.

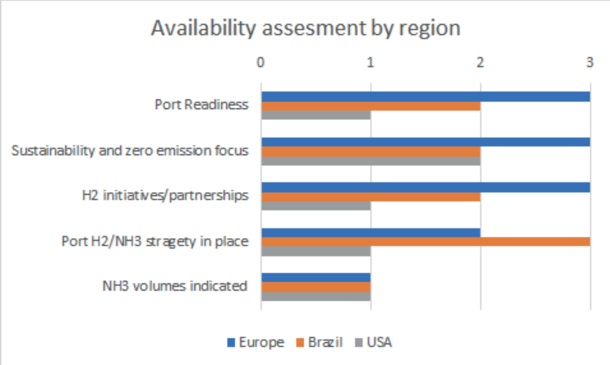
### GREEN AMMONIA AVAILABILITY:

The availability of green ammonia as a marine fuel depends on sufficient local green energy, production capacity, infrastructure, and suitable bunkering facilities. The relevant regions, countries and ports indicate varying approaches and strategies on ammonia. There are also significant differences in governmental incentives between the regions contributing to such variations. Our findings suggest that **all three relevant port locations have to solve several supply chain challenges before they are ready to provide green ammonia for bunkering.**

Production of blue and green ammonia has the potential to increase significantly in the years to come. Still, it will depend highly on governmental support and competitive pricing of renewable energy for production. The Middle East, Western Australia and North Africa have the most remarkable potential for ammonia production with good access to renewable energy sources, available land areas, and low offtake to electrical grids.

**Europe (ARA region):** We have identified 16 green ammonia projects, mainly focusing on fertilizer production. Two projects (Yara and Proton Ventures) are located in the ARA region and target a total production capacity of 174,000 t/yr.

**Brazil:** Out of 10 known green ammonia projects in Latin America, only one, located in Chile, plans to produce green ammonia for marine fuel. Hence the supply of green ammonia to Brazilian ports can prove challenging.




**Gulf of Mexico:** Due to American policies and tax mechanisms, the region focuses more on blue ammonia production than the ARA region and Brazil. Four projects in the Gulf of Mexico are known. The total production capacity of the three with known ambitions is 1,309,000 t/yr, all located in Louisiana.

### SAFETY, RULES AND REGULATIONS:

Switching from a well-known and established fuel to a substance with a higher safety risk profile will put new and increased demands on suppliers, owners and crew. We must ensure the same or better safety for people and our surroundings. That means developing and implementing safe designs, new operational knowledge and fit-for-purpose training programs.

**Although there are challenges to be addressed, the project has not identified any regulatory showstoppers for operating.** Until prescriptive requirements for the design of vessels are in place an alternative design approach through the IGF Code may be utilized. The main remaining uncertainty is the potential diverging approaches by national and local authorities.

### TECHNICAL RETROFIT:

The team has thoroughly reviewed aspects relating to retrofitting the vessel to ammonia propulsion. They have evaluated required modifications, additional onboard systems, integrations, and main equipment locations. Through this, we have identified a feasible concept of retrofitting one of Grieg Star's existing L-class vessels to bunker, store, handle and sail on green ammonia.

The group concludes that, **although the required modifications are more extensive than initially an-**

**ticipated** and the complexity is significant, it is technically feasible to retrofit a Grieg Star L-Class vessel to operate on ammonia within a reasonable timeframe, given a working motor technology solution. The chosen configuration would allow the vessel to sail the longest leg on ammonia. As such, we can operate the vessel on full ammonia utilization given available bunkering at, or close to, the three relevant ports.

Results from testing of MAN ammonia engine solution were not available at the time of writing. These tests' results are crucial to understanding the remaining challenges, risks, and timelines towards a commercial product and, subsequently, a successful vessel retrofit to ammonia propulsion.

### FINANCE AND ESG:

Retrofitting a vessel to run on green ammonia represents a significant investment, in the evaluated case >50% of the vessel's fair market value. Such an investment will depend on a stable regulatory framework supporting long-term functioning market mechanisms and continuous green ammonia availability to be viable.

We have a significant chicken-and-egg challenge: Green ammonia production is awaiting visibility on offtake volumes from shipping. Simultaneously the shipping industry depends on known availability to facilitate the required modification. External funding mechanisms are crucial to create momentum for deep-sea application of green ammonia.

**Given available competitively priced ammonia and a suitable regulatory framework, there can be substantial benefits by retrofitting to ammonia.** These could be retaining earnings capacity and potentially extending vessels' economic lifetime.

### OPERATIONS:

We have concluded that the operational consequences of an ammonia retrofit are limited and lower than expected. The main impact will be from the ammonia holding tanks being placed in a cargo hold. For the wood pulp trade relevant for this pilot, the calculations show an approximate 3,5% reduction in cargo intake by such a modification.

By installing additional tanks for ammonia and not reducing the original onboard fuel oil capacity, the vessel will retain its operational flexibility. **With the high uncertainties regarding ammonia availability, maintaining fuel flexibility is vital to ensure vessel market value after modification.**

On the other hand, the high investment cost, in combination with the scarce availability of ammonia, will likely have a significant effect on vessel flexibility. **The vessel will be limited to trade where ammonia is available to capitalize on the investment** and ensure a return on equity. The cost of such limitations is hard to estimate.

### BARRIERS:

With a conversion cost of more than 50% of the vessel's fair market value the financial burden of such an investment is significant. At the time of writing, there is still uncertainty on green ammonia availability, no clear sight of international mechanisms to influence alternative fuel pricing relative to conventional fuels, and no firm indication of market willingness to pay a sufficient premium for vessels operating on low carbon fuels. The main barrier to move forward with the pilot is this combination of high conversion investment costs and the uncertain availability of competitively priced green ammonia.

One may achieve competitive pricing by securing local green energy pricing/availability for maritime green ammonia production and increasing global pricing of carbon fuel emissions (e.g. EU-ETS). With the current chicken-and-egg challenge where green ammonia availability investments are awaiting vessels for potential offtake, and vice-versa, the typical market mechanisms are not sufficiently creating their own momentum. The industry will require government support to ensure the rapid development of a functional market supporting competitive operations on green ammonia. Contracts of difference are necessary to achieve competitive pricing of green ammonia in the short term. Such contracts secure compensation for the extra costs connected to green ammonia compared to conventional fuel. Contracts of difference are temporary, as competitiveness through the benefits of upscaling the market in combination with the increasing cost of emitting $CO_2$ is likely.

### RISKS:

Converting to utilizing a new fuel at the early stages of regulatory, technology and supply chain development naturally yields a significant degree of uncertainty. As the new market for alternative fuels develops based on new regulations, the risk models are highly dependent on understanding the regulations and mapping their future consequences. The primary regulation driving the new market is IMO's CII framework which aims to push reduction by setting increasingly stringent limits on allowed CO2 emissions towards 2050. The current regulation is, by many, expected to be vulnerable to gaming. With the regulation coming up for revision in 2026, the outcomes and potential market volatility are incredibly challenging to predict. Another aspect is that the CII regulation by measuring each vessel is not incentivizing close-to-zero conversion of single vessels but rather a slower reduction across a fleet. The governmental consequences of not adhering to the CII regulations are unclear at the time of writing. The framework shall be reviewed in 2026 and potentially modified.

We have identified potential diverging approaches and regulations from local and regional governments as a risk. For this pilot intending operation in a fixed route, this number of local authorities is limited but needs to be accounted for before moving ahead.

The safety aspect needs to be carefully handled both concerning personnel and the environment. Ammonia is already being transported as vessel cargo today. Still, changing cargo to fuel will introduce new challenges concerning regulations and competency.

The required motor technology is under development, with some central questions on maximum potential ammonia utilization, management of emissions, and timeline for a ready commercial product to be answered. Although these questions are challenging and need to be answered before shipowners can make an investment decision, the technology development is far progressed, and testing is ongoing. With the strong commitment from the engine manufacturer, we view the risk of failing to reach a sufficiently strong solution as moderate.

### OPPORTUNITIES:

Moving forward with this pilot poses an opportunity for moving the market towards broader adoption of ammonia as a fuel in the shipping industry. At this early stage in technological and regulatory development, Governmental support will play a key role in kick-starting a functional marketplace for utilizing green ammonia to transport most of the world's goods. With the concept developed here, where the vessel keeps most of its market and fuel flexibility, this pilot project could get the ball moving ahead of a stable and favourable market and framework.

The new inclusion of the marine sector into EU-ETS and the funds collected to be allocated back to the industry is a positive development. Relative pricing towards conventional fuels highly depends on green energy pricing/incentives and carbon pricing mechanisms. There is movement in the right direction with the EU, including marine transport in their ETS framework and IMO discussing the tax on GHG emissions.

# Participants

ABB

AMMONIA

BREEZE Ship Design

Chevron

DAPHNE TECHNOLOGY

DNB

DNV

dsb

G2 OCEAN

OSM MARITIME

HYUNDAI GLOBAL SERVICE

KLIMA- OG MILJØDEPARTEMENTET

MAN

PENSÉE OSHIMA

Sjøfartsdirektoratet Norwegian Maritime Authority

SKULD

suzano

UMOE ADVANCED COMPOSITES

WÄRTSILÄ

YARA

MI ZERO-EMISSION SHIPPING MISSION

# Terms used

| TERM | EXPLANATION |
|---|---|
| ARMS | Ammonia Release Mitigation System |
| CCS | Carbon Capture and -Storage |
| CII | Carbon Intensity Index |
| Deep Sea Shipping | Refers to the maritime transport of goods on intercontinental routes, crossing oceans |
| DW | Double-Walled |
| DWT | Dead-Weight Tonne |
| E/R | Engine Room |
| ESD | Emergency Shut-Down |
| ESG | Environmental, Social and Governance |
| ETS | Emission Trading System |
| FPR | Fuel Preparation Room |
| FSS | Fuel Supply System |
| FVT | Fuel Valve Train |
| GHG | Greenhouse Gas(es) |
| GSP | Green Shipping Programme |
| IGF | International Code of Safety for Ships Using Gases or Other Low-Flashpoint Liquids |
| IMO | International Maritime Organization |
| LNG | Liquefied Natural Gas |
| LPG | Liquefied Petroleum Gas |
| M/E | Main Engine |
| MGO | Marine Gas Oil |
| Open hatch/bulk carrier | Cargo ship, designed for direct access to the hold through cargo hatches extending the full width of the ship. |
| P&I | Protection and Indemnity |
| ppm | Parts Per Million |
| SCR | Selective Catalytic Reaction – NOx abatement technology |
| SOLAS | Safety Of Life at Sea |
| QRA | Quantitative Risk Analysis |
| SFOC | Specific Fuel Oil Consumption |
| TCS | Tank Connection Space |
| TEU | Twenty-Foot Equivalent Unit |
| VLSFO | Very Low Sulfur Fuel Oil |

# Background

**With the goal of realizing the first ocean-going open hatch/bulk carrier to be powered by green ammonia, Grieg Maritime Group and GSP launched the pilot work in the beginning of 2022.**

The aim of the pilot's study phase has been to assess the technical and commercial feasibility of retrofitting an open hatch bulk carrier for green ammonia operations in a trans-Atlantic route. What are the key barriers, risks, and possibilities? How does the business case look, and is green ammonia viable as fuel on this specific trade?

The pilot-case relates to a specific vessel type, in a defined geography with an established value chain.

Through five work-streams, commercial, technical, infrastructural, financial and operational aspects were explored.

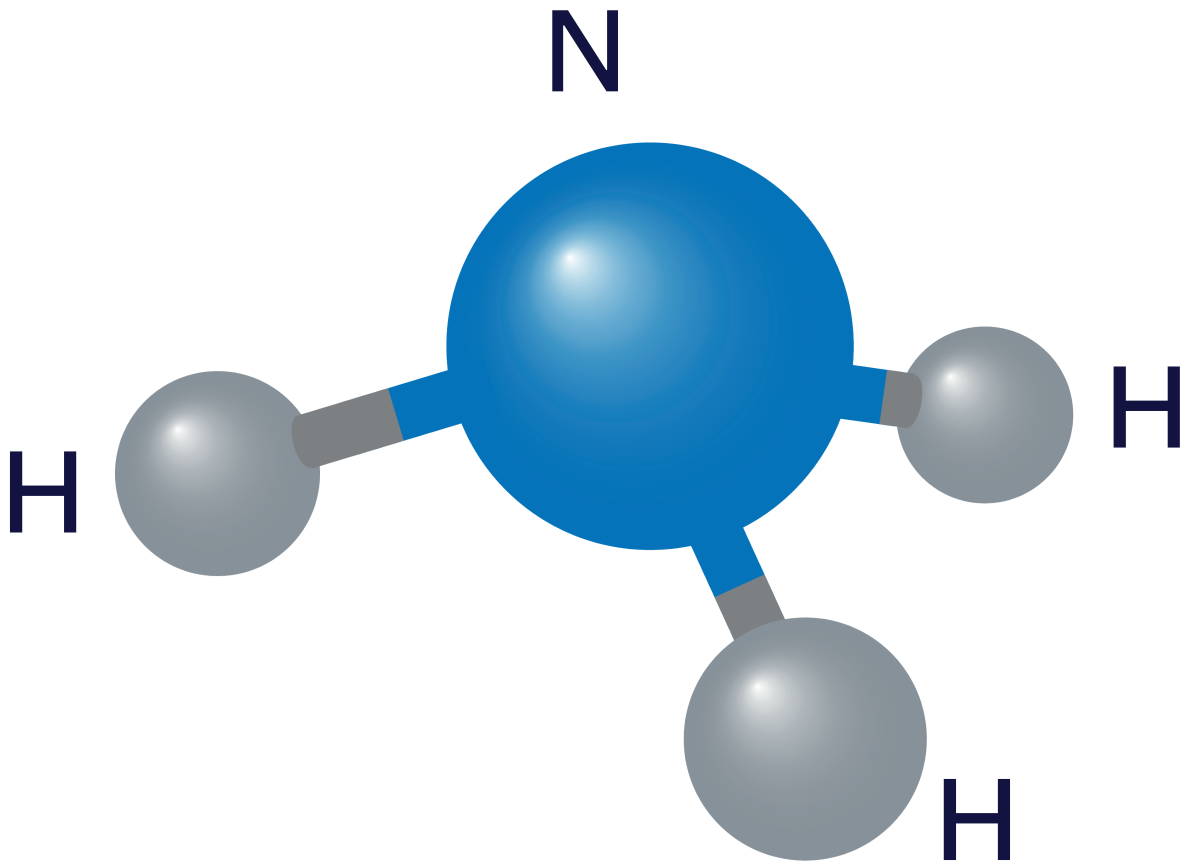
Grieg Maritime Group is the pilot owner, and GSP is the facilitator.

The companies that have contributed to the work in this pilot are, in alphabetical order and in addition to Grieg Maritime Group and Green Shipping Programme: ABB, Ammonia, Breeze Ship Design, Chevron, Daphne Technology, DNB, DNV, DSB, G2Ocean, Hyundai Global Service, Norwegian Ministry of Climate and Environment, MAN, Oshima Shipbuilding, OSM Maritime, Norwegian Maritime Authority, Skuld, Suzano, UMOE Advanced Composites, Wärtsilä, Yara, and Zero-Emission Shipping Mission.

## Business case

| | | | | |
|---|---|---|---|---|
| GREEN AMMONIA AVAILABILITY | SAFETY, RULES & REGULATIONS | VESSEL RETROFIT TO AMMONIA | ESG & FINANCE | OPERATIONS |
| LEAD: YARA | LEAD: NMA | LEAD: GRIEG STAR | LEAD: GRIEG STAR | LEAD: G2 OCEAN |


LEG 1:
4700 NM
LEG 2:
4810 NM
LEG 3:
4915 NM




# Ammonia

## Ammonia ($NH_3$) is a colorless gas under ambient conditions with a density lower than air, and with a sharp and penetrating odor.

The boiling point at atmospheric pressure is -33.3°C. Hence, the pressure and/or temperature required to store ammonia as a liquid is moderate compared to e.g., the storage of LNG, which has a normal boiling point of -162°C. The vapor pressure of ammonia at 45°C is approximately 17 bars, which means pressure vessels designed for this pressure in theory has infinite holding time. Although gaseous, anhydrous ammonia is lighter than air, the rapid evaporation following a sudden release of pressurized, liquid ammonia may cause liquid carry-over to the gas cloud. The ammonia droplets may disperse in the gas, forming a cloud that is heavier than the ambient air.

Ammonia will corrode galvanized metals, cast iron, copper and its alloys, such as brass. Careful material selection is required.

The lower heating value of ammonia is 18.6 MJ/kg. The gravimetric and volumetric energy density of ammonia compared to MGO is 44% and 32%, respectively. Hence, carrying equal amounts of energy as ammonia requires significantly more space and weighs more than the same energy amount carried as MGO. In addition, the pressure vessels required to handle liquid ammonia adds both weight and space constraints.

Being a carbon-free molecule, ammonia's byproducts of combustion have no carbon footprint. However, the production of ammonia is usually categorized by color into three groups:

### GREEN AMMONIA

Green ammonia is ammonia produced from renewable energy inputs. One way of making green ammonia is by using hydrogen from water electrolysis and nitrogen separated from ambient air.

### BLUE AMMONIA

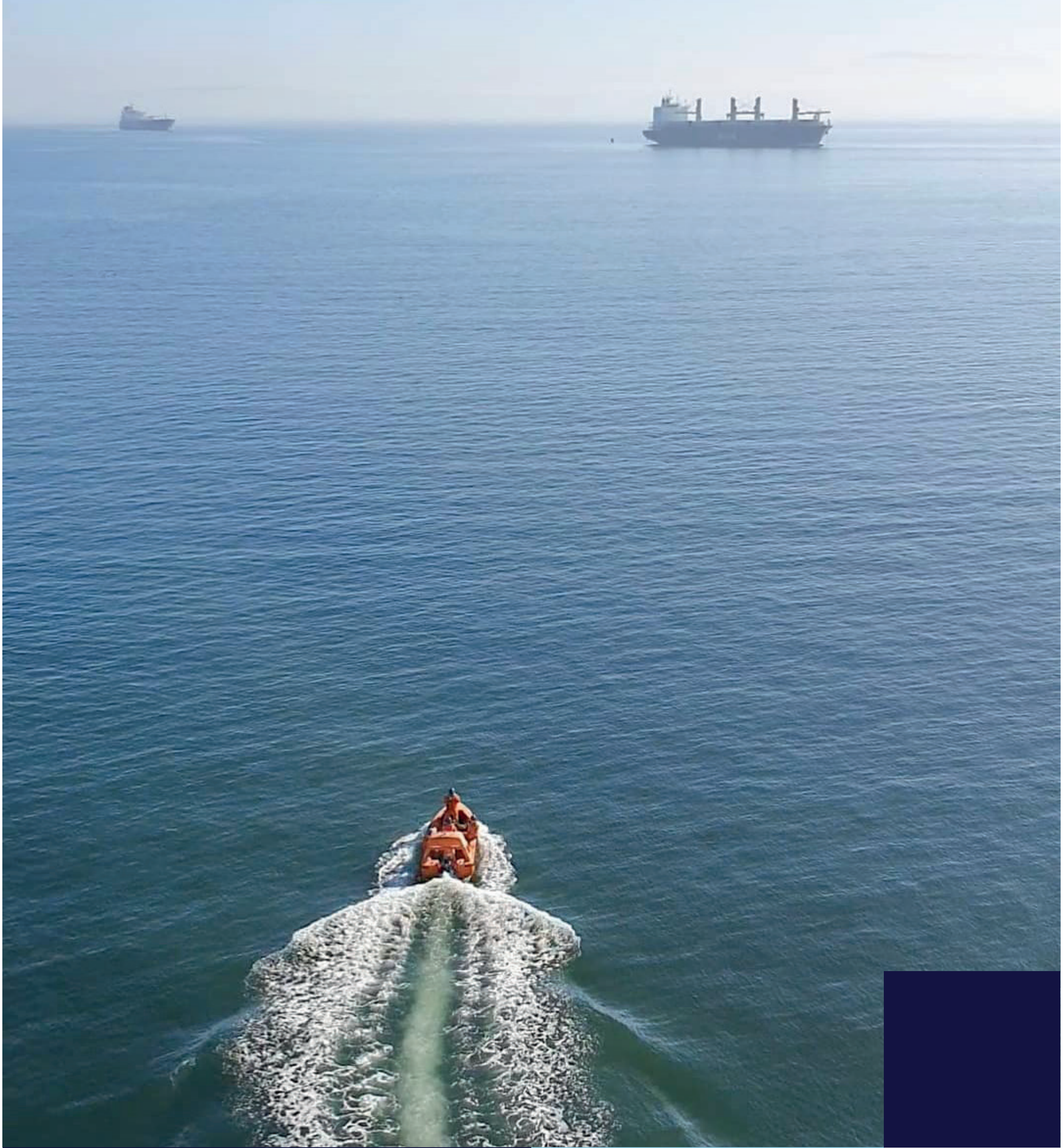
Blue ammonia is generally produced from natural gas, with the byproduct of the process, $CO_2$ being captured and stored (CCS).

### GREY AMMONIA

Grey ammonia is ammonia produced from e.g., natural gas without any CCS.

## Properties of ammonia

| | | |
|---|---|---|
| -33<br>°C BOILING TEMPERATURE (1 ATM) | 18<br>BAR VAPOR PRESSURE AT 45 °C | 0.68<br>T/M3 VAPOR PRESSURE (45 °C) |
| 15-28<br>PER CENT FLAMMABILITY RANGE | 651<br>°C AUTO IGNITION TEMPERATURE | 8<br>mJ MINIMUM IGNITION ENERGY |
| 531<br>g/l SOLUBILITY IN WATER (AT 20 °C) | Main hazards<br>TOXIC, EXPLOSIVE, CORROSIVE, FLAMMABLE | |



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WORKSTREAM 1:

# Green Ammonia Availability

## Summary

The availability of green ammonia as a marine fuel is governed by two main areas that must be in place: firstly, the production of green ammonia for trade, and secondly, the infrastructure and availability in the ports.

Market reports commissioned by Yara Clean Ammonia conclude that the amount of blue and green ammonia produced for trade will increase by 200% by 2030 compared to 2022 levels. The same reports conclude that low cost of renewable energy, existing infrastruc-ture and governmental support are key factors for the successful upscaling of production. The Middle East, Western Australia and North Africa show the greatest potential. This ranking is most likely to be impacted by the recent regulatory announcements of the US fostering the production of clean hydrogen and so ammonia. The availability of green ammonia in Brazil is a potential barrier, as right now, Latin America's only production plant focusing on the marine fuel market is located in Chile.

The European ports appear most ready to facilitate the availability of green ammonia for bunkering, but the high cost of renewable energy is a barrier to local production.

## Availability of ammonia – current market and forecast

### EUROPE

Yara is the largest grey ammonia producer in Europe (excl. Russia), with a production capacity of 4,506 kt out of a total production capacity of 27 million tons. Prior to the war, Ukraine was the country with the highest production capacity, with 5.7 million tons. The effect of the current situation in the region is uncertain. In terms on merchant capacity, Yara also has the largest market share in this region with roughly 1 million tons on a total regional merchant capacity of 4 million tons per annum.No new production capacity of grey ammonia is forecasted for Europe, and merchant ammonia balance expected to remain stable with consistent import demand towards 2035.

The ARA (Amsterdam, Rotterdam, Antwerp) area is key and will need to increase the area's ammonia bunker storage capacity to meet the ambitious ARA plans. In the short term, only limited demand for bunker is forecasted, until IMO regulations take full effect.

# 49.2

GLOBAL PRODUCTION CAPACITY IN MILLION TONS

**European bunkering infrastructure projects:**

**1. H2Global:** it's a support scheme designed to accelerate the market uptake of green hydrogen, including its derivatives such as ammonia. There will be a competitive tender to facilitate purchase agreements and sales agreements with EU customers. Delivery sites shall be ports in Germany, Belgium or the Netherlands, to start in 2024.

**2. Bornholm Bunkering Hub:** Eight organizations formed the Bornholm bunker hub in June 2021 to focus on how local Power-to-X initiatives could support the demand for sustainable fuel from the 60,000 ships that pass the Danish island each year. Bunkering of imported fuel shall be available from 2025, local production planned by 2030.

**3. European Green Corridors Network:** Port authorities of Gdynia, Hamburg, Roenne, Rotterdam and Tallinn shall establish Northern Europe/Baltic Sea Green Corridors.

**4.Grieg Ammonia Distribution Vessels:** World's first green ammonia distribution vessel, fueled on green ammonia, called MS Green Ammonia. The 120 m long tanker will have a cargo capacity of 7500 m3, or 5000 tonnes of green ammonia, and will be available by 2026. LMG will help with developing the design, and Wärtsilä the engine, and the vessel will be able to load up to 1000 m3 per hour both to quay and ship to ship.

**5. Scandinavia:** Azane Fuel Solutions Yara International has pre-ordered 15 floating bunkering terminals from Azane Fuel Solutions enabling shipping fleets' uptake of emission-free green ammonia as fuel and so to establish a carbon-free ammonia fuel bunker network in Scandinavia

## NORTH AMERICA

CF industries is the largest grey ammonia producer in the region, with 8.2 million tons production capacity. North America's 2022 gross ammonia production capacity was 23 million tons, with the US having the largest capacity of 17 million tons. No major changes in capacity are forecasted with regards to grey ammonia.

The US could become a pioneer in blue ammonia production due to high potential of carbon capture and storage. CO2 is already captured and used for EOR (enhanced oil recovery), a process by which CO2 is injected in existing oil fields with the aim of increasing production. As a result, US has significant progress in carbon capture technologies compared to other regions. Furthermore, there might be several suitable depleted oil fields that could be used for CO2 storage With the recent regulatory developments in the US, (mainly the Inflation Reduction Act) it can be expected that clean ammonia development (green and blue) will be accelerated due to the anticipated positive impact on the price competitivity of US hydrogen. The total known capacity of current blue ammonia production in North America in 2,27 million tons/year, yet this capacity is connected to Enhanced Oil Recovery and so is not considered as clean ammonia by many stakeholders.

Carbon Capture and Storage Blue ammonia projects in the US will, if realized, increase the total production capacity by 2,8 million tons. The projects are mainly clustered around the Gulf Coast..

## LATIN AMERICA

Nutrien is the largest grey ammonia producer in the region, with 2 million tons production capacity. Latin America's 2021 gross ammonia production was 23 million tons, with Trinidad and Tobago having the largest capacity with 5.7 million tons. No new grey production capacity is forecasted for the region.

The merchant ammonia production capacity in 2022 is 9 million tons, with more than half originating from Trinidad & Tobago.

There are numerous green ammonia projects ongoing in Latin America, mainly in Chile, but also in Brazil. In general, the status of the energy and port infrastructure can be considered as the main challenge for green ammonia developments in the Region. Only one of the announced projects so far, located in Chile, has a target market that includes marine fuel and a planned capacity of 250,000 tons/year. It is expected that green ammonia from other projects would also transfer sales to marine fuel applications as soon as the market develops. Similar to the other regions, the existing ammonia trade could be leveraged to help ensure access to clean ammonia if the demand would arise.

### GLOBALLY

Globally, 44 million tons (23%) of ammonia is produced for trade, out of a gross production of 185 million tons. The global demand of merchant ammonia (excluding China) has been stable during the last decade, with an increase from 30 to 31 million tons. The forecast for the total global production capacity from 2021 to 2026 shows an increase of 1.9 million tons from 47.3 to 49.2 million tons.
Today's commercial grey ammonia market is dominated by trade between four major export points (Trinidad and Tobago, Russia, Middle East, and Indonesia) and six major demands centers (US Gulf, Brazil, NW Europe, Morocco, India, NE Asia).

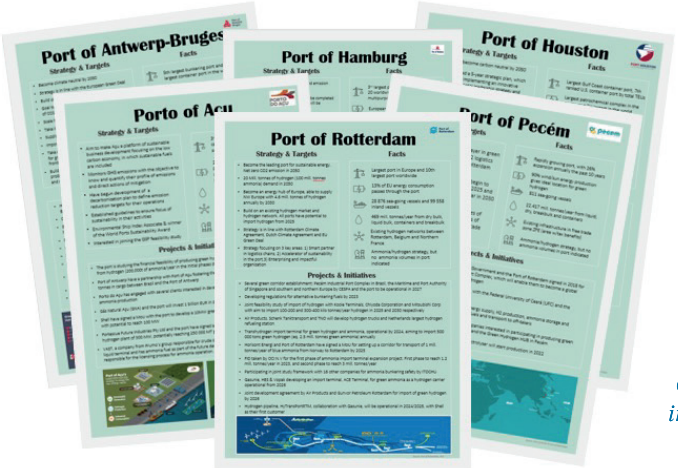
Global ammonia value chains are adapting, as new technologies, business models and trade routes redefine the market, in particular resulting from the emergence of blue/green ammonia supply and demand. Ammonia fueled ammonia carriers are also expected have an impact with the emergence of clean ammonia shipping through clean trading routes.

The announced blue and green ammonia production capacity in 2030, about 85 million tons, is more than three times the amount of traded ammonia today. All these announcements have a different level of maturity and it is yet to be seen of these volumes announced how many will actually materialize. Critical factors in this are (amongst others) cost of renewable energy, effective access to land, availability of existing infrastructure (energy, port and terminal) and governmental support (permitting, funding, ...). Proximity to demand clusters is of course another factor be taken into account when assessing the viability of new production facilities, yet ease of ammonia transport facilitates connection between supply and demand areas Nonetheless current forecasts agree that the expected demand will be able to be met.

Out of the 12 regions/countries evaluated, the Middle East, Western Australia and North Africa shows the greatest potential for developing green ammonia clusters, Europe ranks slightly below the abovementioned regions, while Other Latin America, which in this case includes Brazil, ranks lowest. Poor governmental support and lack of proximity to demand are the main reasons for the apparent low potential.

The Brazilian ports proved to be forwardleaning and prone to have high probability of utilizing the availability of green ammonia, when production is scaled up. However, out of the green ammonia production projects in South America, the only one with a target market for marine fuel is in Chile. Brazilian production capacity may therefore be a significant barrier.

Another study (Zero Carbon Shipping, 2022) shows that the announced projects developing, and ultimately producing green and blue ammonia match the volumes from the expected demand. However, the majority of the projects are in the early phases and currently conducting feasibility studies. All stakeholders and policy makers must support early mover initiatives, to reduce risks and costs, and share concepts and opportunities to facilitate realization of projects to meet the upcoming demand.




*One pagers are found in the appendix at the back of this report*

## Potential supply of ammonia

Similar to technology readiness levels, port readiness levels will be critical in enabling the effective use of ammonia onboard vessels. To evaluate the potential supply of ammonia, the team haves interviewed several ports in Europe, USA, and Brazil, in total 11 interviews. The summary from each interview is displayed in a one-pager. Each one-pager gives an overview of the port's sustainability strategy and goals, some facts about the port, and the ports projects and initiatives. The one-pager can be found in appendix

The outcome of the interviews shows a range in port-readiness levels across the conti-nents.
European ports achieve the highest score on the port readiness level, compared to Brazil-ian and American ports. They show a clear focus on sustainability, and concrete goals on how they are working towards limiting their CO2 emission. Though none of the ports have indicated ammonia volumes, they have engaged themselves in several projects and initia-tives, either alone, with industry partners or other ports.

Brazilian ports score medium in terms of port readiness level. They are not as active as European ports but show an eagerness in engaging themselves in projects and initiatives within green hydrogen and ammonia. Some of the Brazilian ports have formed partner-ships with European ports, specifically Port of Pecém and Port of Açu with Port of Rotter-dam.

American ports score lowest on port-readiness level. The ports have included sustainabil-ity in their strategy, but target this in different ways. Some ports have begun preparing for a green transition, while others are still focusing on business as-is. This will, however, most likely change now with the Inflation Reduction Act of 2022, aiming to reduce carbon emis-sions by 40% within 2030 by providing subsidies to the green hydrogen production.

| | |
|---|---|
| Europe | Highest score on port readiness level·<br>Focus on sustainability and zero emission<br>Several initiatives and partnerships within hydrogen<br>Hydrogen/ammonia strategy in port, but no volumes of ammonia in-dicated in port |
| Brazil | Medium score on port readiness level·<br>Focus on sustainability but in different aspects<br>Some initiatives and partnerships within hydrogen<br>Some ports with hydrogen strategy in port but no volumes of ammo-nia indicated |
| USA | Low score on port readiness level<br>Focus on sustainability but in different aspects<br>Few initiatives and partnerships within hydrogen<br>Few ports with hydrogen/ammonia strategy in port and no volumes of ammonia indicated |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3O REANMER
JEAN B BALDOZA

PHOTO: 2O SHAWNTEL AGUJAR

WORKSTREAM 2:

# Safety, rules and regulations

## Summary

This part is a product of Work Stream two in the Pilot Green Ammonia Powered Bulk Carrier and focuses on safety, rules and regulations. The document provides background and criteria regarding safety, rules and regulations in relation to ammonia as fuel, i.e., relevant aspects of safety, rules and regulations both at sea-side as well as land-side. Included in this document is a chapter on ongoing processes with updating regulations.

Additionally, the document also includes a chapter on experience and insurance related to ammonia in general. For further work in relation to safety, rules and regulations on ammonia as fuel it is recommended to look further into competency and training, operational procedures, and effect on management concept for handling ammonia.

# Safety

### HEALTH EFFECTS

Ammonia is a toxic substance and lethal at much smaller concentrations than the flammability range. Acceptable human exposure limits to ammonia are defined by legislation and is typically a function of concentrations and exposure time. Examples of exposure guidance are shown in in table 1 and table 2.

Table 1 Exposure guidance (Karabeyoglu A, Brian E., 2012)

| Effect | Ammonia concentration in air (by volume) |
|---|---|
| Readily detectable odour | 20 – 50 ppm |
| No impairment of health for prolonged exposure | 50 – 100 ppm |
| Severe irritation of eyes, ears, nose and throat. No lasting effect on short exposure | 400 – 700 ppm |
| Dangerous, less than ½ hours exposure may be fatal | 2000 – 3000 ppm |
| Serious edema, strangulation, asphyxia, rapidly fatal | 5000-10000 ppm |

Based on Acute Exposure Guideline Levels (AEGL) for airborne chemicals defined by the Environmental Protection Agency (EPA) US, the limits to ammonia exposure can be identified as shown in table 2.

Table 2 EPA Acute Exposure Guideline Levels (EPA, 2016)

Ammonia 7664-41-7 Expressed in ppm

| | 10 min | 30 min | 60 min | 4 h | 8 h |
|---|---|---|---|---|---|
| AEGL 1 | 30 | 30 | 30 | 30 | 30 |
| AEGL 2 | 220 | 220 | 160 | 110 | 110 |
| AEGL 3 | 2700 | 1600 | 1100 | 550 | 390 |
| | | | | | |

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

Anhydrous ammonia is a hydroscopic compound, which means that it seeks water from the nearest source, including the human body. This places the eyes, lungs, and skin at greatest risk because of their high moisture content. Caustic burns result when the anhydrous ammonia dissolves into body tissue. An additional concern is the low boiling point of anhydrous ammonia and the chemical freezes on skin contact at room temperature. It will cause burns like, but more severe than, those caused by dry ice (Schwab, Charles V. et al., 1993). Most deaths from anhydrous ammonia are caused by severe damage to the throat and lungs from a direct blast to the face. When large amounts are inhaled, the throat swells shut, and victims suffocate. Exposure to vapors or liquid can also cause blindness.

Combustion of ammonia may form toxic nitrogen oxides. It is recognized that NO2 can aggravate cardiovascular and respiratory diseases. Although considerable research has been conducted understanding the formation process of this pollutant, its formation and consumption during combustion and post-combustion processes using ammonia are still at the core of the research agendas of various research groups (Valera-Medina et al., 2018).

### ENVIRONMENTAL EFFECTS

From a safety point of view, drainage of ammonia spills overboard and discharge of ammonia vapor underwater may in some instances be preferable to keeping ammonia onboard. However, release of ammonia to the sea has impact on the environment. Ammonia is classified as toxic to aquatic life with long lasting effects according to GHS (Globally Harmonized System of Classification and Labelling of Chemicals).

Combustion of ammonia in internal combustion engines may generate NOx, but also N2O which is a powerful greenhouse gas with a global warming potential 300 times that of CO2. It is assumed that existing SCR technology can handle the NOx problem, and that engine manufacturers will need to find solutions to handle N2O if ammonia is going to be a viable zero emission fuel.


# Rules and Regulations

## CURRENT REGULATIONS

The use of fuels is regulated by the International Maritime Organization (IMO) through the International Convention for the Safety of Life at Sea (SOLAS). The regulations for conventional fuel oils are prescriptive and based on decades of experience. Utilizing fuels with a flash-point below 60°C (defined as Low Flashpoint Fuels) has generally been prohibited to prevent tank explosions and fires. In 2015, the SOLAS Convention was amended to allow the use of low flashpoint fuels for ships complying with the International Code of Safety for Ships Using Gases or Other Low Flashpoint Fuels (IGF Code).

The IGF Code provides an international standard for the safety of ships using low flash-point fuel and requires that the safety, reliability, and dependability of the systems shall be equivalent to that achieved by new and comparable conventional oil-fueled main and auxiliary machinery. It is emphasized that operational procedures shall not replace safety barriers through the ship design. The IGF Code specifies a set of functional requirements applicable for all fuel types covered by the Code, but only contains specific design requirements to LNG.

Until fuel specific regulations are in place, approval of ships using other gaseous or low-flashpoint fuels than LNG will be based on the alternative design approach, demonstrating that the design complies with the basic functional requirements of the IGF Code. This risk-based approval process is referred to as the 'alternative design' approach (part A sec. 2.3 in the IGF code), where an equivalent level of safety needs to be demonstrated as specified in SOLAS regulation II-1/55, and approved by the Administration. The approval process for the alternative design approach is described in IMO MSC.1/Circ. 1455. It can be a time-consuming process with a high degree of uncertainty and therefore potentially have a higher business risk than the prescriptive experience-based rules that the maritime industry is used to working with. This must be considered as a barrier against uptake of alternative fuels in the industry.

Vessels flying the Norwegian flag are regulated by Regulations of 27 December 2016 No. 1883. Vessels built or retrofitted to use a low flashpoint fuel after 1st of January 2017 must comply with the IGF Code. In addition, equipment constituting or forming a part of the tank or fuel system shall be accepted by the Norwegian Maritime Authority ref. sec. 3 in mentioned regulation. Ongoing work with updating regulations Until specific regulations for ammonia as fuel is developed and adopted by IMO or Flag State, the alternative design approach must be applied for every newbuild or retrofit. Defining the categorization of ammonia within the 1455-process is often discussed. One approach is to use a simplified QRA to cover discovered hazards in the early process. A simplified QRA focuses on new components and toxicity primarily.

When a Classification Society has developed a set of rules covering the use of a fuel where specific design requirements are not included in the IGF Code, a Flag Administration may accept the application of this rule set to ease the alternative design approach. A set of class rules may also form basis for development of international regulations in IMO. Most of the recognized classification societies have tentative rules, guidelines or specific rules for ammonia at this point

### IMO

The 8th session of the sub-committee on carriage of cargoes and containers (CCC8) was held in September 2022. During this session ammonia was on the agenda in both the working group for amendments to the IGF Code and in the working group for review of the IGC Code.

The working group for "Amendments to the IGF Code and development of guidelines for low flashpoint fuel" agreed to change the existing title of the output to "Amendments to the IGF Code and development of guidelines for alternative fuels and related technologies", to accommodate for alternative fuels regardless of their flashpoint.

The group initiated the work for development of guidelines for the safety of ships using ammonia as fuel and agreed on issues to be further considered in the correspondence group. The guidelines will be structured as the IGF code with goals and functional requirements, in addition to new chapters regulating the toxicity related safety provisions. The guidelines are scheduled to be discussed at CCC 9 in 2023 and finalized at CCC 10 in 2024, however it was noted that multiple classification societies have published ammonia rules and that this can speed up the process.

Regarding review of the IGC code there were no technical discussions on updating chapter 16 that prohibit the use of toxic cargo as fuel, because no draft text for safety provisions was submitted for discussion. It was agreed that this issue shall be handled in the correspondence group and Norway is working on a proposal for safety provisions to be submitted for discussion at CCC 9, aiming for adoption by 1 July 2026 and entry into force on 1 January 2028. This is the earliest possible timeline for updating the IGC code. However, if the safety provisions for allowing the use of toxic cargo as fuel are agreed upon at CCC 9, vessels built to these specifications can be approved based on the equivalent safety provision until the rules enter into force.

### DNV RULES

The classification society DNV introduced the class notation Gas fueled ammonia in July 2021, with corresponding class rules published in DNV Rules for Ships Pt.6 Ch.2 Sec.14. The rules took effect in January 2022, and were updated with a revision July 1st 2022, being effective from January 1st 2023. The rules give class requirements for the fuel system on ammonia fueled vessels from bunkering flange to consumer.

DNV's class notation is developed with the functional requirements and main safety principles of the IGF Code as a benchmark, utilizing many of the safety barriers that for LNG are suitable for limiting the risk of explosion and cryogenic temperature exposure to reduce the risk of exposure to toxic gases from fuel leakages. The main safety principles are segregation of the fuel system to protect from external events, use of double barriers to protect crew and personnel from toxic exposure in the event of a leak from the fuel system, leakage detection to give appropriate warnings and enable automatic safety actions, and automatic isolation of leakages to reduce the magnitude and consequence of a leakage. The barriers introduced from the four main safety principles are tailored for reducing risk of exposure to toxic gas.

In addition, ammonia has for decades both been transported as a cargo on ships and has been used as a refrigerant for fishing vessels. To this effect, experience has also been taken from the IGC Code and DNV's rules for ammonia as a refrigerant when developing class rules for ammonia as fuel.

The largest difference in DNV's class rules for ammonia, when comparing to IGF Code requirements for LNG fuel, is the requirement of prohibiting releases of ammonia to the atmosphere in a concentration exceeding 30ppm at any time in normal operation. This introduces the need for an ammonia release mitigation system (ARMS) able to capture and/or treat normal operation releases of ammonia, including but not limited to automatic or manual fuel system purging operations and fuel system pressure relief valve openings.

## Rules and regulations regarding handling of ammonia on shore

The regulatory framework for the on-shore handling of ammonia is based on both international and national directives, laws and regulations. In addition to the regulatory framework there will be a list of applicable guidelines for the handling of ammonia in different ways.

In the context of this workgroup, we consider the activities connected to the refueling of ammonia to ships. The refueling can be done from a fixed installation on shore or as a truck to ship bunkering operation. Ammonia can also be transferred to the receiving ship through a ship to ship bunkering operation.

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JEAN B BALDOZA

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Compliance with the health and safety requirements is essential in order to ensure safe operations. Requirements should be subdivided into general and additional requirements which need to be met by equipment and protective systems and sufficient distances to third party personnel.

## INTERNATIONAL DIRECTIVES

### Seveso III Directive

The Seveso-III-Directive (2012/18/EU) aims at the prevention of major accidents involving dangerous substances. However, as accidents may nevertheless occur, it also aims at limiting the consequences of such accidents not only for human health but also for the environment.

The Directive covers establishments where dangerous substances may be present (e.g. during processing or storage) in quantities exceeding certain threshold. Depending on the amount of dangerous substances present, establishments are categorized in lower and upper tier, the latter are subject to more stringent requirements.

Operators are obliged to take all necessary measures to prevent major accidents and to limit their consequences for human health and the environment.

### Pressure Equipment Directive (PED)

Pressure equipment with an operating pressure greater than 0.5 barg falls under the scope of the Directive and therefore CE marking is required by law. This includes equipment such as (steam) boilers, pressure vessels, heat exchangers, piping, pressure cookers, etc. If the pressure equipment meets the requirements of PED, CE marking may be applied, and the equipment may be traded freely across the European market. Notified Bodies for PED can assist in demonstrating conformity with PED and applying the CE mark to your products.

The PED divides pressure equipment into different risk categories. The services that are required by notified bodies depend on the risk category of the pressure equipment or device. There are different modules (conformity assessment procedures) for demonstrating compliance with the requirements of PED to enable the CE Mark.

ATEX Directive

ATEX (ATmospheres EXplosibles, FR) is the name commonly given to the two European Directives for controlling explosive atmospheres:

1. Directive 99/92/EC (also known as 'ATEX 137' or the 'ATEX Workplace Directive') on minimum requirements for improving the health and safety protection of workers potentially at risk from explosive atmospheres.
2. Directive 2014/34/EU (also known as 'ATEX 114' or 'the ATEX Equipment Directive') on the approximation of the laws of Members States concerning equipment and protective systems intended for use in potentially explosive atmospheres.

## NATIONAL LAWS AND REGULATIONS IN NORWAY

**The Fire and Explosion Protection Act** states that everyone is obliged to show care and act in such a way that fire, explosion and other accidents are prevented.

**Regulations of 8. June 2009 relating to the handling of flameable, reactive and pressurised substances including requisite equipment and installations**

The purpose of the regulation is to protect life, health, the environment and material assets against accidents and incidents involving dangerous substances. The regulation applies to the handling of dangerous substances, and the use of equipment and facilities used in such handling. In the regulations, dangerous substance means flammable, reactive and pressurized substance, see more detailed definition in § 4 where it includes, among other things, it appears that explosive substances are not covered by these regulations.

The regulation applies to the transport of flammable, reactive and pressurized substances in pipelines over land and covers design, construction, construction, startup, operation, termination and more. The regulation applies to all transport of dangerous substances in pipelines regardless of pressure.

The regulations regulate the loading, unloading and stationary storage of dangerous substances on board ships if the ship is moored in a port or moored in inland waters within Norwegian territorial borders. The regulation does not apply to ships that are in ordinary operation.

**Regulations of 10. October 2017 relating to pressure equipment (Pressure Equipment Directive 2014/68/EU)**

The regulation implements EU directive 2014/68/EU (which replaces PED 97/23/EF) on pressurized equipment in Norwegian law. The purpose of the regulation is to ensure that pressurized equipment and assemblies that are made available on the market meet basic safety requirements. The regulation regulates pressurized equipment and assemblies for a permitted maximum pressure PS greater than 0.5 bar (overpressure) and which are designed, manufactured, marketed and put into operation. The regulations shall ensure that pressurized equipment and assemblies are in a proper condition when they are put into operation for the first time. The regulation also regulates the obligations of the market participants, i.e. the manufacturer, representative, importer and distributor. The regulation also applies to technical control bodies, user inspectorates and third-party bodies when they carry out conformity and certification procedures.

**Regulation of 30. June 2003 relating to health and safety in explosive atmospheres (Directive 99/92/EC - risks from explosive atmospheres)**

Regulations on health and safety in potentially explosive atmospheres have provisions for the protection of workers and other persons against the risk of fire, explosion and similar incidents that may occur where flammable or explosive substances are present in the workplace. The requirements in the regulation apply to most workplaces where flammable or explosive substances are present or may occur. The regulation is authorized in the Working Environment Act, the Fire and Explosion Protection Act, and the Electricity Super-vision Act.

# Experience and insurance

## METHODOLOGY

We have investigated Skuld's exposure to, and experience from, insuring LPG carriers on a P&I mutual basis from 2007 to date, as this vessel payload shares the same properties as ammonia.

The Club's P&I portfolio consists of approximately 4,000 vessels, and subsequently, an extensive number of claims are handled every year.

In the investigation we have applied the following approach with the aim to identify the Club's experience from insuring vessels transporting ammonia as cargo:

1. 1. Identify weighted number of LPG carriers on risk per policy year since 2007
2. 2. Identify and investigate P&I mutual claims involving transportation of ammonia since 2007

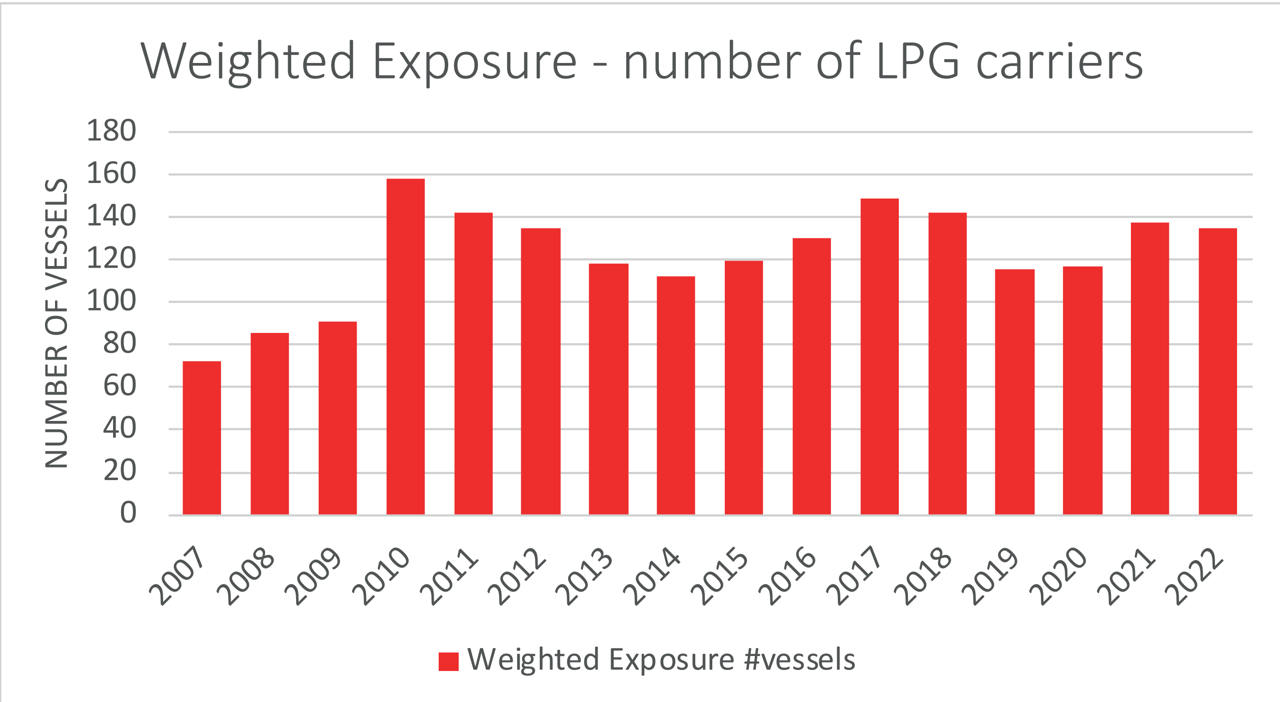
## SUMMARY FINDINGS

The Club's claims record shows that number of incidents related to transportation of ammonia is much lower than first anticipated. With a yearly average exposure of 123 LPG carriers on risk per policy year since 2007, Skuld have only handled six claims on a P&I mutual basis where ammonia as cargo was a contributing factor to the incidents.

The low number itself is an interesting finding. Through our investigation, we found that there was great variation in which operations the incidents were linked to for example connection/disconnection of cargo arm, to pressure testing on manifold, to regular maintenance of cargo equipment.

## EXPOSURE AND CLAIMS

The Club's weighted exposure in number of LPG carriers can be seen in the below graph and includes both Owners' Mutual P&I and Charterers' P&I. On average, per policy year, the Club have had 123 LPG carriers on risk.




Investigation into the Club's claims record shows that the number of claims related to transportation of ammonia is very low. Records show that since policy year 2007, Skuld have handled ten claims involving transportation of ammonia onboard LPG carriers. However, ammonia as cargo were only a contributing factor to six of the ten identified incidents.

Considering the low number of incidents, we decided to review each insurance case separately as per below list.

| Nb. | Region | Case description | Contributing factor(s) |
|---|---|---|---|
| 1 | Europe | Ammonia vapours escaped through the vent mast riser | |
| 2 | Europe | Pilot exposed to vaporized ammonia | Leak from expansion valve causing leak to pumproom |
| 3 | Europe | Terminal employee injured by gas release during pressure test of loading arm connection and manifold | Unproper connection of cargo ARM to manifold, and terminal employee should not have been on deck by the manifold |
| 4 | Europe | Two crew members and three shore workers exposed to vaporized ammonia | Quick Connect Coupling self-disconnected and became detached from the ship's manifold flange during purging of loading arm and shoreline(s). |
| 5 | Europe | Shore personnel exposed to ammonia vapours in connection with disconnecting the cargo arm from the manifold | Upon disconnection of the cargo arm some liquid remained in the cargo arm and spilled into the drip tray under the manifold. |
| 6 | Europe | Gas Engineer exposed to vaporized ammonia during maintenance work of cargo equipment | |

# Review of all claims related to transportation of ammonia

### CASE 1 - AMMONIA VAPOR RELEASE

One minute after confirming readiness to start discharging a cargo of ammonia, the overfill alarm was activated in cargo tank #2P. Shortly after the vessel started discharging on request by the terminal, the pressure on the manifold was at 5 Bar. Five minutes into discharging, the high-pressure alarm on cargo tank #2P was activated and seconds after the crew observed that the relief valve of cargo tank #2P was lifted and ammonia vapours escaped through the vent mast riser. Right after, the emergency shutdown was activated by CO and the excess cargo was transferred from tank #2 to #1. No injury to people was reported.

### CASE 2 – PILOT EXPOSED TO VAPORIZED AMMONIA

There was a minor leakage in the pump room due to a defective expansion valve. During the embarkment of the pilot, the pilot passed the pumproom at the exact time the doors to the same were opened. This caused the leakage to escape the pump room and exposed the pilot to a small amount of vaporized ammonia. The pilot was sent to the local hospital for a health check but was found in good condition.

### CASE 3 - TERMINAL EMPLOYEE INJURED BY GAS RELEASE DURING PRESSURE TEST

Before discharging a cargo of liquefied ammonia, a pressure test of the loading arm connection to the vessel was planned. During the leak test, no people are allowed on deck by the manifold area. However, terminal workers boarded the vessel during the leak testing and were located within the manifold area. The test failed due to an improper connection of the cargo arm to the ship's manifold, and clouds of vaporized ammonia were released, subsequently, exposing terminal workers to the toxic gas. The cargo compressor was immediately stopped, and terminal workers was taken to the hospital.

### CASE 4 – AMMONIA VAPOR INJURED TWO CREW MEMBERS AND THREE SHORE WORKERS

The vessel had berthed with a cargo of liquid ammonia. Discharging operations commenced and were completed the following day. After completion of the tank inspection, the vessel commenced hot gas blowing via the manifold connection to purge the loading arm and shoreline (s), as per the Terminal request. During this operation, the hydraulically operated Quick Connect Coupling self-disconnected and became detached from the ship's manifold flange. This caused a huge cloud of ammonia vapour to escape into the surrounding area. Seconds later, the emergency shutdown alarm was raised, the cargo compressor was stopped, hot gas blowing was suspended, and all vessel valves were closed.

At the time of the incident, when the automatic disconnection of the loading arm from the ship's manifold flange occurred, two crew members were in the vicinity. A first crew member was positioned at about 5-10 metres forward of the manifold and the second crew member was at a position about 15 metres aft of the manifold. Both reportedly sustained minor, non-fatal injuries caused by exposure to the escaping ammonia vapour. Reportedly, three terminal workers were also taken to the hospital due to the gas escape.

### CASE 5 – SHORE WORKER EXPOSED TO AMMONIA VAPORS

After the completion of discharging a cargo of ammonia, the shore personnel, being responsible for the purging of the cargo arm upon completion of cargo operations, started disconnecting the cargo arm. Upon disconnection of the cargo arm, some liquid remained in the cargo arm and spilt into the drip tray under the manifold. As a result, there was a cloud of ammonia vapours created. One of the shore workers inhaled ammonia. The shore worker was able to escape from the dangerous situation and, reportedly, sustained minor, non-fatal injuries caused by exposure to the escaping ammonia vapour.

### CASE 6 - GAS ENGINEER EXPOSED TO VAPORIZED AMMONIA DURING MAINTENANCE WORK

During maintenance work of cargo equipment, the gas engineer was exposed to vaporized ammonia in his eyes. After having contacted the hospital, it was decided to contact the local rescue team to arrange a medical rescue flight. The injured crew member was safely picked up by a helicopter and taken to the local hospital.

## Competency and training when handling ammonia

Changing skill needs as a result of new technology is a major challenge in the maritime industry. During 2022, the NMA has published new guidelines on competence require-ments related to chemically stored energy (battery). Going forward, similar assessments related to ammonia, hydrogen and autonomous shipping will be important issues. The NMA has ongoing work on competency requirements for seafarers on vessels with am-monia as fuel. One recommended project to take a look at is "Green Curriculum – Ensuring Safe Work for Mariners" (2022) by International Chamber of Shipping (ICS), Interna-tional Transport Workers Federation (ITF), Institute of Marine Engineering Science and Technology (IMarEST), The Nautical Institute (NI) and Ocean Technologies Group (OTG). This working group has a consultative status at IMO which means that their work could have a potential to influence the work to be done in STCW. NMA is also involved in work in Maritime Technologies Forum (MTF) together with Japan, UK, DNV, ClassNK, LR and ABS where competency and crew training is on the present agenda. Hopefully this will contrib-ute in closing the knowledge gap and provide value to the development of future training standards.

## Operational procedures when handling ammonia

It is mandatory to have operational procedures, this is covered by The International Safety Management (ISM) Code. The operational procedures are ship-specific and must be written to suit the ship with its ship-specific technology, ship-specific operation and trade. Operational and operating procedures when using ammonia as a fuel must include the additional hazards associated with handling ammonia, but cannot be a substitute for good system design with adequate safety barriers.

## Conclusion

Work package 2 have not observed any regulatory showstoppers for a Green Ammonia Powered Bulk Carrier. The regulations allow for alternative design through the IGF Code and such a process may rely on recognized class rules and guidance's until final IMO regulations are adopted. Challenges and hazards uncovered in the workshop must be resolved, but these are considered technical challenges and, as the working group assesses, there are no regulatory showstoppers inhered in these areas.

However, the following areas should be further processed:

Clarification and integration to the various port authorities to be performed. There may be national and local restrictions where the vessel may operate, perform bunkering, and possibly purge operational systems.

Education and training of crew in relation to operate ammonia fuelled ships. The work should be prioritized both nationally and internationally, in order to reach a common basic competence standard, regardless of nationality and flag (crew and ship).

Through The International Safety Management (ISM) Code, there is a requirement that the crew knows the systems on board and can handle these in a safe and secure way for both personnel and vessel.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3O REANMER
JEAN BALDOZA

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WORKSTREAM 3:

# Vessel Retrofit to Ammonia

## Aim of the work stream

To investigate whether one of Grieg Star's L-class vessels technically can be retrofitted from burning conventional fuel (i.e., VLSFO and MGO) to burn ammonia.

## Method

The overall workload within the workstream was split into 7 sub-streams, in large based on the companies represented in the pilot, and according to Figure 6.2.1. By doing so smaller (Team) meetings could be hosted, and where the discussion could be limited to what interested/concerned the participating parties in each respective sub-stream.

As the feasibility study phase of the pilot was restricted on time, and testing of new engines is both challenging and complex operations, there has been limited work with processes linked to the combustion: i.e., after treatment of exhaust gases, lubrication of the engine and potential changes to the turbocharger. All this due to limited data available from MAN's test bed.

It was also decided rather early in the process that the option with including auxiliary power generation should be excluded, as the primary focus in this pilot was the M/E which accounts for about 85% of the vessel's yearly fuel oil consumption.

To start the work with exploring various technical solutions, without waiting on input from other workstreams and/or internal research from member partners, a minimum requirement and assumption list was created – see Figure 6.2.2.

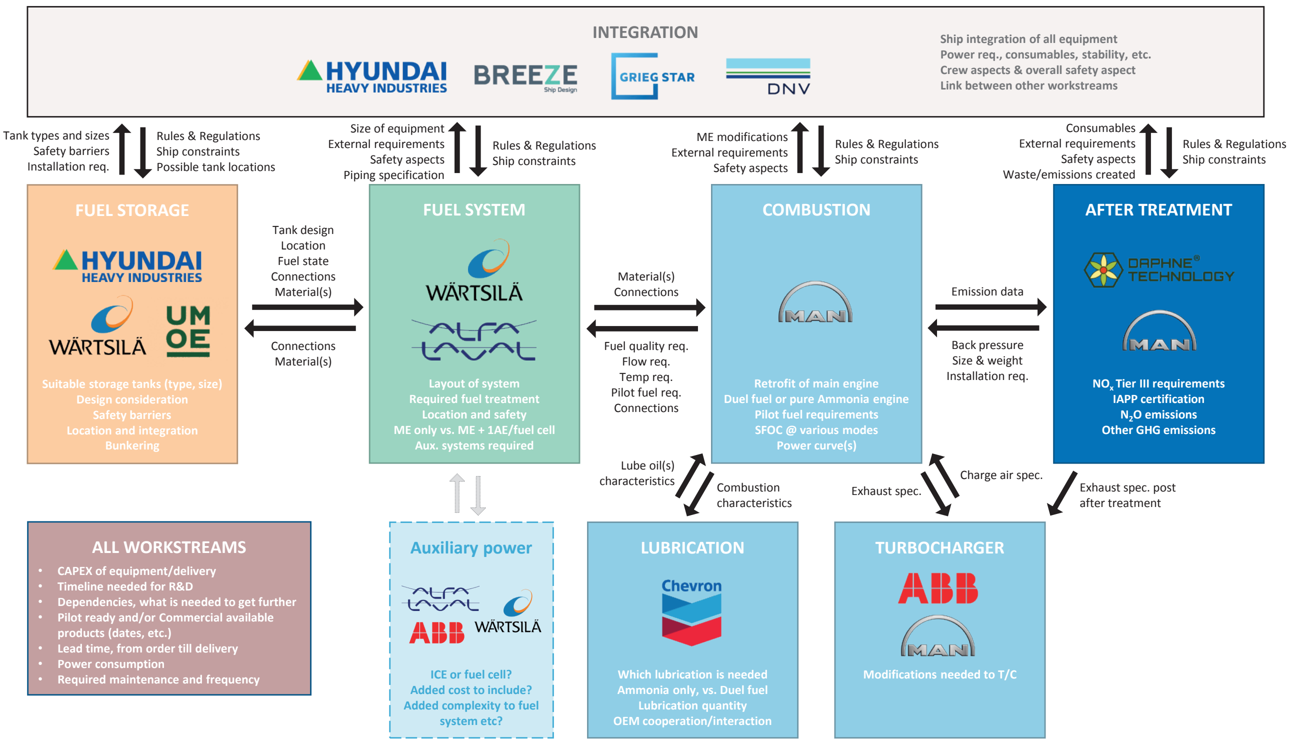



*Figure 6.2.1: Intended work setup within the vessel retrofit workstream.*

| | MINIMUM REQUIREMENT/ASSUMPTIONS | OPTIONS TO EXPLORE |
|---|---|---|
| FUEL STORAGE | • Receive chilled Green Ammonia by barge<br>• Tank(s) suitable to hold minimum 1,300 $m^3$ Green Ammonia (assumes 13kn sailing, 5% pilot fuel)<br>• Bunkering @ each continent, and both on STBD and PORT side<br>• Storage tanks either far forward or far aft<br>• Reliable tank soundings<br>• No safety risk for crew | • Type of storage tank (compressed, chilled, combination, etc.)<br>• Stand alone vs. integrated into ship's structure<br>• Several small tank vs. one large tank<br>• Ventilation of tanks<br>• Location of tanks, FWD vs. AFT<br>• Material selection<br>• Emergency release – e.g. in case of fire<br>• Purging of tanks for inspection? |
| FUEL SYSTEM | • Transport Green Ammonia from storage tank(s) to Main engine<br>• Do the fuel treatment required to meet MAN's preliminary requirements (at fuel inlet):<br>  • Min 99.5% (w/w) pure Ammonia<br>  • $H_2O$ between 0.1 and 0.5% (w/w)<br>  • Fuel pressurised to about 80 bar @ 25-55°C<br>• Any leakages to be captured, and not be a threat for the crew | • Additional cost to include fuel system for 1 A/E and/or fuel cell<br>• Fuel system CAPEX and OPEX for various options…<br>  • Liquid to liquid<br>  • Liquid to compressed to liquid<br>  • Compressed to liquid<br>• Size and complexity of each system (what can be installed)<br>• Design of recirculation system<br>• Purging system for maintenance |
| COMBUSTION | • Main engine (MAN B&W 5S60ME-C8.1) to run on Green Ammonia (diesel cycle)<br>• Engine to be dual fuel<br>• Propeller arrangement with fixed shaft<br>• Any leakages to be captured, and not be a threat for the crew | • Pilot fuel requirements running on Ammonia<br>• SFOC @ each operating mode<br>• Emissions @ each operating mode<br>• Purging system for engine maintenance |
| AFTER TREATMENT | • Emissions to meet regulations<br>• Total GHG emission to below today's levels (even if not regulated)<br>• Emissions released not to be harmful for living beings | • Best way to reduce $NO_x$ emission to be compliant with Tier III<br>• Any other emissions that must be treated/removed<br>• Different operation if running on VLSFO or Green Ammonia<br>• OPEX expenses with various systems |

*Figure 6.2.2: Initial list of minimum requirements and/or assumptions, and wish list of what to explore for each primary process. At large this remains valid today.*

## Main findings

In short it is technically feasible to retrofit Grieg Star's L-class vessels from burning conventional fuels to green ammonia, however it has been identified the modifications required are larger than initially anticipated and hence also the related costs. Main findings are:

- Today's fuel tanks are kept as is
- A single storage tank of about 2,000 m3 inside cargo hold no. 1 is the most suitable location
- Reliquefaction units, bunkering station, tank connection spaces (TCS) and ammonia release mitigation system (ARMS) installed in connection to the storage tank
- Fuel preparation room (FPR): Containing recirculation system, fuel supply system, fuel valve train, knock out drums and potentially the nitrogen plant, to be installed in a new engine room space inside starboard WBT no. 7
- All spaces with potential ammonia leakage(s), must be mechanically ventilated and require minimum 45 air changes per hour. In addition separate bilge system is required for all drip trays that potentially will be contaminated with ammonia
- All piping not caontained in secondary enclosures designed to safely handle ammonia leaks to be double walled
- Ventilation outlets to be located at least 10 m from any ventilation inlet, vent tower for controlled release of gases potentially contaminated with ammonia must have an outlet minimum 25 m from any opening. Emergency release of ammonia (e.g. during fire) is allowed through the latter
- Main engine (M/E) efficiency, burning ammonia expected to be equal to today's dual fuel engines (to be confirmed)
- M/E fitted with a selective catalytic reduction (SCR) to reduce $NO_x$ and $N_2O$ emission, the en-

gine's specific fuel oil consumption (SFOC) expected to increase with about 4%

- Ship's cargo hold capacity will be reduced with 4,522.6 m³ (6.77% of ship's original capacity). In addition container space of 30 TEUs will be lost from the weather deck (3.68% of ship's original capacity).
- It is estimated the vessel's DWT will be reduced with approximately 450 mt (0.88%) to accommodate new equipment and structure. If tank's full capacity is used the fuel weight will be about 1,325 mt, a 40% increase in the vessel's total storage capacity of fuel and lubricating oils

A simplistic overview of the proposed layout can be seen in Figure 6.3.1. Additional information of each system can be found in subchapters 6.3.1. through to 6.3.5.

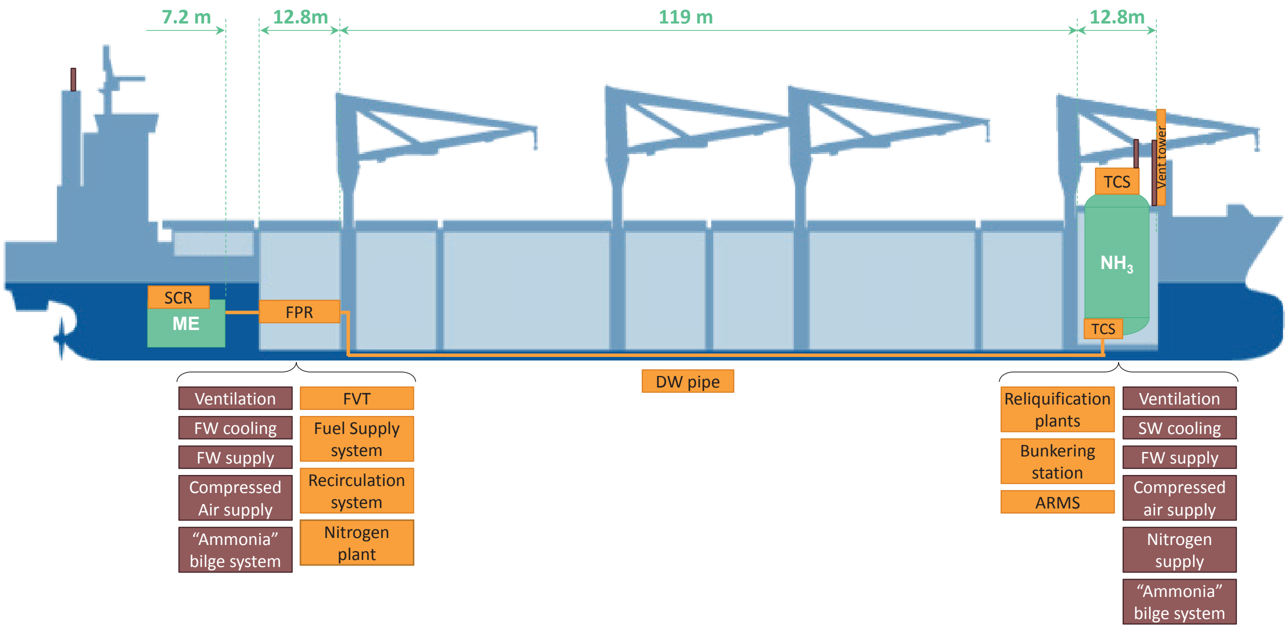



*Figure 6.3.1: Outline of main system components, and required subsystems/utilities (excluding power and firefighting capabilities)*

Items that require further research and investigation:

- Global strength and stability of the vessel with all added equipment and structures
- Strong indication class notation HC-B cannot be kept, so a downgrade to HC-A is likely. But with what restrictions?
- Design of tank supports, and their alignment to primary structural members
- Maintenance of equipment potentially containing Ammonia: Purging procedures (including time required)? Safety precautions when opening up the equipment? Will the crew be qualified to maintain everything? Shipyards and their standpoint on maintaining these systems? Availability of qualified service engineers capable of maintaining all equipment?
- Parking arrangement for cargo crane no. 1, in respect to ventilation and vent tower location? As well revision of crane's boundary limits (in regards to collision with new structure(s))
- Handling of equipment going in/out of the ship's equipment store, located forward of cargo hold no. 1: Can cargo crane no. 1 still be used for these purposes (as cargo may be lifted over the tank)?
- Placement of ventilation ducts and outlets in regards to potential ammonia content in exhausted air, especially in regards to aft duct for FPR (and potentially M/E). This as $NH_3$ is hygroscopic (i.e. absorbs humidity) so if released into humid air will fall rather than dissipate into the air. This might be a risk in regards to the lifeboat's placement
- The separate bilge system that will be used for collecting ammonia contaminated water (ammonium hydroxide), where to dispose and what are the storage requirements onboard?

There are for sure some other aspects that have been overlooked, and that would require careful consideration if going forward with the project. In addition it is expected initial designs and theories must be revised as more and more knowledge is gained from both full scale testing and early ammonia projects, as well during the final design work. In below subchapters are our findings presented in more detail.

# Fuel storage tank and auxiliary equipment

The correlation between fuel state and type of tank is strong, as well what auxiliary equipment that is needed to keep the fuel in the desired state. As a decision on one parameter, will affect the other ones, it was decided to decide the fuel state first, and from there decide what tank type would be the most suitable, and last what auxiliary equipment/systems that would be required.

### FUEL STORAGE STATE AND TANK TYPE

Large volumes of ammonia available for bunkering will be shipped fully refrigerated and thus also bunkered fully refrigerated. Thus, this gives a design prerequisite of both the onboard fuel storage and fuel treatment system that it shall be able to handle this condition. For a given onboard fuel storage volume, and provided that systems for pressure maintenance are adequate and according to governing acts and regulations, bunkering fully re-frigerated ammonia allows for higher vessel autonomy compared to bunkering fully pressurised ammonia.

Ammonia shall be stored onboard in a semi-refrigerated state. This solution provides the best balance between safety, cost and general operational flexibility. Ammonia can be bunkered from a fully refrigerated state (-33 °C), and safely stored at temperatures up to +5 °C (equivalent to a design pressure of a tank of 5.1 bara). A summary of evaluations performed when selecting Semi-refrigerated as the storage state for ammonia in the Pilot is available upon request.

A Type C-tank has been selected for fuel storage. The key rationale behind the selection are:

- Schedule and ease of integration; although IMO type A tanks will give more storage volume/hull volume they will require hull strengthening and full secondary barrier with a significantly increased retrofit time and are thus not recommended for retrofit projects.
- Design flexibility; IMO type C tanks allow for more ship layout variants to consider in selection of the optimum location.

Asummary of the evaluations performed when selecting an IMO Type C tank for fuel storage in the Pilot is available on request.

### STORAGE TANK SIZE AND LOCATION

Assuming that bunkering facilities are available at each port of call, the longest leg of the route governs the required storage volume.

Based on fuel consumption, loading limit, tank design temperature/pressure, and appropriate margins, the required volume of the storage tank(s) is calculated to be about 2,000 m³. Table 6.3.1.1 present what storage capacity that would be required to sail the longest leg on ammonia at 5 different speeds. Details of calculations done to obtain required tank volumes are available upon request.


REQUIRED HOLDING CAPACITY

| Speed | Duration | VLSFO | NH3 |
|---|---|---|---|
| [kn] | [Days] | [mt] | [m3] |
| 10 | 20.5 | 375 | 1,274 |
| 11 | 18.6 | 418 | 1,417 |
| 12 | 17.1 | 470 | 1,593 |
| 13 | 15.8 | 529 | 1,798 |
| 14 | 14.6 | 604 | 2,046 |
| 15 | 13.7 | 691 | 2,343 |

Assumptions:

- ME VLSFO consumption based on longest leg only
- 5% pilot fuel required (energy based)
- Gravimetric energy density: 18.6 MJ/kg (NH3) and 41.6 MJ/kg (VLSFO) respectively
- $\rho NH_3$ @ 5.1 bar & 5°C = 626.3 kg/m3
- 30% fuel margin added and maximum filling 98% (used for both VLSFO and NH3 calculations)

*Table 6.3.1.1: Required holding capacity of ammonia, based on the longest sailing leg (4,915 nm) and speeds from 10 kn through to 15 kn. Assumptions used are stated under the table. The average sailing speed for our L-class vessels ranged between 12.9 and 13.7 kn over the last 5 years.*

As comparison the existing FO tanks have a total holding capacity of 3,185 m³. If applying the same safety margin and maximum filling rate as the assumptions above, the vessel has an endurance of 67 days compared to about 15 days sailing on Ammonia.
Several locations were considered for locating the fuel storage tank(s) including various cargo holds, poop deck, longitudinal tanks on deck and extension of the hull. Figure 6.3.1.1 shows early and initial concepts of these.

In addition to tank location, the number of storage tanks the required volume should be distributed between was also considered.

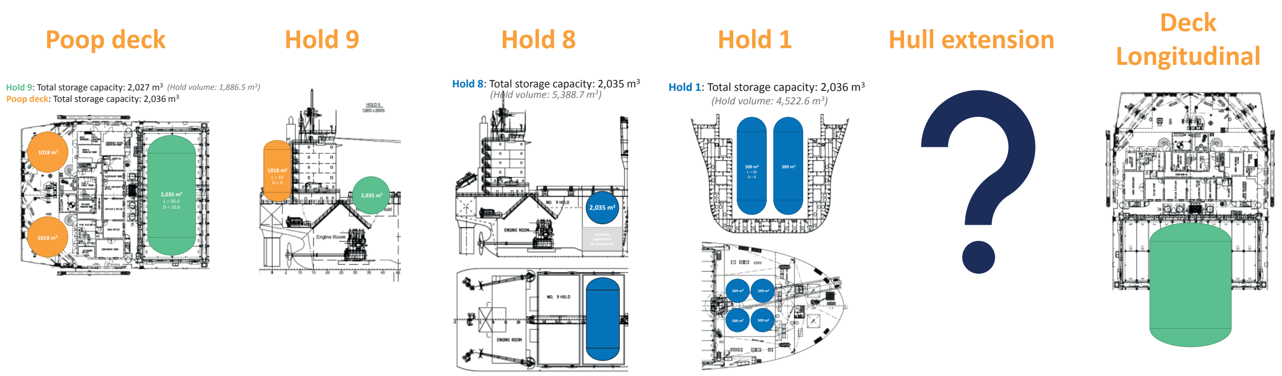



*Figure 6.3.1.1: Overview of potential tank locations considered, some excluded early in the process.*

The selected solution is a single, vertical, insulated 2,000 m³ Type C tank located in Hold 1. A single tank was selected as it provides the most efficient use of the available space. Some key considerations in the selection of Hold 1 include:

- Safety – bunkering and fuel storage located away from accommodation, good dis-tance from ship side to storage tank (exceeding Class requirements), have the least impact on cargo operation during port calls
- Effective use of space (vertical tank orientation)
- Available space in Hold for placement of reliq. units
- No impact on ability to carry deck cargo (e.g. windmill blades)

The expected expansion of the tank is approximately 15 mm. The tank shall be supported by one fixed and one sliding support.

The tank weight is approximately 225 t.

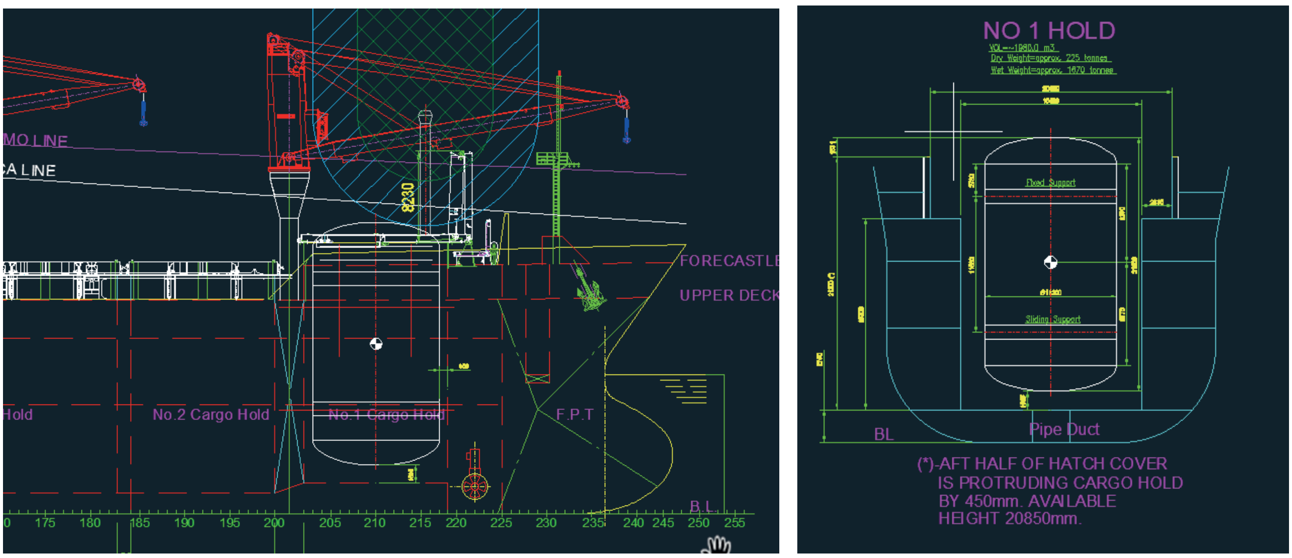



*Figure 6.3.1.2: 2,000 m3 Ammonia Storage Tank located in Hold 1, see Appendix T5*

### REQUIRED AMMONIA FUEL STORAGE AUXILIARY TECHNOLOGIES

For tanks containing liquefied gases that do not have a design pressure equivalent to the vapour pressure of the fuel at maximum ambient design temperature, two or more independent pressure maintenance systems are required. Possible pressure maintenance systems may be any one of the below or in combination:

- Oxidation of boil-off gas vapour
- Cooling of liquid phase
- Reliquefaction of boil-off gas vapour

Oxidation of boil-off gas vapour is a direct loss and is not recommended due to both environmental and economic reasons.  Cooling of liquid phase requires fuel circulation and a closed cycle refrigeration loop. Reliquefaction of boil off gas vapour uses a semi – open refrigeration loop of same principles as conventional cargo reliquefaction units on LPG carriers however smaller in size and capacity.

Smallest current commercial reliquefaction unit from e.g. Wärtsilä has a net cooling capacity of 206 kW at 36°C seawater temperature and 1 bara suction pressure. This capacity is some 3 to 4 times higher than required. Due to a current lack of smaller reliquification units, this unit is used as the basis for further evaluations in this Pilot study.

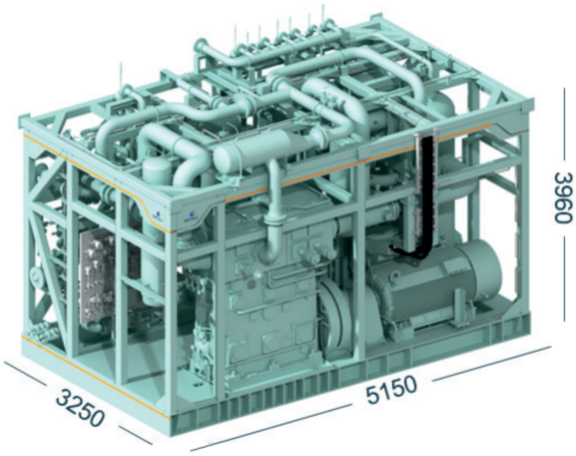



*Figure 6.3.1.3: Typical boil off gas reliquefaction unit – note, capacity is 3 -4 times the requirement for the Pilot project.*

As discussed above, two independent systems for pressure maintenance are deemed required. Hence, a skid with two identical and independent units is proposed. Alternatively, two separate small skids could be considered. The refrigeration systems are designed for direct condensation against seawater and return of condensate to the fuel tank. Estimated total weight is 27 metric tons, dimensions as given in Figure 6.3.1.3.

The refrigeration units shall be in a dedicated room, and require active ventilation, see subchapter 6.3.5 for additional details regarding ventilation. To distribute the weight between port and starboard side it was concluded the best was to place one unit on each side, and within its own ventilated space.

Each refrigeration unit shall operate independently and there shall be two independent vapour lines from the fuel tank and two independent vapour headers running towards the refrigeration units. Similarly, there shall be two independent condensate return lines to the fuel tank.

## Fuel supply system

The fuel supply system: including the recirculation system, fuel supply system (FSS), the fuel valve train (FVT), knock out drums and ammonia catch system, will all be located in the fuel preparation room (FPR). As the FPR by class rules is not allowed to be located inside the engine room (E/R), nor have direct access to this, the intention is to create a separate space for this inside water ballast tank (WBT) 7S, and where access to this will be from the cofferdam between cargo hold space 7 & 8 and potentially the escape trunk from the engine room, located forward of hold no. 8. In addition the FPR will require a 900 mm cofferdam between itself and the E/R. See subchapter 6.3.5 for additional information about the new machinery space.

The fuel supply system will, to a large extent, resemble the proven systems for LPG fuel supply systems. The fuel system will be divided into one low pressure side and one high pressure side where the low pressure side comprises the fuel tank with low pressure pumps sending liquid ammonia at pressures in the range of 21 – 24 bar to the high pressure side.

The high pressure side located inside the fuel preparation room comprises the remaining fuel supply system, and will among others increase the pressure to about 80 bar, control the flow velocity, ensure correct fuel temperature and start/stop processes of running the engine on ammonia. The latter also includes emergency shutdown (ESD) of the engine.

Figure 6.3.2.1 shows a schematic overview of the complete fuel supply system as mapped out by MAN. Please note this is only a preliminary layout, and that at writing of this report it is already known MAN has done several changes. It should also be stated that Wärtsilä has their own proposed system layout, as well Alfa-Laval, and where each solution have their benefits and drawbacks.

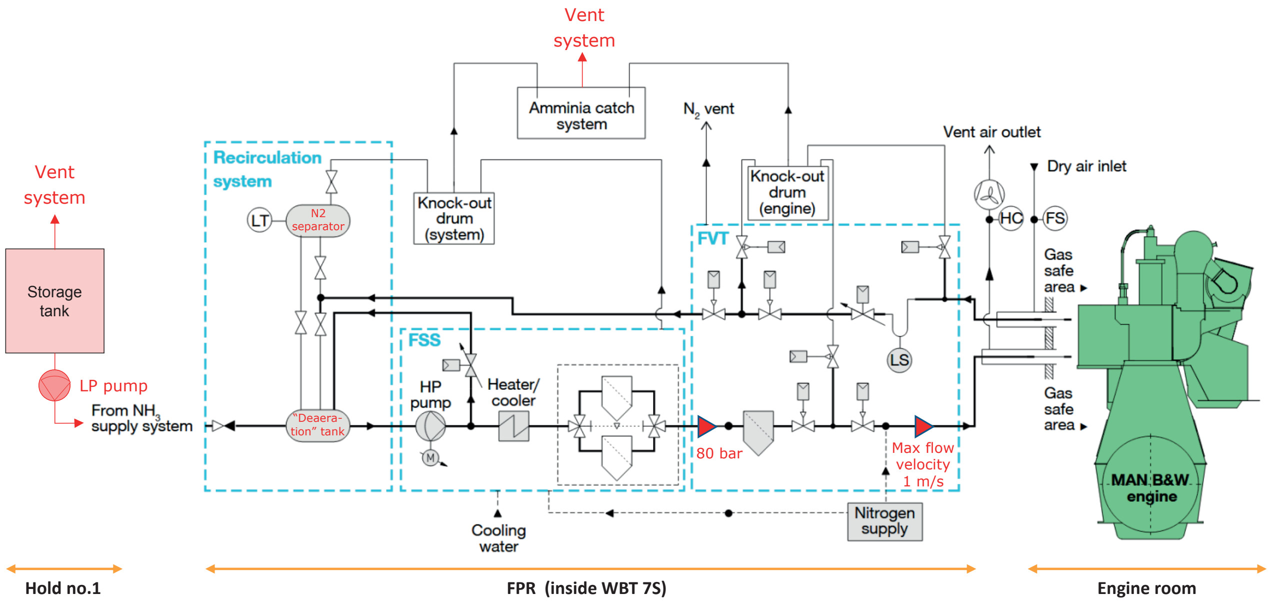



*Figure 6.3.2.1: Principle of fuel supply system, as mapped out by MAN. Some small changes are expected. Wärtsilä's fuel system design can be found in Appendix T6*

What the final fuel supply system will look like is not 100% sure, and there might be findings during full scale testing that requires additional changes. However it is not believed any change would cause a showstopper for a retrofit project. For reference Wärtsilä's FSS comprises the following main components (table 6.3.2.1):

| Equipment | Description |
|---|---|
| Fuel Tank | 1 x 2,000 m3 (gross capacity) |
| LP Pumps | Two centrifugal pumps, one in operation and one in standby |
| Fuel conditioner | One Plate Heat Exchanger to adjust the temperature to correct level by heat exchanging with glycol / water mixture |
| HP Fuel pump | Two pumps, one in operation one in standby |
| Recycle cooler | One Plate Heat Exchanger used to cool down the returning flow from the Fuel Valve Train (FVT). Please note this is not part of MAN's solution, as the plate cooler is installed after the HP pump. This saves the cost of an additional heat exchanger, but will be priced higher as it must withstand considerable higher pressures |
| Catch tank | Liquid collection tank to recover liquid fuel from the fuel lines after shut down, fuel change or ESD |

*Table: 6.3.2.1: The main components of the fuel supply system, and a short description of their purpose and function*

## Main Engine

As mentioned above the full scale testing of MAN's Ammonia engine was delayed throughout the pilot, and where final design considerations hadn't been taken (as test data from test bed is required). Due to this reason there was limited information that could be shared at the time of writing this report, but where the premisses from the engine designers were that the engine efficiency should not be any worse than today's 2-stroke engines. That said, the required amount of pilot fuel was not known but where the aim was to match today's LNG engines in pilot fuel requirements.

The main engine installed onboard Grieg Star's L-class vessels are 5S60ME-C8.1 engines, i.e. an engine with 5 cylinders, 60 bore pistons and electronically controlled injection. This is the engine family (S60) MAN has announced will be the first ones running on Ammonia, and where retrofit packages will be made available. A typical retrofit package will include:

- New cylinder heads, as shown in Figure 6.3.3.1
- Various piping on the engine
- Fuel valve train (inside FPR)
- Knock out drums (inside FPR)
- N2 separator (inside FPR)

As it is 100% certain MAN will have a 2-stroke engine capable of running on ammonia, there is no concern that a retrofit kit would not be available. And therefore no showstoppers were identified in connection to the main engine, and throughout the pilot. That said, it is unclear what the operating expenses will be and whether it will be possible to achieve the engine efficiency aimed for, and hence recommended to await full scale engine test data to have all this verified. Last but not least, there are large uncertainties what the procedures will be in regard to the maintenance of this

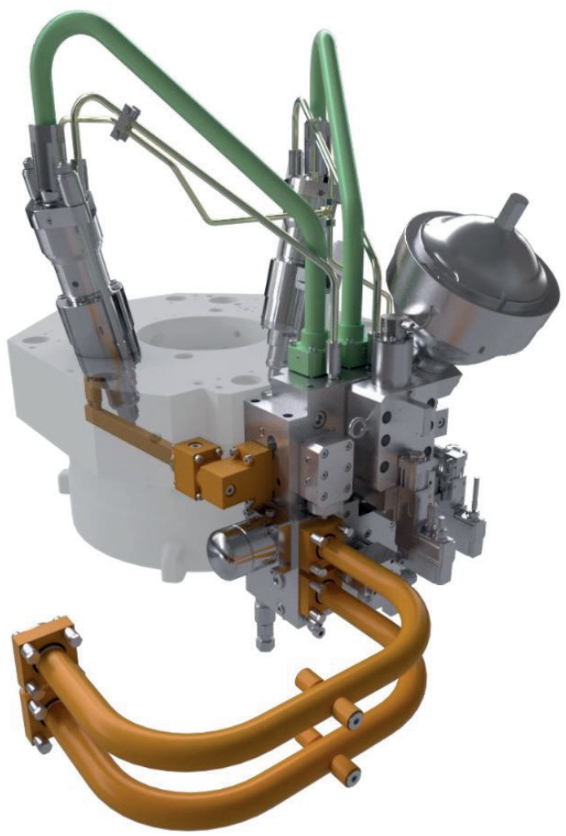


*Figure 6.3.3.1: Ammonia cylinder top. Yellow pipes are doubled walled ammonia pipes, green hydrau-lic pipes for the fuel injectors. Small pipes to fuel injectors are for sealing oil. The big aluminium block is the equivalent to FIVA valves on MAN ME engines (electronically controlled engines)*

equipment, both from scheduled maintenance and emergency repairs. It is believed that MAN will gain some experience on these topics during the full test scale, and hence better advise what precautions that must be taken and procedures followed to overhaul the various components

### LUBRICATING OIL FOR MAIN ENGINE

As no full test scales have been done till today, no clear indication exists what tuning is required on the lubricating oil's formulation to ensure efficient and sufficient cylinder lubrication. That said it has been decided that existing BN40 cylinder oils, meeting today's category II requirements, will be used as starting point and further development of the product taken from there. What is clear is that the amount of pilot fuel will have a large impact on what the final product will look like, and that required feed rates must be determined from scrape down measurements and evaluating engine condition by port inspections as done today.

For other new oils, such as sealing oil, engine tests will reveal whether this is something that must be considered as a consumable and hence what specification it should meet. As well what an appropriate stock onboard would be.

## Post treatment

Exhaust gases created by combusting ammonia will be rich in $NO_x$ and also contain $N_2O$, where the latter is also known as "laughing gas" and has a $GWP_{100}$ of 265 times $CO_2$ (according to IPCC's 5th assessment report). Hence it is crucial that exhaust gases go through a post treatment to ensure the emissions released to air will not contain any $N_2O$, nor exceed $NO_X$ emission levels currently in place ($NO_X$ Tier II and Tier III rules). All this can be solved by using a SCR.

As MAN's full scale engine test hasn't yet started, no emission data is yet available and consequentially unknown what concentrations of $N_2O$ and $NO_X$ the exhaust gases will contain. Or for that matter any other green house gases (GHG), or potential harmful gases such as $NH^3$. That said there has been laboratory research in the field and where some preliminary findings have been done:

- Indication that plasma enhanced SCRs have the greatest potential of reducing $NO_X$ and $N_2O$ in exhaust gases
- Concentrations of $N_2O$ in exhaust gases to be around 100 ppm
- About 4% of the engine's $NH_3$ supply need to be used to treat the exhaust gases

With this information the required ammonia storage would increase from 1,798 $m^3$ to 1,870 $m^3$ (72 $m^3$ increase) if sailing the longest leg at 13 kn. The actual consumption – excluding the 30% margin and maximum filling rate of 98% – would be about 54 $m^3$.

As more experience is gained what the composition of exhaust gases are – combusting ammonia inside a pilot fuelled 2 stroke engine – the more detailed research can be done into novel SCRs technology to ensure the total emission of GHGs will remain low. No technical showstoppers have been identified that new technology will not be able to solve emission challenges, but the cost of running these might be high.

## Ship integration

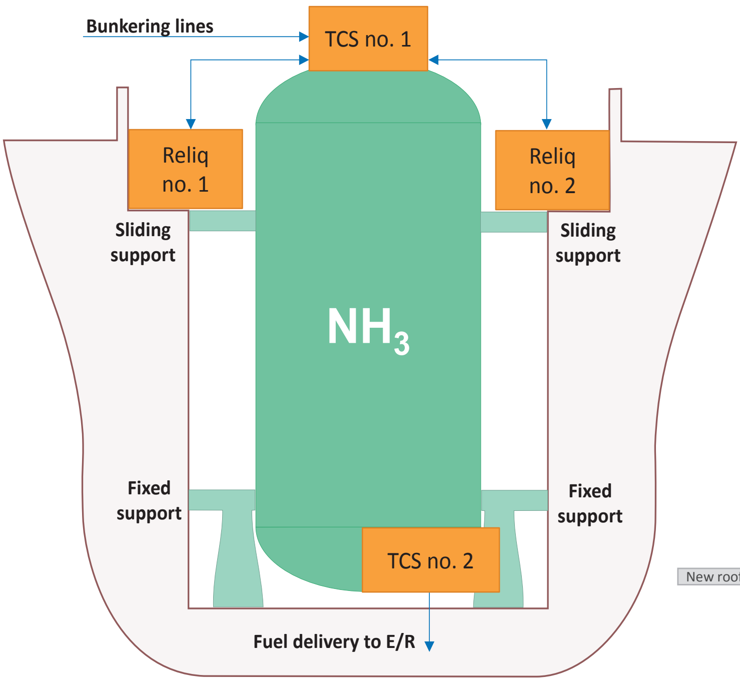
All equipment above must be integrated into the existing hull, as well must be connected to each other to operate seamlessly as a single large system, and this with safety and reliability in mind. This part will try to add some insights into those aspects, as well capture some common systems that must be included in the final package.

### HOLD NO. 1 MODIFICATIONS

The storage tank for ammonia will be located in existing cargo hold no. 1, and placed in vertical orientation in the hold's centre. Distance between the tank and forward/aft bulkheads will be 800 mm each, while distance to port/starboard bulkheads 2,100 mm each (4,800 mm at top part). A space of about 1,600 mm will be left between hold's tanktop and the storage tank's bottom.

The intention is to fix the tank rigidly in one end, and let the other end move freely to not introduce and stresses due to temperature expansions of the tank (-33°C degrees to +5°C). As the vertical forces must be transferred to the hold's tanktop, the bottom end will be fixed and absorb forces in all directions, while the top support only take up forces in the plane: i.e. horizontal forces.

The tank will be fitted with 2 TCSs, one in the bottom which only will contain the 2 LP pumps for fuel delivery to the FPR. While the top TCS will contain all other connections: bunkering lines (delivery and return), safety valves, connections to reliq. units (vapor suction and condensate return) and vapor sampling valves (at 3 different tank levels).



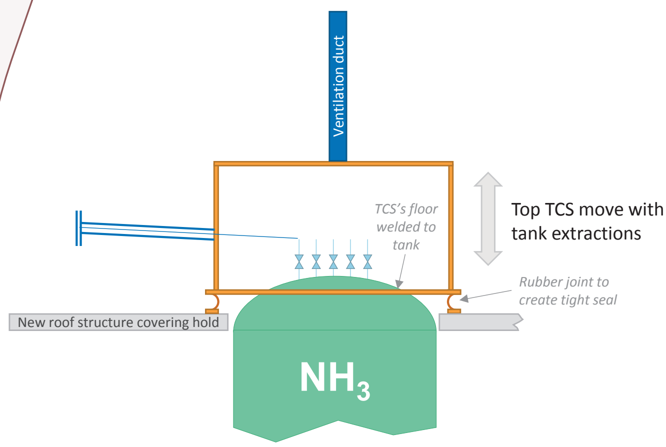




*Figure 6.3.5.1: To left configuration of storage tank, TCSs and reliq units inside cargo hold no. 1. To right schematic overview of top TCS and its integration to new roof structure (replacing existing foldable hatch cover). Expected tank expansion (due to temperature changes) is 15 mm.*

To protect the tank and the cargo hold from green sea, the existing hatch cover (foldable) will be replaced with a permanent roof structure. As the top TCSs, welded to the tank's top, need to expand with the storage tank's expansions it cannot be rigidly fixed to the new roof structure. To ensure the weather tightness of the hold, a rubber joint will be installed between the new roof structure and the top TCS. See Figure 6.3.5.1 for details.

The reliq. units will be installed on the existing benches inside the cargo hold, but where they would need additional floor structure so some new balconies would be required to be built. Double walled piping between reliq units and TCS to be routed through new roof structure and new machinery spaces for reliq. units (as these need forced ventilation). Due to vertical movement of top TCS, it is estimated closest pipe support to TCS cannot be any closer than 4-4.5 m.

The reaction forces the supports must withstand have been calculated for all relevant cases required by the IGF design code and class society requirements, and where the extreme values obtained are found in table 6.3.5.2.

| Support | X | Y | Z |
|---|---|---|---|
| Bottom | ± 35,266 | ± 36,884 | 13,108 |
| Upper | ± 1,638 | ± 4,846 | 0 |

*Table 6.3.5.2: Most extreme reaction forces that supports will experience in each direction. All values in kN. X is in longitudinal direction, Y in transverse and Z in vertical*

The largest forces the supports may experience will be in the transverse plane (X-Y), and on the bottom supports. To ensure these large forces are effectively distributed and absorbed by the hull it is important that the supports are aligned with the hold's primary structure. See Figure 6.3.5.2 where all main girders and stringers have been highlighted in regards to the tank.

No design nor engineering has been done on the support structure from the tank to the hull, so if the project would be brought forward this must be looked into, as well the interaction between the tank and hull in regards to allowable hull movements. As the forces are large, it is expected hull reinforcements will be required even if the forces primarily are directed to the hull's main structural members.

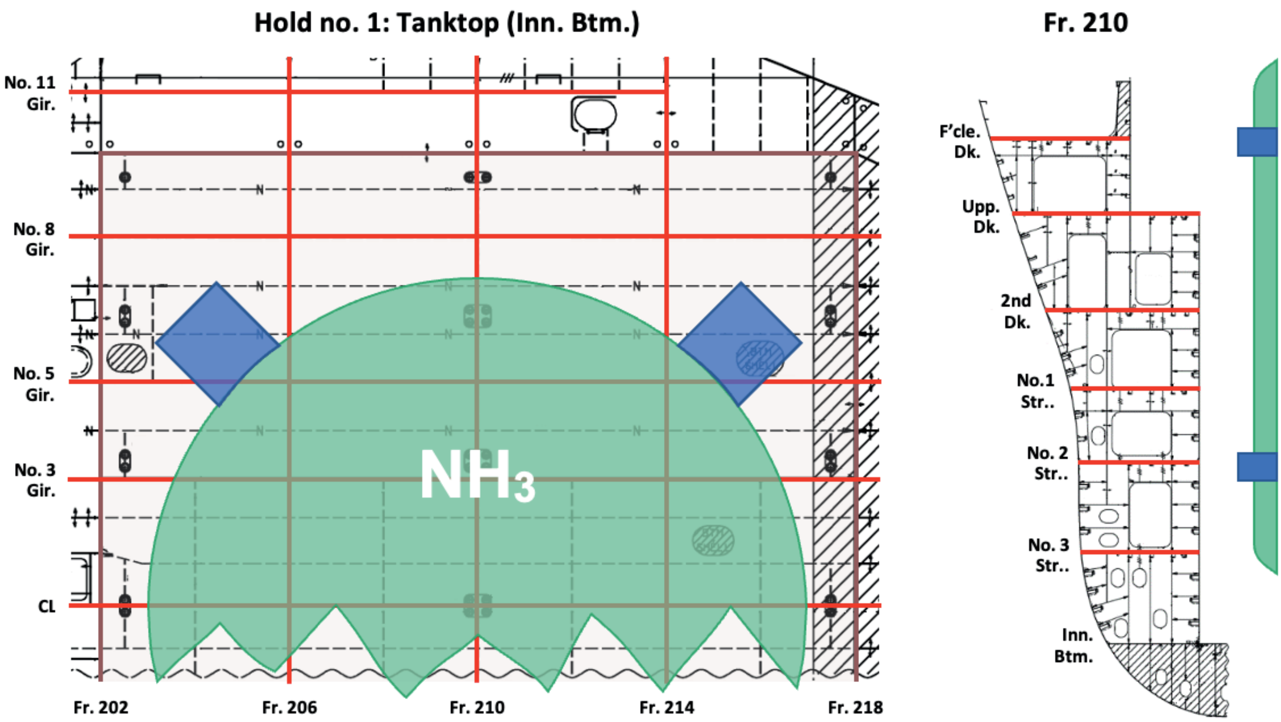



*Figure 6.3.5.2: To left ammonia storage tank (green) seen from the top, and the bottom supports (blue). The cargo hold's bottom is bounded and shadowed in light brown, and where primary structural members are highlighted with red lines. Recommended that vertical forces from the bottom tank supports are distributed along main girder no. 5 and 8, as well frame 202 and 206 for the aft support, and frame 2014 and 218 for the forward. To right are the main structural members in vertical direction shown, and where it is recommended that the bottom support (fixed) is aligned with 2nd stringer, and the top support (sliding) with the forecastle deck. The figure is only showing frame 210, but where the main structural members are the same for frame 202 and 218 (aft and forward bulkhead of cargo hold) to where the supports are intended to be connected.*

## FUEL PREPARATION ROOM

As the FPR is not allowed to be inside the engine room – i.e. no direct access is allowed between them, nor are they allowed to share boundaries other than if separated by a cofferdam of minimum 900 mm width – it was decided to utilise the neighbouring WBT 7S to avoid major engine room modifications.

The FPR's location, size and alignment to existing hull structure inside WBT 7S can be seen in Figure 6.3.5.3 In this the existing escape trunk from the engine room is visible (green), as well existing cofferdam between cargo hold no. 7 and 8. As the class rules require a cofferdam between the FPR and engine room, a new cofferdam will be fitted between these two spaces.

The LP fuel supply will be routed into the FPR through the forward cofferdam (hold 7/8), as well the return line to the ARMS system for any gases that must be neutralised. The HP delivery line to the engine, and the return will be routed through the forward cofferdam. Through this cofferdam also pipes for FW cooling, compressed air, service FW and ventilation ducts will be routed.

## NITROGEN FOR PURGING

No evaluation has been made whether a nitrogen plan will be installed, or if the vessel should rely on compressed nitrogen delivered on bottles, but based on the pipe length from the FPR to storage alone (0.30 m3 ≈ 210 kg NH3) a nitrogen plan may be required. This may be installed in the FPR, or inside the E/R not too far away from the new cofferdam.

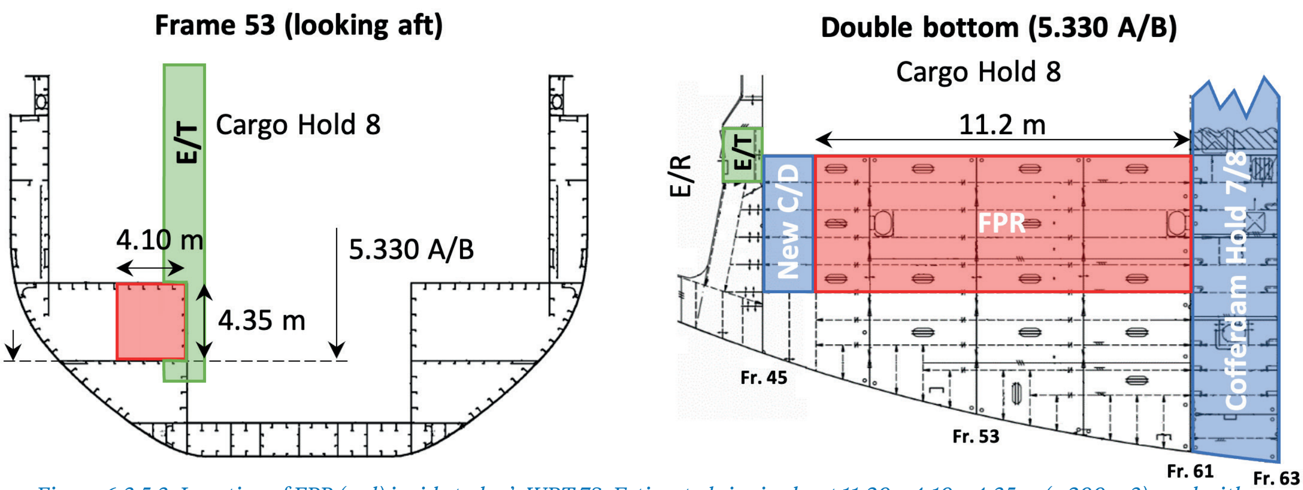



*Figure 6.3.5.3: Location of FPR (red) inside today's WBT 7S. Estimated size is about 11.20 x 4.10 x 4.35 m (≈ 200 m3), and with a new cofferdam (small blue rectangle, ≈ 28 m3) installed between engine room and FPR. This would also allow direct access to escape trunk (green) if found desirable. Total ballast capacity removed from WBT 7S is estimated to about 240 m3, equal to about 23.5% of tank's original capacity. Added weight, including equipment and new structure, is estimated to about 35 mt.*

## BUNKERING SYSTEM

The fuel bunkering system should preferably be located near the fuel storage tank, on open deck area and should at least have the following features:

- Control and monitoring of the bunkering operation shall be possible from a safe location where tank pressure, tank level and overfill alarm is easily available to monitor.
- A gas detection system
- A water spray system (water curtain) designed to limit the spread of ammonia vapour in case of any leakages occurring. All possible leakage points at the bunkering station shall be covered.
- Remote start of water spray pumps as well as remote operation of any normally closed valves shall be in a readily accessible position that is not made inaccessible in case of fire or leakage of toxic gases in the areas to be protected. Further, remote operation of water curtain system shall also be available at the bunker station control platform.

The bunker lines are without secondary enclosures and shall be drained after bunkering either to fuel tanks or bunker vessel. Drainage must also be possible during ESD. The bunkering manifold should be located above tank connection point to enable drainage to the tank. When not in operation the bunker system shall be drained and purged with nitrogen.

The bunker manifold shall be equipped with dry-disconnect couplings and break-away devices protecting the transfer system from overstressing in case of drift-off.

The bunker station shall have the option of bunkering with vapour return back to shore/bunker vessel as well as being able to bunker without vapour return. Bunkering without vapour return is made possible with simultaneous operation of the refrigeration units.

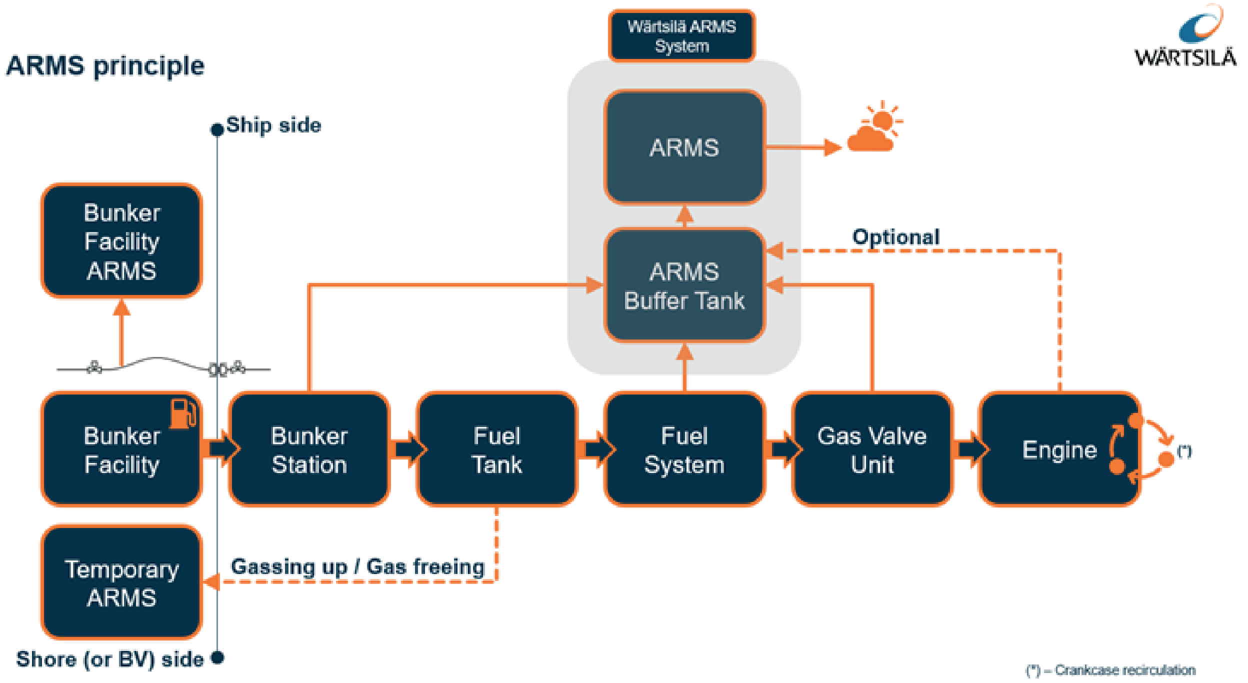



*Figure 6.3.5.4: Principle of Wärtsilä ARMS system*

## AMMONIA RELEASE AND MITIGATION SYSTEM

As per (Class) requirements, an Ammonia Release and Mitigation System (ARMS) is required on all marine vessels using ammonia as fuel. The requirement is definite and dictates that any releases shall not have ammonia concentration exceeding 30 ppm.

There are several known principles that may offer ARMS functionality, but no system is as yet commercially available for marine installation.

Absorption/scrubbing with water or an acid solution is frequently used onshore but adds a logistical element that is undesirable onboard a ship. Additionally, ammonia solubility in water or water/acid solution is temperature dependent and the solution may release ammonia if exposed to higher temperatures.

A promising alternative technology is oxidation where ammonia releases are oxidized to water, nitrogen and nitrogen compounds.

Regardless of operation principles, the ARMS system shall collect ammonia from piping and engine during purging or draining operations, handle releases from safety valves on piping system (not safety valves on fuel tanks) and any other operational releases.

Wärtsilä is currently developing ARMS technology based on oxidation and which will offer simple and reliable operations.

As the exhaust from the ARMS system must be released at a safe distance from any openings onboard, it is found the best solution to utilise the vent tower for this purpose. As this will be located forward, next to the storage tank, it has been found the most ideal is to locate the ARMS system inside hold no. 1 and forward the reliq unit on port side's bench. See more details about vent tower and etc. below.

## VENT TOWER AND MECHANICAL VENTILATION

In terms to ventilation there are 3 aspects that must be considered, they are emergency release of ammonia, release of operational waste (through ARMS) and mechanical/forced ventilation of spaces containing ammonia equipment. More details of each system and their specific requirements below.

**Emergency release:** In case of fire, or any other operational malfunctions, and where the pressure inside the ammonia storage tank suddenly increases and exceeds the set safety pressure, the overpressure should be released through a vent tower. This to prevent the tank to explode, and cause a larger hazard than if released "controlled". This vent tower must have its exhaust minimum 25 meters from any openings, and ideally located as close as possible to the storage tank. From all practical means a location forward of cargo hold no. 1 seems to be the most sensible location, but will nevertheless require some modifications to existing ventilation covers, access doors and potentially baby hatch to equipment store. This need to be further studied if the project is brought forward.

**Exhaust from ARMS:** As mentioned above operational waste from handling ammonia onboard must be sent through the ARMS to ensure the concentrations of ammonia is below 30 ppm. To safely release these gases the class rules state they should be discharged no closer than 25 meters from any opening, which is the same requirement as for the vent tower. To avoid 2 towers of 25 meters, by all practical means it has been found best to combine these two into a single tower.

**Forced ventilation:** All spaces containing equipment handling ammonia, and where it is an increased risk of potential leakages (e.g. valves, joints, seals, etc.), should continuously be ventilated. The requirement states that each such space must have 45 air changes per hour, and hence it is desirable to keep those spaces small. That said, there is also a requirement on number of air changes per $m^2$ wetted drip tray area the space contain, and which is 300 $m^3$/h. So both requirements should be taken into account when determining the sizes of these spaces (e.g. TCS, FPR, Reliq. units, ARMS, etc.). Further there is a requirement on redundancy, and hence each space must be equipped with minimum 2 fans, and where each of them must have a capacity of minimum 30 air changes per hour. In terms of the exhaust these must be minimum 10 meters from any ventilation inlet, and at least 4 meters above main deck.

As there are spaces that require forced ventilation both forward and aft of the vessels, we see that we need a common exhaust mast for all the equipment aft (FPR and ME), as well forward (TCSs, reliq. units and ARMS). As the top TCS must be free to move with tank expansions, a separate ventilation tower would be needed for this space. For the other 4 spaces it should be possible to combine all the exhaust through the same tower, and ideally be incorporated into the vent mast structure. For the aft tower, the exact location has not been determined, but due to close proximity to accommodation it may require to be routed all the way to the top of funnel/ accommodation.

## BILGE SYSTEM FOR WATER POTENTIALLY CONTAINING AMMONIA

All machinery that is used with ammonia will also need periodical maintenance, and where it must be expected some ammonia remains inside the equipment after nitrogen purging has been completed. To safeguard the crew/service engineer performing the maintenance, it is likely FW will be used to ensure those gases are mixed with water rather than being a potential risk to the engineer. Hence all ammonia related equipment must be fitted with drip trays, which are separate from the existing bilge system. This as the ammonia contaminated water, also known as ammonium hydroxide, is both toxic and an environmental hazard and consequentially cannot be pumped overboard and should be disposed at shore. It is unknown whether there will be infrastructure for this in all ports, but expected ports delivering ammonia to the vessel would also be able to handle this "waste".

The exact requirement of this bilge system is not known, and what an appropriate storage tank size would be, as well where it can be located onboard and what venting requirement it require. This is something which still needs to be defined.

## DW PIPING

All piping not contained in secondary enclosures designed to safely handle ammonia leaks must be of double walled type, and where leakage detection is required for the inner pipe. This can be solved by various means, where the most common are:

- Outer space – i.e. the space between inner and outer pipe – is continuously ventilated and where a sniffer detect any traces of NH3
- The outer space is under-pressurised (or vacuum) and the pressure monitored. Rapture on the inner pipe would mean a sudden pressure increase, while a rapture on the outer pipe would bring the pressure to atmospheric pressure
- The outer space is slightly pressurised (a few bar) and as above the pressure monitored. A pressure increase would mean rapture/leakage on the inner pipe, while a pressure drop a leakage on the outer pipe

A single solution can be chosen, or a combination of them all, to best match the need for a particular piping in question. What is common for them all is that if leakage of $NH_3$ is detected the valves for the pipe section must automatically be closed to prevent any additional ammonia escapes.

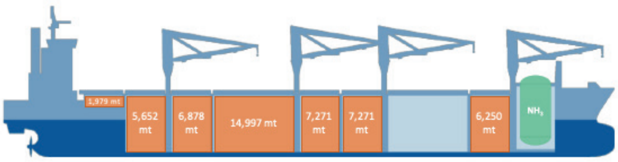
The longest section of double walled piping will be from the forward located storage tank in Hold 1, to the sternly placed FPR. This particular double walled pipe (approximately 135 meter in length, with inner diameter 2”, outer 4”) has been found feasible to install inside the existing pipe tunnel in the double bottom. Due to the environment inside the pipe tunnel, it has been concluded the best would be to install this section with the outer space pressurised with $N_2$ to prevent any build-up of icing. Due to the length of the pipe, it would also be required to install expansion loops at approximately each 48 meters.

For all other double walled pipes, e.g. between reliq. units and TCS, FPR and ME, bunkering lines no evaluation has been done on what type of double walled piping that suits the best. But in general if exposed to outer elements should be either vacuum filled or pressurised with nitrogen to prevent any build-up of icing (in the outer space, so that leakage detection would not be possible).

**AS IS**


- Vessel at load line
- Hold no. 3 empty
- 50,749 mt of cargo equally distributed on all other holds (8) (Weight per hold had to be increased by 27.2% of its “original” capacity)

**NH³ RETROFITTED**




- Vessel at load line
- Hold no. 3 empty
- Hold no. 1 empty as now contains NH3 storage tank (i.e. cannot hold any cargo)
- 50,299 mt of cargo equally distributed on remaining 7 holds (450 mt deducted from DWT due to new installations, weight per hold had to be increased by 39.2% of its “original” capacity)

*Table 6.3.5.1: Implication of HC-B notation, and removing cargo hold space capacity.*

## CLASS NOTATION

The vessel has today a HC-B class notation, which mean the ship's global hull strength is sufficiently strong so that any of its 9 cargo holds can be empty while still being on load limit, i.e. the cargo is distributed only over 8 cargo holds.

As the new storage tank will be installed in cargo hold no. 1, all its cargo holding capacity will be lost, while only a partial of its total cargo carrying capacity in mt will be utilised (even if the storage tank will be 100% full). This would mean that the cargo that should have been inside hold no.1 – if e.g. cargo hold no. 3 was empty – need to be distributed over 7 holds rather than 8. See Table 6.3.5.1 for a direct comparison.

Doing this exercise, it is evident that the cargo that has to be filled in the remaining cargo holds are greater than the holds are built for. And hence it would no longer be possible to keep the HC-B notation. That said, the holds are sufficiently strong to allow any of the smaller holds to be empty in combination with hold no. 1. Hence the vessel could change to the simpler HC-A notation where it is specified which hold can be left empty. The only holds that must be exempted are the two large holds, hold no. 3 and 6.

The only holds that must be exempted are the two large holds, hold no. 3 and 6.

PHOTO: 2O SHAWNTEL AGUJAR

**WORKSTREAM 4:**

# ESG and finance

## Summary

The work stream has been looking at the financial and environmental implications for an ammonia retrofit, such as financial risks and benefits as well as costs associated with stricter regulations on emissions. Questions considered by the work stream were:

1. What is the estimated cost of the retrofit and what are the financial implications?
2. How can the investment be financed and are there external capital sources available?
3. What is the alternative to retrofit (i.e. the cost of doing nothing)?
4. How are tightening environmental regulations affecting the investment case?

The results from this work stream have shown that there can be substantial benefits by retrofitting to ammonia, i.e., fewer (or no) lost revenue days due to slow steaming, lower carbon tax cost and lower residual value risk on vessels as environmental regulations become more stringent.

The cost component is substantial, and although the cost will differ between vessel types, it is in general evident that competitive financing is needed to obtain a viable investment case. Despite the high cost, preliminary calculations indicate that vessels that are retrofitted can be more competitive than conventional fuel vessels when all costs are considered.

- Potentially, the economic lifetime of retrofitted vessels are extended.
- Emissions will reduce dramatically, estimated reductions is potentially 75% compared to conventional fuel vessels.
- There are still other emissions, such as PM (e.g., NOx and N2O), but the overall environmental footprint will reduce when considering well-to-wake emissions. The extended life-time of retrofitted vessels will also impact the life-cycle environmental footprint.

## Method

Grieg's L-class vessels have been selected for the pilot, and all financial calculations are based on these. That said, the work stream has worked with an aim to make the findings transferable to other segments and vessel sizes. The underlying considerations should therefore be applicable for other vessel types despite financial output (i.e. amounts) being different.
Main findings – related to the core of the pilot and the key questions for this work stream

1. The estimated retrofit cost is USD 22 million. This is expensive and, depending on the financing structure, will increase the cost base of operating vessels. Positively, the benefits of using ammonia can be substantial and offset part of this cost increase.
2. Financial risk sharing is a key consideration to justify the investment cost. External financing is available (and can be very competitive), but some of this capital requires deep knowledge on application processes (especially grants/subsidies).
3. The cost of doing nothing also carries risk as tighter environmental regulations mean that vessels need to adapt, for instance through further slow steaming. However, if possible to run on biofuel, the need to retrofit is less.
4. The environmental footprint is greatly improved, reducing emissions by an estimated 75%. Lower emissions reduce carbon tax and the need to slow steam, hence tighter regulations are positively affecting the investment case (and also reduces "strandedasset" risk)

### 7.3.1 Investment cost breakdown

#### CAPEX ELEMENTS

Please note below figures are approximate for the retrofit presented in this pilot. Various elements can alter the cost, for instance the placement of the storage tank(s) and consequent different piping layout, etc. The cost of such potential alternatives has not been analysed; analysis has only been based on the work done by Work Stream 3: Vessel Retrofit to Ammonia.

| Capex elements | Million USD |
|---|---|
| Main engine | 10 |
| Fuel supply system | 6 |
| Storage tank | 4 |
| Shipyard work | 2 |
| **Total estimated retrofit cost** | **22** |

To put the estimated investment cost of USD 22 million in perspective to the overall value of the vessel, the fair market value of an L-class vessel was USD 35M per year-end 2021 (market value assessed by two independent brokers). The retrofit cost is consequently considerable.

#### OPEX ELEMENTS

The operational expenses are expected to increase with an ammonia retrofit, but it is very difficult to estimate a cost with a high degree of certainty as there is limited operational experience to refer to.

The estimated increased operational expenses amount to USD 200,000 per year (approx. USD 550/day) and mainly consist of;

1. maintenance of new systems
2. the need for specialised service engineers
3. the dry-dock cost for the main engine (spread out over the drydock interval period)

This is a high-level estimate for the time being, and it is expected that the cost range can be narrowed down as owners and operators get acquainted, and obtain more experience, with operating a deep sea ammonia fuel system.

### 7.3.2 Risk considerations

In terms of financing a project like this, commercial terms and conditions will differ between companies and is difficult to generalize. It may in addition be easier for an industrial shipping company to support and secure financing for such a project given its long-term horizon. For the sake of this report the financing considerations therefore take a more general project financing approach, highlighting risks that could impact a project's cash flow on standalone basis and where mitigating factors should be contemplated in terms of gaining access to finance.

#### OPERATIONAL RISKS

##### Fuel availability

Reference is made to Chapter 4 "Work Stream 1: Green Ammonia Availability" and the findings presented there. Fuel availability is key in the assessment, mainly due to the high capital expenditure and estimated increase in operational expenses. Inability to obtain ammonia removes all the benefits related to a retrofit, making the investment case useless.

The cost of the retrofit will need to be compensated through (i) reducing lost revenue days from slow steaming to remain compliant with regulations such as the carbon intensity indicator ("CII"), and (ii) preventing/limiting carbon tax which increases the voyage cost. Fuel availability is consequently paramount.

It is important, though, to note that it is not necessary to have fuel availability in all ports in order to obtain benefits. Running on ammonia for only one of the three designated sailing legs in this pilot will provide sufficient emission savings to improve the CII scoring and reduce both lost revenue days and carbon tax. The classification of the ammonia (green, grey, etc.) will of course play a key role in determining the CII.

### Cost competitiveness vs. traditional fuel

Little is so far known about the cost of ammonia as a maritime fuel as the infrastructure and production is not there yet. However, the energy density in ammonia suggests that approx. 2.8 times more ammonia (in $m^3$ terms) is needed to move a vessel over the same distance compared to conventional fuel.

Although this could indicate a higher fuel bill on top of the investment cost, the environmental benefits result in fewer lost revenue days compared to vessels running on conventional fuel. In addition, the carbon tax bill will be smaller. Also, as vessels only need to run on ammonia for shorter periods to achieve CII benefits, it is possible to switch back to cheaper conventional fuel when the targeted benefits are achieved.

### Technical risks/off-hire

As new systems are needed to run on ammonia, the technical risks increase. It is expected that there will be a need for trial and error to familiarize with systems and how these operate and perform in various conditions. A broader adoption of ammonia allow for more real-life testing, consequent system feedback and improvements and also availability of spare parts. This is expected to reduce the technical risks and drive cost down.

There is a risk of more off-hire in the familiarization phase as the potential problems will be new (and therefore also need new solutions). Also, in case of a breakdown there might be a need for specialized spare parts with limited availability and longer lead times. Importantly, the vessel will also be able to run on conventional fuel, which reduces the risk of inability to sail or meet required loading/discharge dates.

## OPERATIONAL RISK MITIGATION

### Charter agreement structure

Too much risk being placed on either party in a charter contract will hinder and slow the transition to greener fuels. An employment structure that ensures some level of certainty of revenue for the vessel might therefore be necessary to justify the investment. Considering a high capital expenditure and uncertainties related to being an early adopter, risk sharing needs to be thoroughly considered. Working together to promote more environmentally friendly transportation is in all involved parties' interests, and as shown later in the chapter, the financial benefit can also be positive for both owner and charterer. Risk sharing in the charter contract can be structured in various ways, for instance through (i) fixed rate longer term employment, (ii) floating rate with a floor or (iii) fixed rate with a profit split on the achieved financial benefits.

### Fuel off-take agreements

Fuel off-take agreements are considered particularly important in the early phase of adoption as availability of ammonia is expected to be limited in volume and geography. Without guaranteed availability, financial risk could be significant. Further, exposure to high volatility in ammonia prices will be a challenge as it will directly impact the competitiveness of the vessel. A too high ammonia price can more than offset lost revenue days for slow steaming conventional fuel vessels, making these more attractive from a cost perspective.

### Carbon tax (EU-ETS) considerations

The European Union ("EU") is scheduled to implement tax on carbon emission from shipping in 2024. This effectively means that vessels with carbon emissions will incur a cost by sailing either (i) in to/out from or (ii) within the EU. The higher the emissions, the larger the bill. This puts vessels running on conventional fuel at a disadvantage through a larger tax bill compared to vessels running on fuels with lower carbon intensity. For now, only the EU is scheduled to tax emissions from the shipping industry, but there are voices proposing a global tax on shipping emissions (for instance the International Chamber of Shipping).

The final solution from the EU on implementation is understood to be as follows (however may change):

- 40% tax on emissions in 2024, 70% in 2025 and 100% in 2026
- 100% of emissions from intra-European routes and 50% from inward/outward EU routes

The EU Carbon Permit price (i.e. carbon emission cost) has ranged between EUR 55-98/tonne over the last


twelve months and is currently approximately EUR 80/tonne. This is also the approx. average price over the last twelve months.

Presented below is an estimation and a breakdown of the expected carbon tax for an L-class vessel prior to a potential retrofit (i.e. running on conventional fuel).

Sensitivity-wise, a change of USD 1 (one) in the carbon price equals an annual cost of approx. USD 11,000 (on 100% tax basis). Hence, for illustration purposes, a carbon price of USD 150/ton results in an annual carbon tax of USD 1.6 million.

Ammonia-fueled vessels are expected to incur limited tax compared to vessels running on conventional fuel, noting that potential emission savings can amount to 75% from current levels (more in 7.3.3).

Being able to reduce, or avoid in full, the carbon tax bill should provide the vessel with a competitive advantage. Vessels running on conventional fuel need to slow down to reduce emissions and offset the carbon tax bill. The below calculation only relates to $CO_2$ emissions, and potential taxes on other GHG emissions will only amplify the need to take measures to offset tax.

| | **50% tax** | **100% tax** | |
|---|---|---|---|
| Total sailing days | 200 | 200 | days per year |
| % of sailing days in/out of EU | 67% | 67% | |
| Days in/out of EU | 133 | 133 | days per year |
| Fuel consumption at super eco | 25.1 | 25.1 | tons per day |
| Bunker consumption in/out of EU | 3,347 | 3,347 | tons per year |
| VLSFO CO2 factor | 3.2 | 3.2 | |
| CO2 emission | 10,709 | 10,709 | tons per year |
| Carbon tax rate | 50% | 100% | |
| Carbon price | 80 | 80 | USD* per ton |
| Annual carbon tax cost | 428,373 | 856,747 | USD per year |

**EURUSD = 1.00*

## FINANCIAL RISKS

### Cash flow risks (incl. effects and sensitivities on cash break-even)

Please note that the below calculations are made based on the existing L-class vessels. These vessels are between 8-10 years old and have repayment profiles on the debt which could differ substantially from other vessel types. For instance will younger vessels that have longer repayment profiles on the debt most likely see a smaller increase in the financing cost when using debt to finance the retrofit. Vessels that have available space to place tanks, etc. in more convenient and cost-efficient spaces are also expected to incur a smaller increase than the below calculation suggests due to a lower retrofit cost (which also reduces the financing need).

Depending on the financing structure of the retrofit, the cash flow risk will increase. The below table presents the expected increase in cash break-even. Assuming the retrofit is funded with 50% debt and a repayment profile and interest rate equal to the existing financing, the daily cash break-even increases with close to USD 5,500/day. However, when including effects of environmental regulations such as lost revenue days due to slow steaming and carbon tax and offset these by a very high-level assumption of estimated reduced cargo capacity, the picture improves and the increase reduces to approximately USD 3,100/day.

| USD/day | Existing financing | Existing financing plus retrofit |
|---|---|---|
| Financing cost | 8,000 | 13,000 |
| OPEX (incl. dry-dock) | 6,500 | 7,050 |
| Cash break-even | 14,500 | 20,050 |
| Lost revenue days | 1,400 | 0 |
| Carbon tax (50% tax) | 1,200 | 0 |
| Reduced cargo capacity | 0 | 200 |
| Adjusted cash break-even | 17,100 | 20,250 |

While higher operational expenses are part of driving cost, the main increase comes from the financing cost. Reducing the debt funding of the retrofit to 25% results in the retrofit investment case becoming a better solution on a daily cash break-even basis compared to not doing anything. See table below for comparison.

| USD/day | Existing financing | Existing financing plus retrofit |
|---|---|---|
| Financing cost | 8,000 | 10,500 |
| OPEX (incl. dry-dock) | 6,500 | 7,050 |
| Cash break-even | 14,500 | 17,550 |
| Lost revenue days | 1,400 | 0 |
| Carbon tax (50% tax) | 1,200 | 0 |
| Reduced cargo capacity | 0 | 200 |
| Adjusted cash break-even | 17,100 | 17,750 |

This, however, is only a snapshot of the current environment and the data points will change along with retrofit cost, outstanding debt, interest rates, lost revenue days, carbon tax price and tax rate, etc. With more stringent environmental regulations the upside to the investment case is expected to strengthen. What is also evident, is that a competitive financing structure is paramount to obtain a financially viable case from a cash break-even perspective compared to a conventional fuel vessel.

The cost of ammonia compared to conventional fuel is not included in the above calculation as it is expected to be covered by the cargo owner (either directly or through a higher freight rate). In such case, one could also argue that the carbon tax should be allocated to the cargo owner. This would alter the above calculation as the carbon tax element disappears, and thereby have a negative effect the financial case for the retrofit. This highlights the cash flow risk, especially as there are still various unknowns related to cost allocation.
Note also that the above calculations do not include return on equity. While lower financing for the retrofit reduces the daily cash break-even, the equity portion of the financing increases which will drive the allin cost higher.

### Interest rate volatility

Depending on the size of a potential financing, adverse movements in the interest rate market can negatively affect the retrofit investment case. Assuming 50% leverage on the retrofit cost, a 1% percentage-point change in interest rate equals approx. USD 300/day in interest expense. This comes on top of the existing interest expense for the financing of the vessel.

### Residual value risk (value development of investment)

If ammonia becomes the preferred fuel for the maritime industry, the value of the retrofit investment is expected to substantially enhance the residual value of the vessel. The retrofit is a major step towards being able to provide transportation with net zero emissions, meaning that it will not be environmental regulations that determine the trading life of the vessel, but its technical condition and ability to operate safely. This is in stark contrast to the current market perception that conventional fuel vessels will need to be recycled early due to tighter environmental regulations.

Should ammonia not succeed as a maritime fuel, the vessel still has the ability to sail on conventional fuel. This is an important risk mitigant, as it maintains trading flexibility (and thereby earnings potential). That said, to maintain a useful economic life and earnings potential, measures need to be made to remain compliant with environmental regulations to avoid stranded-asset risk.

In other words, doing nothing is probably also not a viable option in the long term. A rapid expansion and development of biofuel infrastructure is probably needed in this case, allowing conventional fuel vessels to blend in substantial amounts of biofuel to reduce emissions and remain compliant.

### Reduced cargo intake (i.e. lower revenue)

Pulp and paper are the main cargoes transported by the L-class, hence the effect by the retrofit on cargo intake is based on these cargoes. In short, the intakeis estimated to reduce by 3.5% .

Financial loss from reduced intake will depend on various items such as the freight rate, cargo transported, fuel cost/consumption, etc. At current, there are too many unknown variables to estimate the loss with any degree of certainty, but for sake of illustration a 3.5% loss in cargo intake is assumed to translate into USD 200/day lower time charter equivalent earnings.

## FINANCIAL RISK MITIGATION

### Risk sharing in financial structure

An important element in the overall financial consideration is whether there are alternative capital sources that are able and willing to share risk. Not only does this provide capital relief for the ship owner, it could also provide a lower cost of capital for the investment (depending on the capital source). Security for the capital provider, however, is key when considering possible alternatives. Normally, the vessel has a senior secured/1st lien loan attached to it. Allowing other capital sources to take a position in the security structure could pose a challenge. Seniority and prioritisation of the security is important and affect cost.

### Export Credit Agency financing

Depending on place of production and sale of the retrofit equipment, financing by an export credit agency is an alternative. This tends to be attractive capital as export credit agencies work to promote domestic producers. As the goal is to promote exports, there could be somewhat more willingness to take risk while at the same time provide a competitive cost of capital. With substantial resources being put into developing ammonia infrastructure and for ammonia to become a viable fuel source for shipping, it could be particularly interesting to provide support for domestic suppliers to the ammonia industry.

### Bank lending

As mentioned earlier, the vessel normally has a senior secured loan attached to it, most likely through a commercial bank. Leveraging up part of the investment through the existing lender(s) appears to be a smooth solution, especially as the lender(s) already have security in the vessel. Available headroom under the vessel's market value to lever up with additional debt is a key factor. Already high leverage will limit the ability to finance the retrofit, while limited existing leverage could give an opportunity to finance the full retrofit cost.

Allowing a second mortgage on the vessel from a new financier requires a very strong security position. Limited ability to solely trigger enforcement under the second mortgage can also expected.

### Equity

Finding an equity partner for the retrofit is considered difficult, however is still an alternative, especially if the retrofit is accompanied with long-term employment. A profit split from the benefits obtained provides certainty in the cash flow, and thereby return on the investment.

Although equity is expensive, certainty of long-term fixed cash flow may push it down somewhat. Shorter term employment is more difficult as risk increases and the cost of capital is expected to be high.

#### Seller's credit from manufacturer

A seller's credit reduces the initial capital expenditure for the retrofit and spreads the cost over a longer period. This is interesting as the capital intensity at the investment point is less and repayments are made from the operational cash flow arising from the retrofit. There is however still a need to coordinate security positions with the existing lender(s).

The incentive for the manufacturer to provide a seller's credit could be high as showcasing successfully functioning products effectively work as marketing. This is especially relevant in the early phase when trying to develop a market, and when uncertainty is highest.

#### Grants and subsidies

Grants and subsidies are effective measures of financial risk sharing, especially for new technologies with high investment cost. Considering the investment cost and expected environmental benefit of the ammonia retrofit, it is expected that this is a well-suited project that would qualify for grants and/or subsidies. However, there are complexities to these products. It can be difficult to navigate and identify relevant and available grants and subsidies, and there may be strict requirements to the application process. This requires early planning to not miss application windows.

Further investigation will need to be done on this topic, and cooperation with consultants specializing in sourcing grants is most likely required to efficiently tap this source of capital. Reference is also made to the work done through the Green Shipping Programme in relation to other pilots when it comes to financing.

#### Prepayment of hire

Depending on the employment structure for the vessel, prepayment of hire to support the initial investment is an alternative. This effectively means that the charterer or cargo owner supports the investment cost. This, however, is most likely only possible if the vessel is on a longer contract (due to the sizeable investment cost). The charterer or cargo owner can obtain the benefits from the retrofit through lower carbon tax and minimal potential lost revenue days due to environmental regulations, hence this could be an attractive alternative.

Considering the potential technical risks related to early adoption of operating deep sea vessels on ammonia, getting charterers or cargo owners to prepay hire could be challenging. Prepaid hire does not guarantee operational performance, and charterers or cargo owners might want to retain the option of cancelling employment in case the vessel does not deliver as agreed. This possibility is effectively removed if hire is prepaid.

### 7.3.3 Sustainability considerations

#### EMISSION PROFILE

From a well-to-tank consideration, assuming the ammonia production is green and that it is transported from the production site to the vessel without any leaks, there are no emissions. From a tank-to-wake consideration, there is a risk of emitting N2O (laughing gas) and different NOx gases. The latter is regulated, but N2O is not (yet). Further, assuming 10% pilot fuel (for instance marine gas oil) and continued use of conventional fuel for auxiliary engines, boiler and the incinerator, total emissions (well-to-wake) are estimated to reduce by 75% from today's emission level on an L-class vessel.

Although quite a few assumptions in the estimation, a substantial part of the ammonia infrastructure is being built to support zero-emission production and transportation. So, even if emissions are higher than estimated above, emission reduction is still substantial.

#### ENVIRONMENTAL FOOTPRINT

Making the most of what already is produced and in operation appears to be the best solution to minimise negative effects on the environment. As such, retrofitting is considered a more environmentally friendly solution than recycling assets early and replacing these with newbuilds.

This is an important element as the retrofit aims to reduce the footprint the vessels make on the environment. On the back of this, not trying to make vessels compliant through retrofits seems to undermine the overarching goal of trying to become more sustainable. This also means that it must be considered whether the footprint of retrofitting vessels is acceptable, and if doing nothing but reducing speed is a better alternative from a sustainability point of view.
The above does not mean that financial considerations are less important, but there is a need to take a broader approach to the effects of retrofitting, doing nothing or ordering newbuilds.

### 7.3.4 THE COST OF DOING NOTHING (BENCHMARK AGAINST INVESTMENT CASE)

Assuming no retrofits or investments are made to improve the performance of the vessel, the vessel mainly has one alternative to meet tightening environmental regulations such as the CII in coming years; further slow steaming. There are two main elements that affect cost in a “do nothing” scenario, (i) lost revenue days from slow steaming and (ii) carbon tax.

All vessels need to trend to a CII score of at least C to remain compliant with prevailing regulations. For ships that achieve a D score for three consecutive years or an E score in a single year, a corrective action plan needs to be developed and approved (i.e. a trend towards «C»). The CII score is highly dependent on market activity, meaning that when the market is tight and vessels are in high demand (and run with higher speeds), the CII score drops. In comparison, in softer years with lower demand, vessels run with slower speeds and the CII score improves. As an example, the L-class vessel would have zero lost revenue days in 2023 to obtain a CII score of C using 2019 as baseline, but would lose close to 18 revenue days using 2021 as baseline. To make the picture additionally complex, the CII score is affected by weather and currents, meaning that the score will most likely never be equal for the same vessel taking the same voyage at different times.

On top of this comes the carbon tax (as presented and calculated earlier). The carbon tax and potential lost revenue days work as incentives to transition to more sustainable fuels and thereby retain the vessel’s competitive edge. Lost revenue days below are estimated using 2021 as baseline year. Assuming the estimated total annual cost is for the ship owner (i.e. also the carbon tax) and that this full cost can be removed by retrofitting an ammonia fuel supply system, the payback period for such system is estimated to be 19 years (incl. opex increase and assuming no further lost revenue days from 2030). This means that the retrofit is fully repaid when the vessel is 30 years old. Assuming carbon emissions are taxed on 100% basis, payback period for the retrofit reduces to 15 years (incl. opex increase and assuming no further lost revenue days from 2030).

Finally, a few comments on the calculation. There is high uncertainty on the estimated future earnings rate and potential lost revenue days, and these factors play an important role in calculating the payback period for the investment. The same goes for the Carbon Permit price which would shorten the payback period if prices were to increase (and vice versa if prices were to fall). There are many unknowns that will affect the return on investment for the retrofit. This also highlights the need to seriously evaluate risk sharing to achieve a successful transition to more sustainable fuels.

### 7.3.5 SCALE AND MATURITY

Ammonia is no doubt in its very early stages as a fuel to the maritime industry. This naturally creates uncertainty which again affects development costs and the rate of adoption. As the technology and infrastructure matures and more scale and availability are achieved, cost is expected to come down. This will improve the competitiveness of ammonia and benefit the maritime industry, supporting adoption of ammonia as a fuel.

In this respect, it is noted that the financial considerations in this report are reflecting early-stage costs and not a fully mature ammonia market.

PHOTO:
2O SHAWNTEL
AGUJAR

WORKSTREAM 5:

# Operations

## Aim of the workstream

The operational work stream has been looking at practical implications for an ammonia retrofit, such as cargo intake reductions and potential obstacles to port productivity. The questions the group looked to answer were:

- How will the conversion to ammonia affect cargo intake of the vessel?
- Will tanks or supply system interfere with breakbulk capacity (deck cargo)?
- Will safety precautions cause delay to cargo operations?
- Will ammonia availability cause the vessel to be captive in the trade, or can it still be engaged in other trades?

## Method

The Grieg Star L-class vessels have been selected for the pilot, and all data is based on these. As technical solutions and safety rules and regulation will set the premises for the pilot, the operational group has not looked to influence the solutions, but rather look at potential impact from the choices made in the relevant groups.

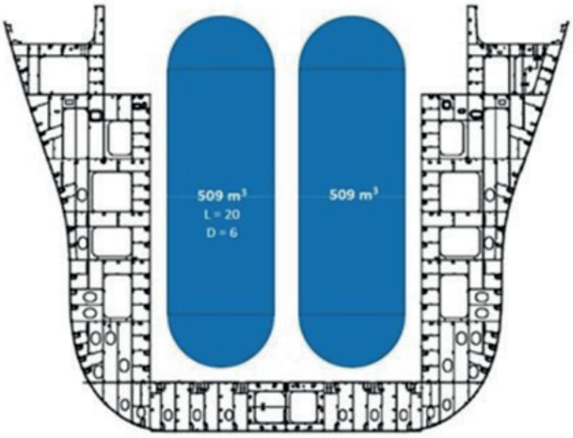
Cargo intake reduction due to the ammonia tanks installation has been calculated using the loading program for the vessel, otherwise the impacts have been assessed as expert opinion by relevant and competent persons.

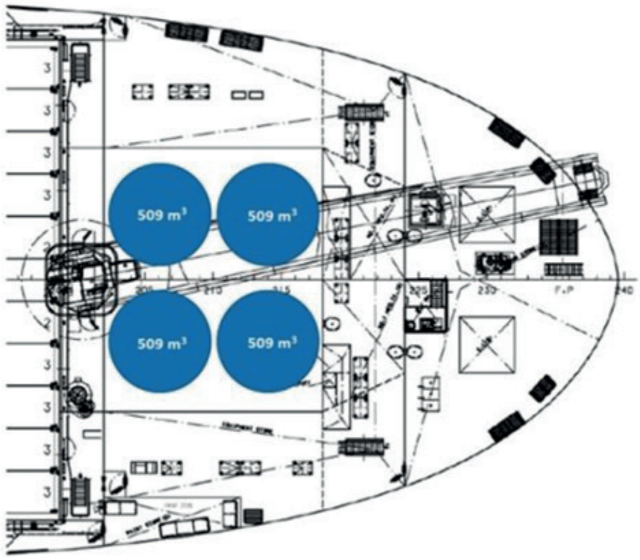
## Main findings – related to the core of the pilot (key barriers)

Ammonia retrofit seems to have limited operational consequences. Main findings based on the questions outlined are:

- Suggested tank placement in hold no 1 will reduce intake of pulp by 1,700 MT (from 48,000 MT to 46,300). This equals a 3.5% reduction.
- Tank placement will not interfere with breakbulk cargo on deck, as tanks will be placed far forward in the vessel and be almost flush with existing deck
- Safety precautions is not known yet. It is possible that a safety zone must be es-tablished during bunkering, but with proper planning this does not necessarily in-fluence productivity. Ventilation from ammonia tanks/supply system can be routed away from work areas.
- Vessel will retain its fossil fuel capacity, and the engine will be dual fuel. This means that the vessel will still be able to operate outside areas where ammonia is available.

**Hold 1**: Total storage capacity: 2,036 m³
*(Hold volume: 4,522.6 m³)*




## IMPACT ON CARGO INTAKE – CARGO HOLDS

The pilot has been focusing on the Grieg Star L-class vessels. A significant cargo for these vessels in the trade is pulp from South America, and pulp intake has been considered for the case study.

Though the vessel's summer deadweight is 50 720 MT, the maximum intake of pulp is about 48 000 MT. The limitation is met on weight, and not volume, for pulp cargo.

Cargo hold no 1 was selected for tank placement, as shown below. To calculate impact on cargo intake, this was simulated in the loading program by considering the tanks as car-go. Weight was assumed to be 2000 tons, distributed as follows:

- Weight of tanks – 400 tons
- Weight of ammonia – 1600 tons

The result of the calculation was that vessel can still safely load 46 300 MT of pulp cargo. This is a reduction of 3.5% from the original intake.

The bending moment and shear forces are verified to be ok in fully laden condition, how-ever loading se-quence would need planning to distribute weights with ammonia tanks in the forward part of the vessel.

**Deadweight Summary**

| Vessel details | Weight [t] | LCG [m] | TCG [m] | VCG [m] | TVM [t.m] | FSM [t.m] | GSM [t.m] |
|---|---|---|---|---|---|---|---|
| Deadweight | 50332.530 | 105.519 | 0.136 | 10.385 | 522681 | 4091 | 0 |
| Lightship | 14261.200 | 90.298 | 0.000 | 13.060 | 186251 | 0 | 0 |
| Displacement | 64593.730 | 102.158 | 0.106 | 10.975 | 708932 | 4091 | 0 |
| **Deadweight details** | | | | | | | |
| Cargo: | 48300.000 | 107.945 | 0.000 | 10.306 | | 0 | |
| Ballast: | 610.000 | 40.253 | 0.944 | 8.558 | | 3462 | |
| Fuel Oil: | 250.000 | 48.733 | -3.715 | 8.417 | | 98 | |
| Diesel Oil: | 202.000 | 10.069 | 1.379 | 15.628 | | 226 | |
| Fresh water: | 105.000 | 0.436 | 0.045 | 13.652 | | 138 | |
| Lub Oil: | 36.530 | 18.964 | -8.402 | 10.483 | | 66 | |
| Misc: | 35.000 | 17.514 | 0.974 | 2.665 | | 100 | |
| Constants: | 450.000 | 105.000 | 16.000 | 13.060 | | 0 | |
| Tween Decks: | 344.000 | 28.800 | 0.000 | 19.250 | | 0 | |
| Deadweight: | 50332.530 | 105.519 | 0.136 | 10.385 | | 4091 | |

## IMPACT ON CARGO INTAKE – DECK CARGO

Cargo on deck, also termed breakbulk or project cargo, is important for the vessel types and gives additional flexibility for the utilization of the ship.

Breakbulk cargo is stowed on top of the hatch covers, taking advantage of the large sur-face of the vessel deck when hatches are closed. Examples of breakbulk cargo are wind-mill blades, yachts or steel pipes.

A potential concern was whether the ammonia tanks would rise higher than the level of existing hatch covers, and thereby obstruct breakbulk cargo areas on deck. Auxiliary sys-tems, such as pipes and venting systems, were also considered.

As it seems, the suggested tank placement will not interfere with deck space. The is also ample space for supply systems below deck and venting as well as bunker manifold can be placed away from cargo areas. Depending on need for shock absorbing and expan-sion area for the tanks, they might rise somewhat higher than the cargo hatches – but this can be mitigated as windmill blades are stowed on pedestals which rises them higher.

## OPERATIONAL INTERRUPTIONS FROM SAFETY PRECAUTIONS

Ammonia is a toxic substance, and precautions must be taken to avoid exposure for crew and stevedores. Critical points are believed to be bunkering operations, but also venting is a potential concern.

Safety regulations are still not mature enough to do any meaningful assessment of the operational implications from safety zones and precautions.

Venting pipes will be placed away from working areas, but depending on radius of safety zone, there is a potential for disruption to operations. As for bunkering, the manifold will be placed for minimal interference as well. Cargo operations may also be planned so that cranes and cargo holds with workers are at a safe distance from bunkering operations.

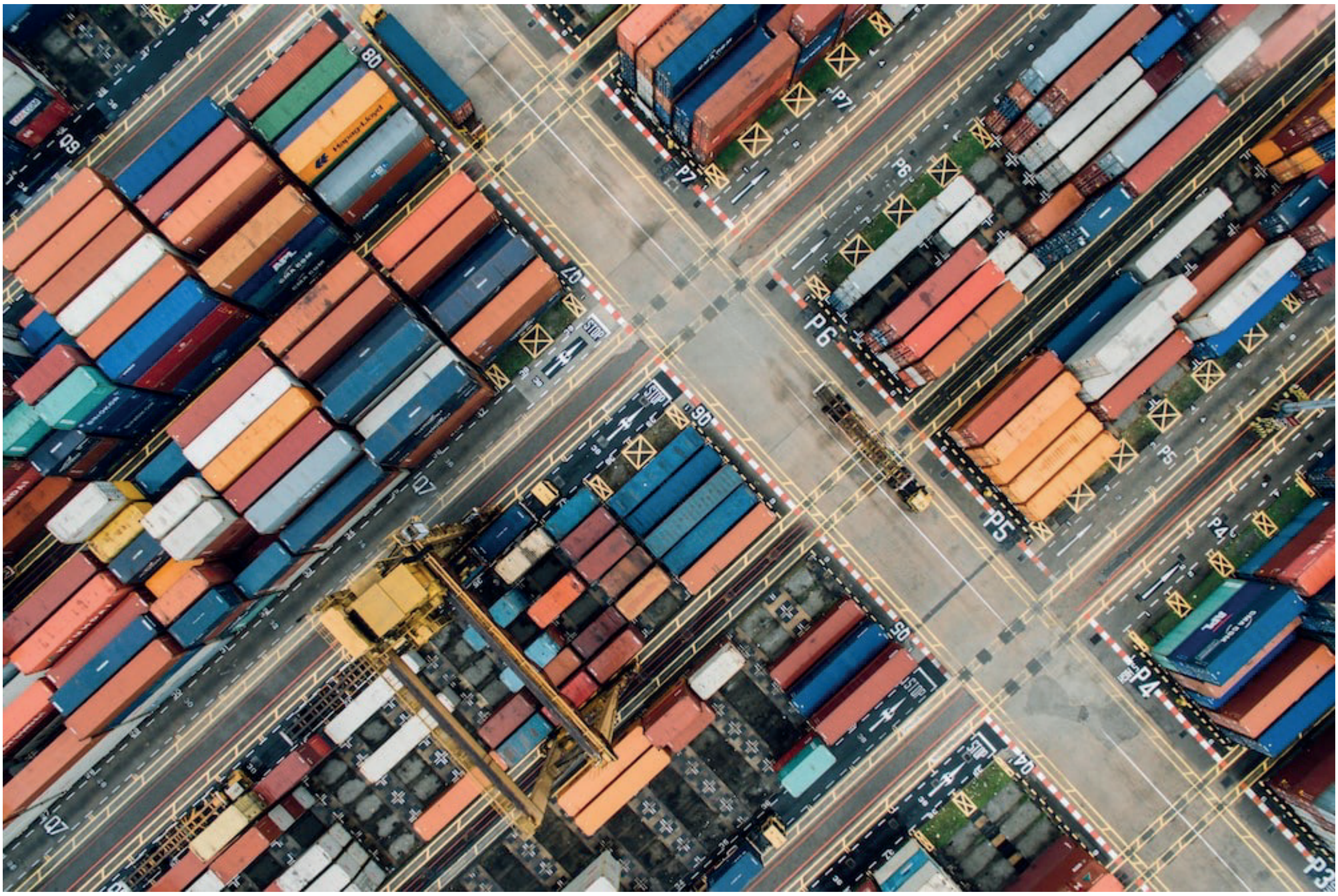
## VESSEL TRADE AREA AND FLEXIBILITY

An initial concern was that ammonia is not readily available worldwide. Even if supply could be secured for the trade lanes in this pilot, the vessel would remain captive to the trade – unable sail outside the range limited by the ammonia capacity onboard.

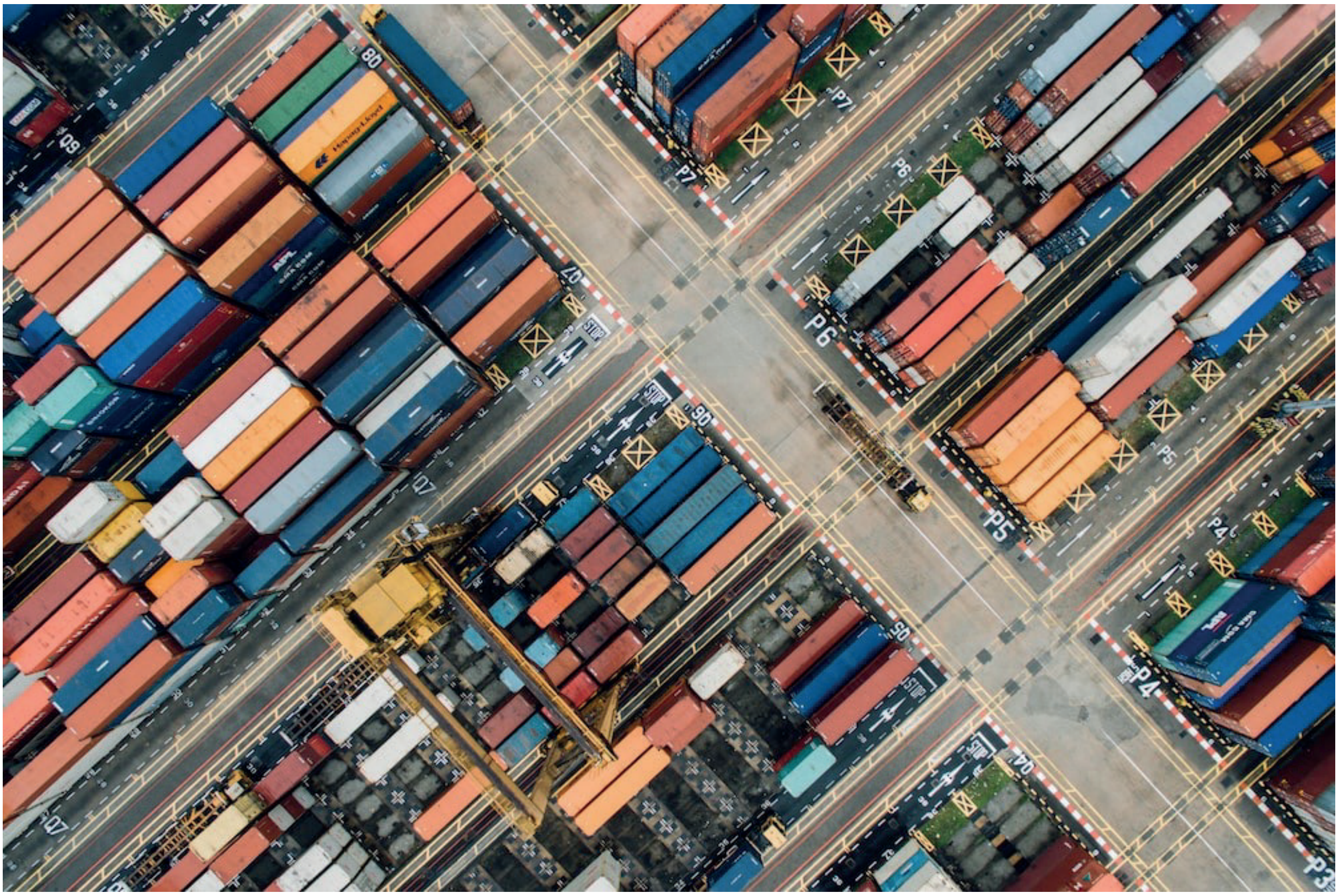
As it seems, the vessel would retain its flexibility. As the ammonia tanks will not take the place of FO tanks, these will remain and maintain their capacity. Combustion of ammonia will also need pilot fuel in the form of marine gas oil or low sulphur fuel oil.

The engine will be dual fuel, meaning that it will be able to operate on FO as well as am-monia. Using the vessel as a conventional fueled ship will be suboptimal given the cost and effort of the ammonia conversion, but it will still be possible in the event that it needs to deviate from the areas where ammonia can be bunkered.


# Appendices




# Europe



# Port of Rotterdam

## Strategy & Targets

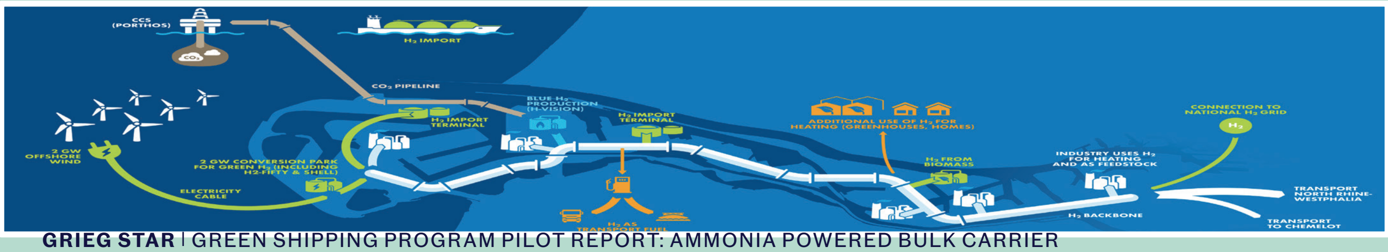
- Become the leading port for sustainable energy. Net zero CO2 emission in 2050
- 20 Mill. tonnes of hydrogen (100 mill. tonnes ammonia) demand in 2050
- Become an energy hub of Europe, able to supply NW Europe with 4.6 mill. tonnes of hydrogen annually by 2030
- Build on an existing hydrogen market and hydrogen network. All ports have potential to import hydrogen from 2025
- Strategy is in line with Rotterdam Climate Agreement, Dutch Climate Agreement and EU Green Deal
- Strategy focusing on 3 key areas: 1) Smart partner in logistics chains, 2) Accelerator of sustainability in the port,3) Enterprising and impactful organization

## Facts

- Largest port in Europe and 10th largest port worldwide
- 13% of EU energy consumption passes through the port
- 28 876 sea-going vessels and 99 558 inland vessels
- 469 mill. tonnes/year from dry bulk, liquid bulk, containers and breakbulk
- Existing hydrogen networks between Rotterdam, Belgium and Northern France
- Ammonia/hydrogen strategy, but no ammonia volumes in port indicated

## Projects & Initiatives

- Several green corridor establishment; Pecém Industrial Port Complex in Brazil, the Maritime and Port Authority of Singapore and southern and northern Europe by CESPA and the port to be operational in 2027
- Developing regulations for alternative bunkering fuels by 2023
- Joint feasibility study of import of hydrogen with Koole Terminals, Chiyoda Corporation and Mitsubishi Corp with aim to import 100-200 and 300-400 kilo tonnes/year hydrogen in 2025 and 2030 respectively
- Air Products, Schenk Tanktransport and TNO will develop hydrogen trucks and Netherlands largest hydrogen refueling station
- Transhydrogen import terminal for green hydrogen and ammonia, operational by 2024, aiming to import 500 000 tonnes green hydrogen (eq. 2.5 mill. tonnes green ammonia) annually
- Horisont Energi and Port of Rotterdam have signed a MoU for setting up a corridor for transport of 1 mill. tonnes/year of blue ammonia from Norway to Rotterdam by 2025
- FID taken by OCI N.V for the first phase of ammonia import terminal expansion project. First phase to reach 1.2 mill. tonnes/year in 2023, and second phase to reach 3 mill. tonnes/year
- Participating in joint study framework with 16 other companies for ammonia bunkering safety by ITOCHU
- Gasunie, HES & Vopak developing an import terminal, ACE Terminal, for green ammonia as a hydrogen carrier operational from 2026
- Joint development agreement by Air Products and Gunvor Petroleum Rotterdam for import of green hydrogen by 2026
- Hydrogen pipeline, HyTransPortRTM, collaboration with Gasunie, will be operational in 2024/2025, with Shell as their first customer



# Port of Antwerp-Bruges

## Strategy & Targets

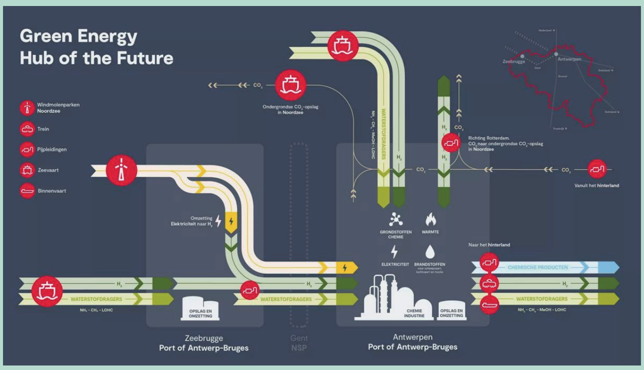
- Become climate neutral by 2050
- Strategy is in line with the European Green Deal
- Build on an existing infrastructure
- Goal to reduce CO2 emission in Belgium with 17% of CO2 by capture and storage
- Scale hydrogen production in Zeebrugge by 2024
- Take in ammonia ships by 2025 in Antwerp
- Supply Germany with green hydrogen by 2030
- Import 150 TWh of hydrogen by 2050
- Take a leading position as a European import hub for green hydrogen and an become active frontrunner in the hydrogen economy
- Build a hydrogen economy through three pillars; production and supply, distribution infrastructure, and consumption and transport

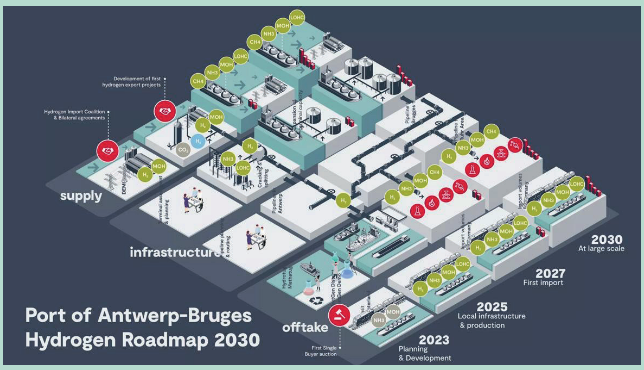
## Facts

- 5th largest bunkering port and 15th largest container port in the world
- Largest chemical cluster in Europe
- 14181 sea-going vessels
- 289 mill. tonnes/year from dry bulk, liquid bulk, containers and breakbulk
- Existing infrastructure (quays, terminals and pipelines) for receiving and distributing hydrogen and ammonia
- Ammonia/hydrogen strategy, but no ammonia volumes in port indicated

## Projects & Initiatives

- Hydrogen import coalition between DEME, Engie, Exmar, Fluxys, Port of Antwerp-Bruges and WaterstofNet for production, transport and storage of hydrogen
- Collaboration with hydrogen network operated by Air Liquide
- Build an open-access hydrogen pipeline by Fluxys, connecting Antwerp and Zeebrugge with the German hinterland, allowing any company to connect to the pipeline, by 2025
- Building an open-access import terminal for green ammonia with Fluxys and Advario, by 2027
- Dual fuel Hydrogen and diesel-powered tug-boat to be operational from 2023 in the port
- Supply and import of green hydrogen from Chile, Oman, Namibia, Egypt or Brazil in 2026
- Building a green hydrogen plant in Zeebrugge, project HyoffWind (25MW), by 2024 and Antwerpen, project Plugpower (100 MW), by 2025
- Project Antwerp@C with Air Liquide, BASF, Borealis, ExxonMobil, INEOS, Fluxys and Total Energies, aim to produce blue hydrogen by capturing, storing and reusing $CO_2$, cutting CO2 emission with 50% by 2030
- Joining HyTrucks consortium that aims to have 300 trucks to run on hydrogen by 2025
- PIONEERS consortium coordinated by Port of Antwerp Port to run port equipment on electricity, hydrogen and methanol by 2026



# Port of Hamburg

## Strategy & Targets

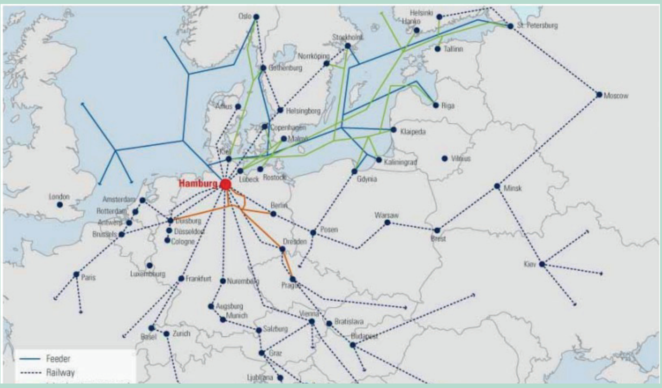
- Goal to become climate-neutral and emission free by 2040
- Port development plan will shortly be completed where hydrogen as energy source will be addressed
- Pursuing to build a self-sufficient green hydrogen sector by 2035 in relation to the North German Hydrogen Strategy set in 2019
- Preparing the port to be supplied with energy from renewable sources, expanding energy exploitation and creating conditions for importing hydrogen derivates by ship or pipeline
- Extended the Renewable Energy Hamburg Cluster with the hydrogen sector and is also looking into importing ammonia

## Facts

- 3rd largest port in Europe and ranked 20 worldwide. Germany's biggest multipurpose port
- European leader for shore-based power
- 7371 sea-going vessels
- 130 mill. tonnes/year
- Europe’s leading rail port, whereas 90% of shipments are carried by rail
- Ammonia/hydrogen strategy, but no ammonia volumes in port indicated

## Projects & Initiatives

- MoU with Air Products to establish a sustainable supply chain for hydrogen
- Air Products and Mabanaft have signed a MoU to build Germany's first large-scale, green energy import terminal in the Port of Hamburg by 2026
- Part of Hamburg Hydrogen Industry Network and exchanging know-how with the port of Rotterdam, Antwerp and Montreal
- Shell, Mitsubishi Heavy Industries, Vattenfall and Wärme Hamburg Sign Letter of Intent for producing hydrogen from wind and solar power, with initial output of 100 MW in 2025, using the port facilities as an import terminal and expanding the gas pipeline networks in the port to accommodate hydrogen
- Green hydrogen test delivery from Abu Dhabi National Oil Company shipped in the form of ammonia
- MoU with HHLA and Hyster Yale Group to deliver hydrogen-powered empty container handlers in 2023 and terminal tractors 2022
- Chile and Hamburg Port Authority have signed a MoU for exporting green hydrogen from Chile to Europe
- CPL and HHLA have created an innovation cluster to test hydrogen-powered port logistics equipment
- Supporting hydrogen initiatives through participation in Clean Marine Fuels and local shipping industry working groups






Source: Port of Hamburg, offshore-energy.biz energy.gov, seatrade-maritime

Niedersachsen Ports

# Port of Brake

## Strategy & Targets

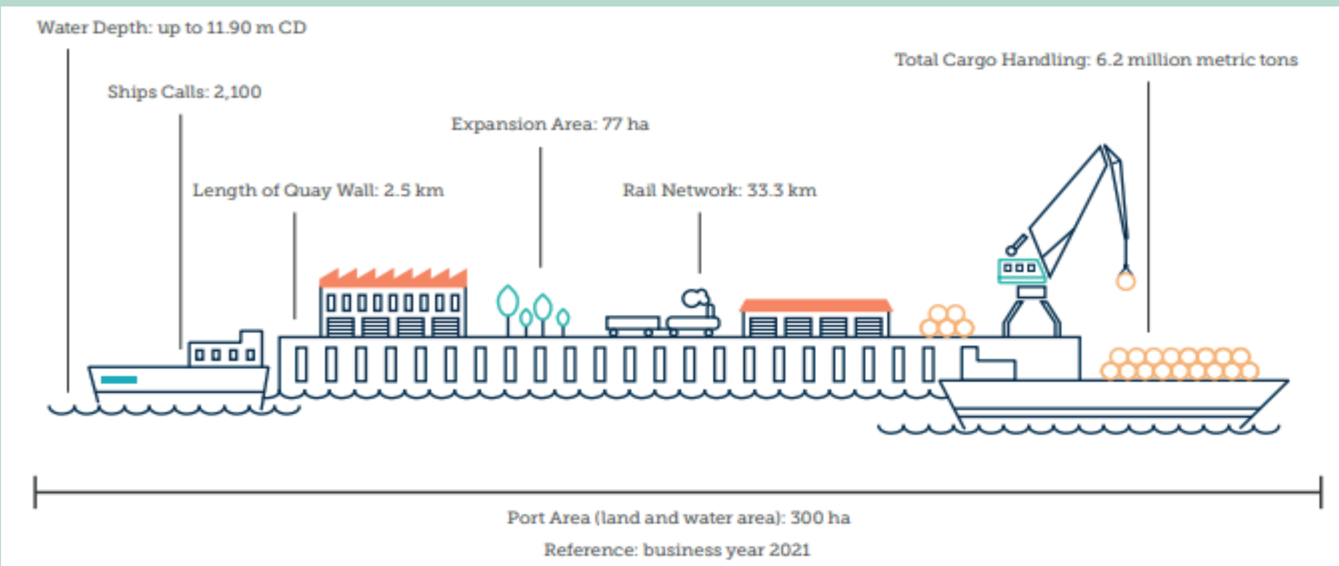
- Support use of renewable energy to maintain and expand the ports and strives to use energy-saving and lower-emission alternatives
- Aim to reduce emission by 25% within 2025 compared to levels of emission in 2017
- Actions to reach goal by improving the energy efficiency and promoting renewable energy, i.e., by using alternative fuels
- Sustainability strategy to cover 4 areas with long-term goals
- Green hydrogen network planned

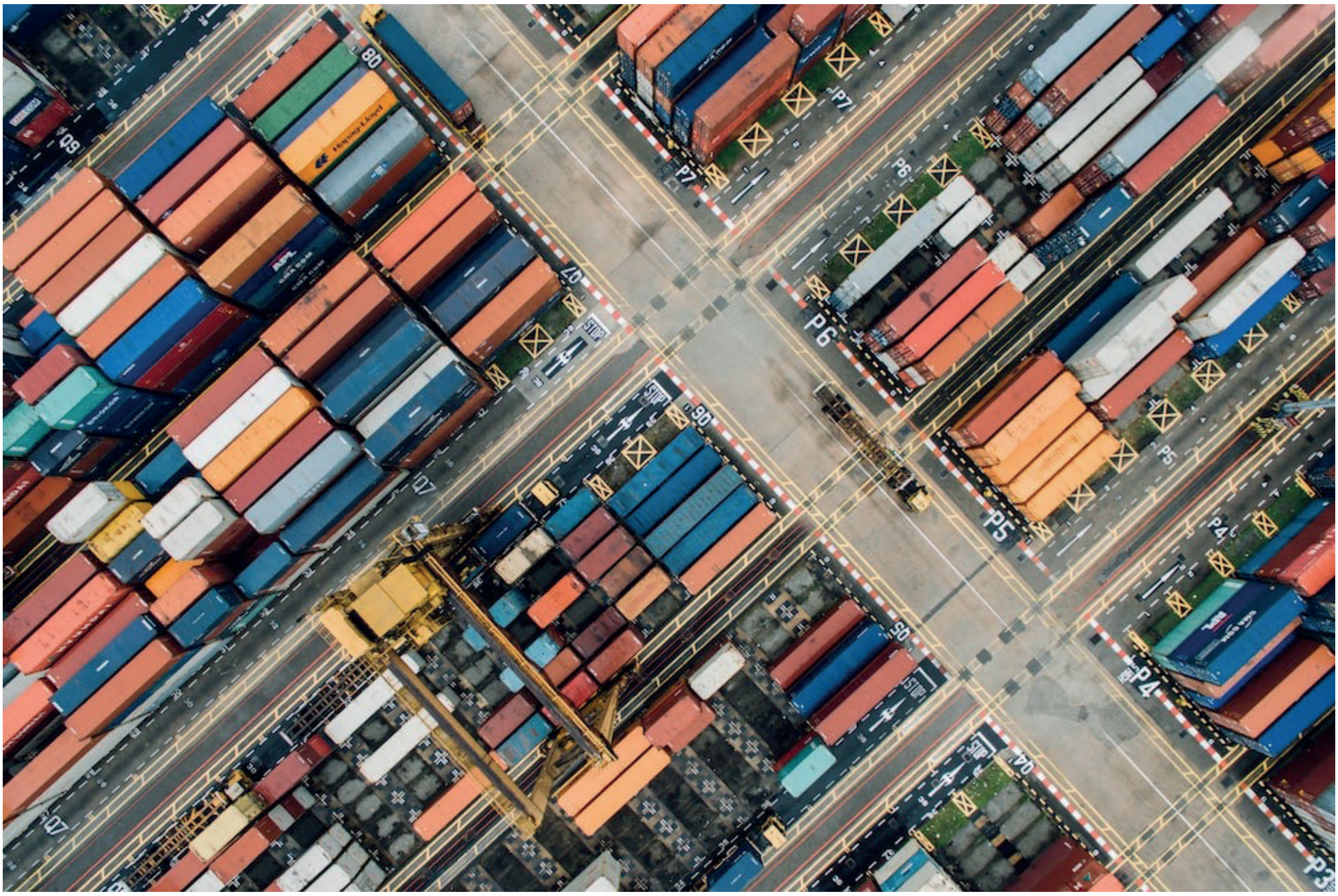
## Facts

- Multifunctional specialty port with a leading position for agricultural products and cellulose
- 2 100 ship calls/year
- 6.2 million MT Breakbulk, grain, lumber, iron
- Rail connection to Europe
- Hydrogen strategy in port but initially for land-based installations. No ammonia volumes indicated

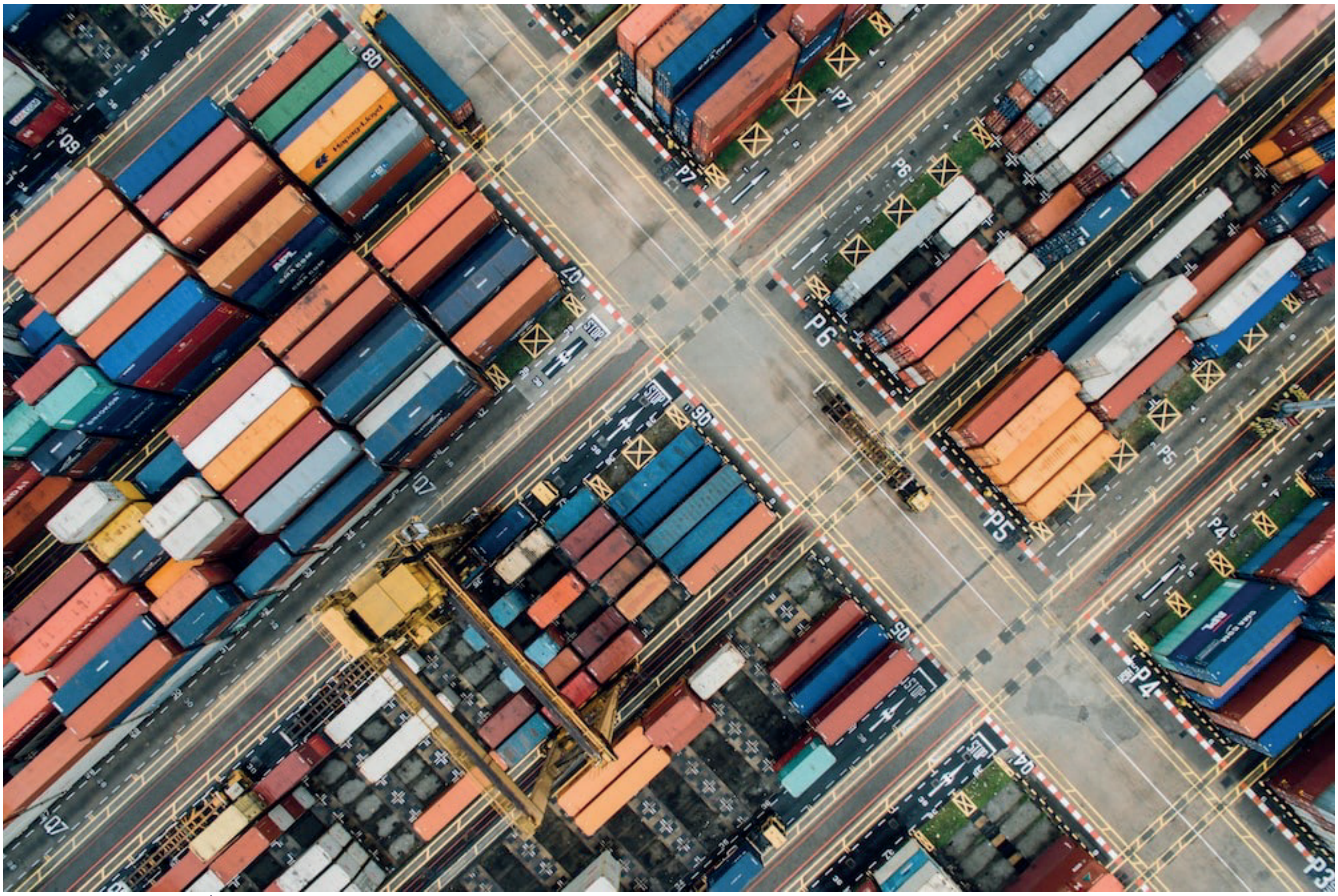
## Projects & Initiatives

- DUAL ports; Developing Low carbon Utilities, Abilities and potential of regional entrepreneurial Ports, an initiative to decarbonize ports and reduce environmental footprint. Current efforts include LED lighting, sediment treatment and appointing Green Port Officers.
- WASh2Emden; Northern Germany has, at times, surplus energy from wind turbines. This cannot be stored in sufficient quantities, which causes turbines to be turned off the grid. This initiative examines opportunities for turning the electricity into green hydrogen for utilization in the port
- Identifying possibilities for distribution and storage of hydrogen
- Memorandum of understanding (MOU) signed with Belledune Port Authority (Canada) to collaborate on energy and manufacturing sectors, with a particular focus on production, shipment and storage of cleaner fuels – green ammonia, hydrogen, biomass and natural gas.





# Brazil



# Port of Pecém

## Strategy & Targets

- Aim to become a world player in green hydrogen and creating a H2 logistics corridor with the Port of Rotterdam
- Port Terminal of Pecém will begin to export green hydrogen from 2025 and aims to reach 1.3 mill. ton/year in 2030
- Expect to export 2,2 mill. tonnes of green hydrogen (12 mill. tonnes of green ammonia) in the next decade

## Facts

- Rapidly growing port, with 26% expansion annually the past 10 years
- 90% wind/sun energy production gives ideal location for green hydrogen
- 811 sea-going vessels
- 22.417 mill. tonnes/year from liquid, dry, breakbulk and containers
- Existing infrastructure in free trade zone ZPE (area w/tax benefits)
- Ammonia/hydrogen strategy, but no ammonia volumes in port indicated

## Projects & Initiatives

- Partnership agreement with Ceará State Government and the Port of Rotterdam signed in 2018 for development of Pecém Industrial and Port Complex, which will enable them to become a global player in the production of renewable hydrogen
- Established a green hydrogen HUB in 2021 with the Federal University of Ceará (UFC) and the Federation of Industries of Ceará (Fiec)
- Developing a value chain from renewable energy supply, H2 production, ammonia storage and distribution, fertilizer production, synthetic fuels and transport to off-takers
- MoUs signed with national/international companies interested in participating in producing green hydrogen and participating in the value chain and the Green Hydrogen HUB in Pecém
- EDP (client) announced that the HUB's first electrolyser will start production in 2022




Source: Port of Pecém & Port of Rotterdam

# Port of Itaqui

## Strategy & Targets

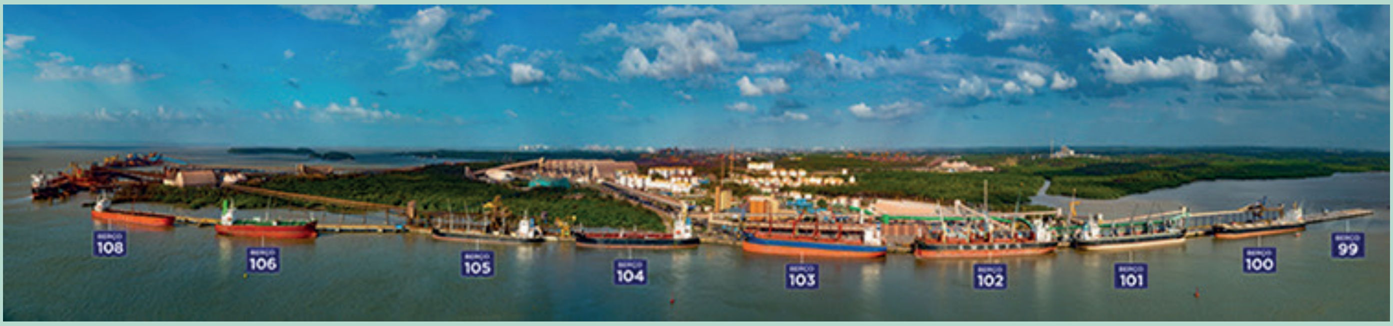
- The port is committed to protecting the environment and sustainability
- The port has defined environmental objectives and goals in accordance with its Environmental Management System policy
- Goals are aimed at controlling environmental impacts, conscientious consumption, reduction of energy and water consumption
- Environmental Ship Index associate

## Facts

- 912 sea-going vessels
- 232 mill. tonnes/year of general cargo and solid and liquid bulk
- Connections with important railroads and highways
- No ammonia/hydrogen strategy and indication of ammonia volumes

## Projects & Initiatives

- The port established a Technical Chamber in 2021 to discuss subjects related to the Climate Change and is in the process of drawing up its decarbonization targets
- Silver Seal of the Brazilian GHG Protocol Program and the Port of Itaqui has published its Greenhouse Gas Inventories, which measures and control direct emissions of gases
- Ships that can demonstrate a reduction of greenhouse gas emissions, will receive a discount on port fees
- EMAP's (Empresa Maranhense de Administração Portuária) research, development and innovation committee study new energy alternatives, i.e., solar energy plans, green hydrogen etc., with local companies and universities
- Project developed by the State Secretariat for Special Projects to implement a Green Hydrogen plant near the port
- The terminal will play an important role in the internalization process of LNG based on Gasmar and Golar Power operations through the port's terminals



# Port of Santos

## Strategy & Targets

- Established 10 sustainability initiatives from 2021-2025
- No specific strategy for the development and usage of alternative maritime fuels
- No specific bunker regulations for ammonia as fuel, but are studying and preparing adjustments to existing regulations to be prepared for new fuels
- Interested in joining the GSP feasibility study

## Facts

- Largest port in Latin America (L.A.)
  2nd largest in container port in L.A.
- 4,853 sea-going vessels
- 133 mill. tonnes of cargo from dry-, liquid-, and breakbulk, containers et
- Connecting 600 ports in 125 countries
- No ammonia/hydrogen strategy and indication of ammonia volumes

## Projects & Initiatives

- The port is working with projects to make the LNG available as an alternative fuel
- Launched discounts for "green ships“ which shows a good score on the environmental ship index
- No collaboration projects towards the development of ammonia as fuel, and was first approached with this topic through the GSP pilot
- Previous experience with receiving and off-loading a ship with 72,000 tonnes of ammonia

# Porto of Açu

## Strategy & Targets

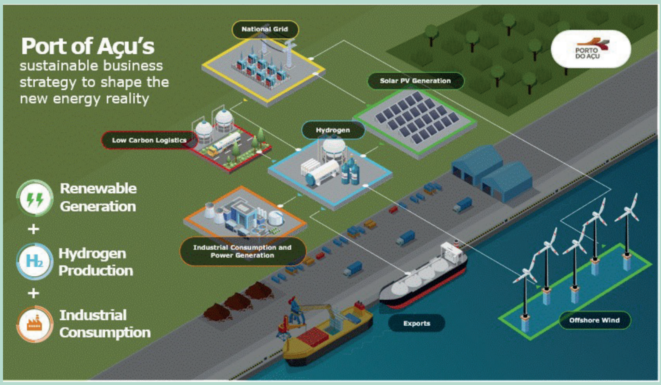
- Aim to make Açu a platform of sustainable business development focusing on the low carbon economy, in which sustainable fuels are included
- Monitors GHG emissions with the objective to know and quantify their profile of emissions and direct actions of mitigation
- Have begun development of  a decarbonization plan to define emission reduction targets for their operations
- Established guidelines to ensure focus of sustainability in their activities
- Environmental Ship Index Associate & winner of the World Ports Sustainability Award
- Interested in joining the GSP feasibility study

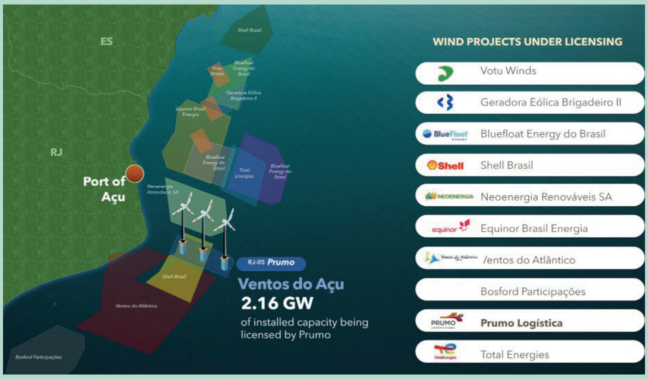
## Facts

- 3rd largest in iron ore terminal & 2nd cargo handling. Largest offshore support base in the world
- 2.4 GW of renewable energy in the pipeline, 30% of Brazilian oil export and largest thermal power complex in Latin America
- 28.9 mill. tonnes/year solid and liquid bulk, general cargo, iron ore and oil
- Infrastructure and multipurpose terminals in place. Largest offshore supply base
- Ammonia/hydrogen strategy, but no ammonia volumes in port indicated

## Projects & Initiatives

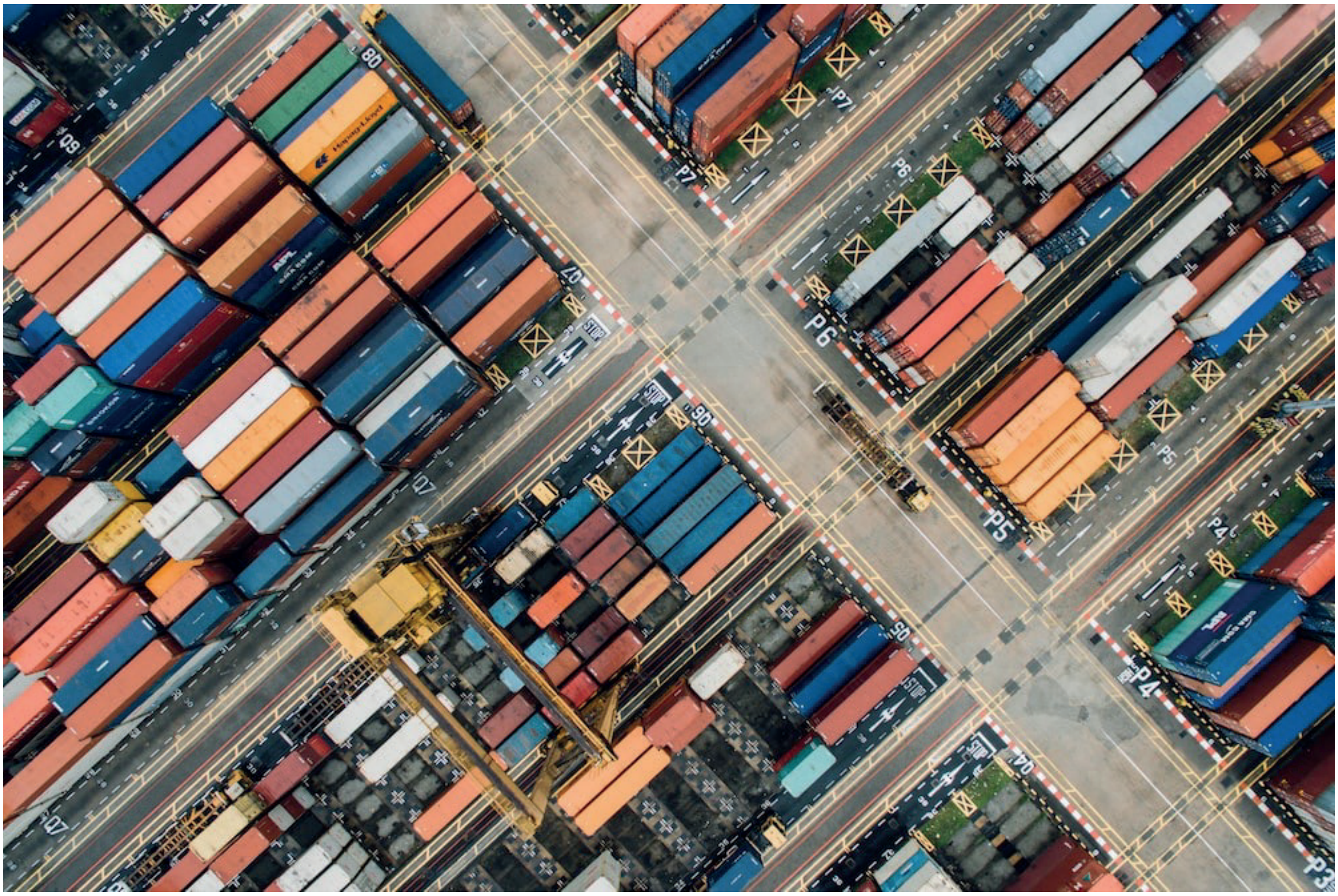
- The port is studying the financial feasibility of producing green hydrogen and production of green ammonia from hydrogen (200,000t of ammonia/year in the initial phases of implementation in 2026-2027)
- Port of Antwerp have a partnership with Port of Açu fostering the Brazilian market trade of more than 7.4mill. tonnes in cargo between Brazil and the Port of Antwerp
- Porto do Açu has engaged with several clients interested in developing green hydrogen for local green ammonia production
- Gás Natural Açu (GNA) and the port will invest 1 billion EUR in developing energy infrastructure at the port
- Shell have signed a MoU with the port to develop a 10MW green hydrogen generation pilot plant in 2025, with potential to reach 100 MW
- Fortescue Future Industries Pty Ltd and the port have signed a MoU to perform a s study for installing a green hydrogen plant of 300 MW, potentially reaching 250 000 MT green ammonia/year
- VAST, a company from Prumo's group responsible for crude oil double banking operations, is developing a liquid terminal and has ammonia fuel as part of the future developments planned. VAST will also be responsible for the licensing process for ammonia operation.



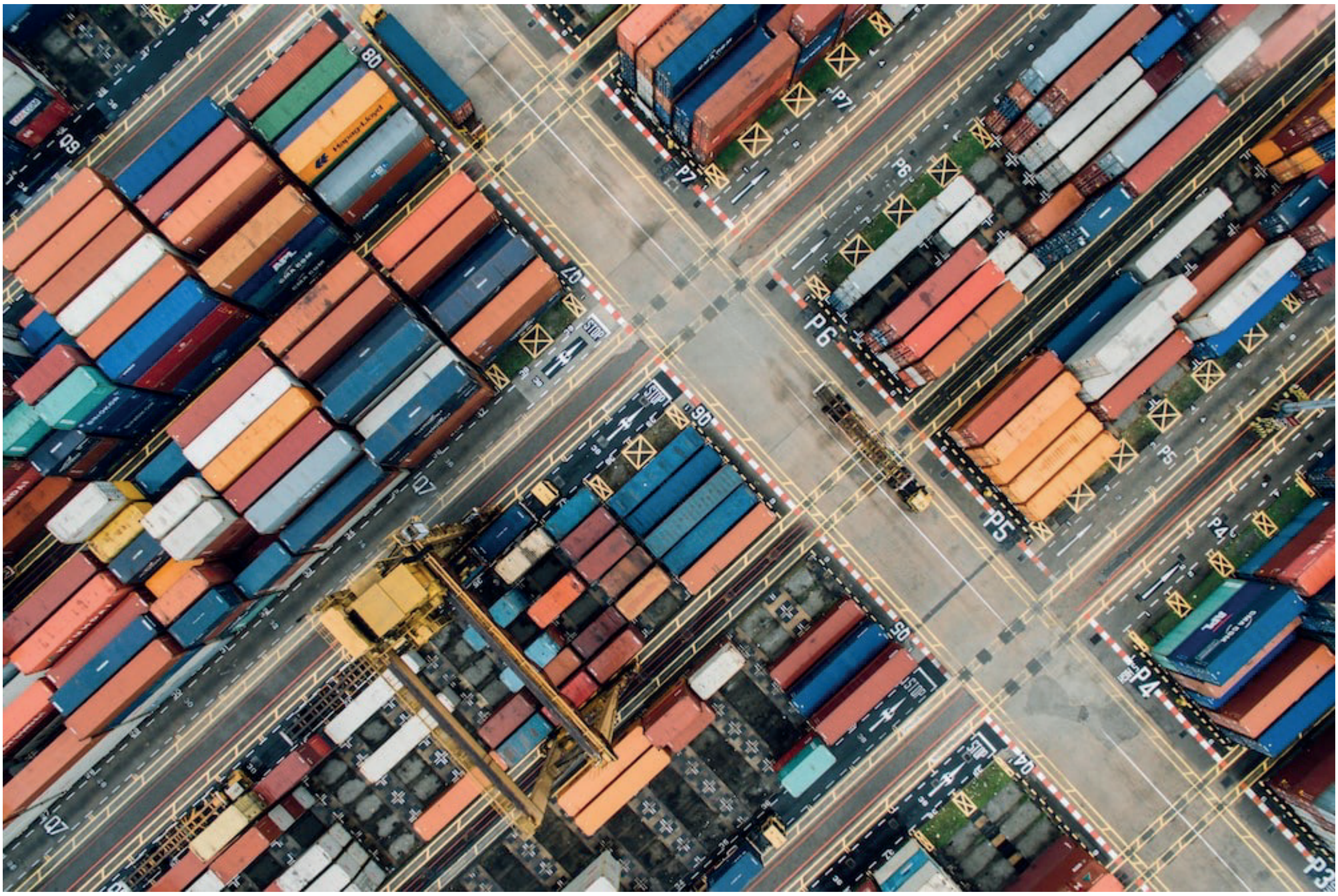






Source: Port of Açu & Reuters




# USA



# Port of Mobile

## Strategy & Targets

- Committed to minimizing impact on the environment and aim to improve air-, water-, soil and sediment quality, wildlife habitat, waste management and energy consumption
- Current driver and overall target was to become Green marine certified in 2018
- Exploring alternative fuel opportunities with fuel producers
- Analyzing effect of The Hydrogen for Ports Act, a grant program for hydrogen infrastructure on port facilities

## Facts

One of the nation's largest deep-water seaports

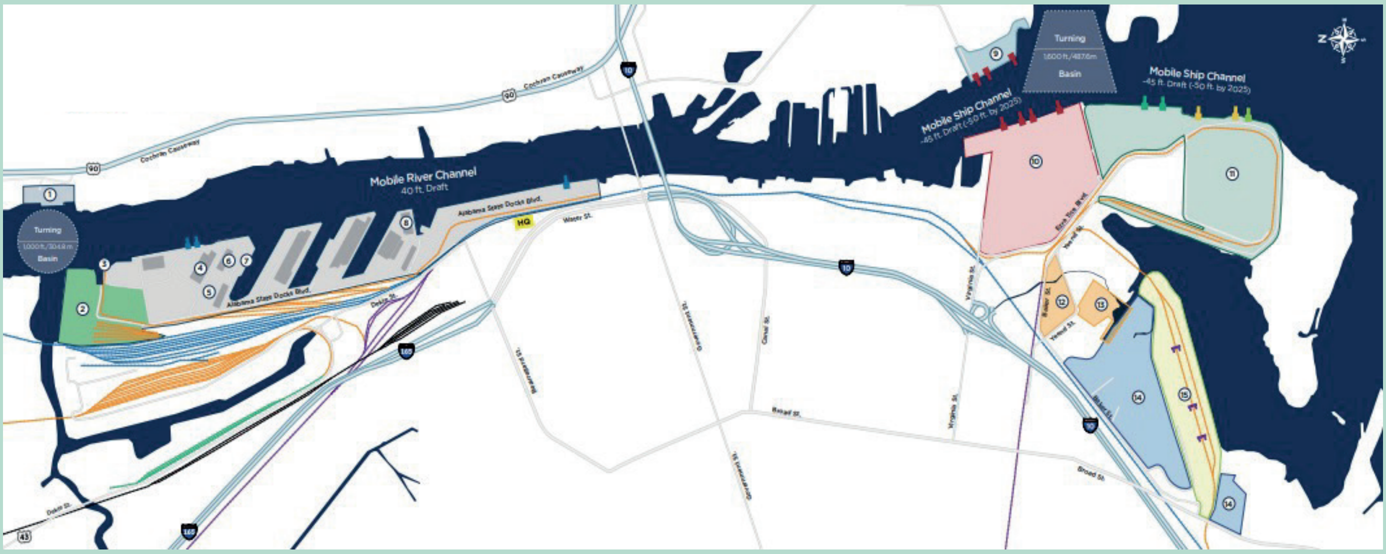
58 million tonnes of international and domestic cargo annually

Access to railroads, interstates, inland waterways

No ammonia/hydrogen strategy and indication of ammonia volumes

## Projects & Initiatives

- Chart Industries, clean energy equipment provider, will expand their business in Mobil, with expectation to double the manufacturing capacity of hydrogen transport trails and begin producing hydrogen bulk storage tanks.
- APM Terminals will conduct their 3rd expansion in 6th years, doubling the capacity to 1 mill. TEUs pr. year by 2025






*Source: Alabama Ports, Areadevelopment*

# Port of Savannah

## Strategy & Targets

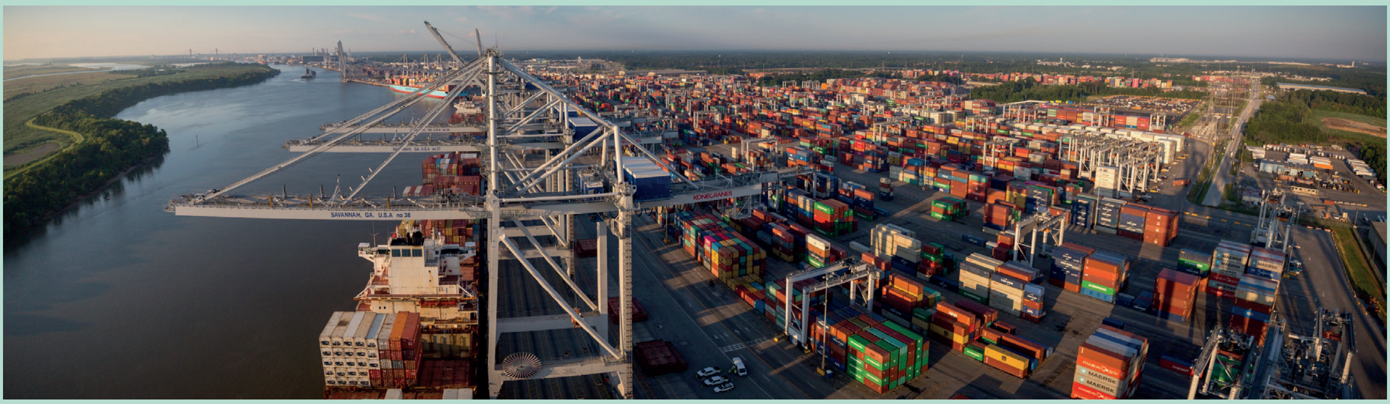
- Committed to conducting port operations in an efficient and environmentally respectful manner
- Looking at developing alternative fuels and support fossil fuel needs, both for inland consumption and for maritime

## Facts

- Largest and fastest-growing container terminal in America, and third-busiest container gateway in the U.S
- Electric ship-to-shore cranes with integrated generators that capture power
- 37.77 million tonnes in 2020
- Connection to key cities and manufacturing points
- No ammonia/hydrogen strategy and indication of ammonia volumes

## Projects & Initiatives

- The port have no current agreements with any green ammonia producers, but are interested and open to discussing
- The port recently acquired a new tank farm on the Savannah River and eager to put it to use. With their acquisition, they will grow their ability to store fuels but there is not yet a commitment on what they will store.  The market demand with determine this.
- The port will provide the capacity needed for auto part imports and exports for the I-95 corridor to Plug Power’s new hydrogen fuel production plan in Camden County in Georgia. The plan aims to produce 15 tonnes of liquid green hydrogen per day.





Source: Georgia Ports

# Port of Houston

## Strategy & Targets

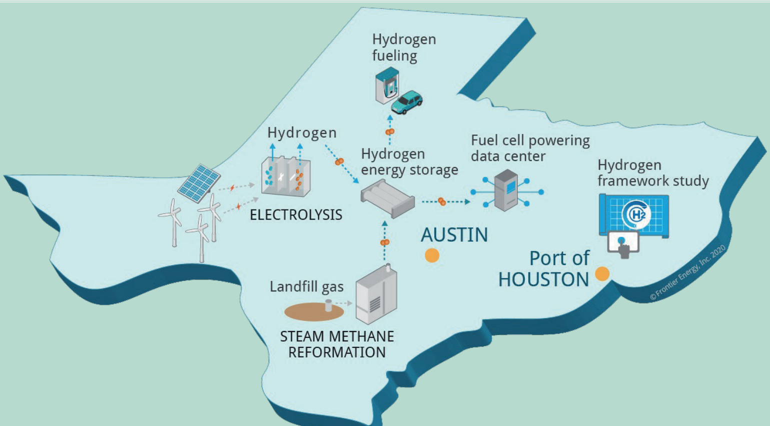
- Goal to become carbon neutral by 2050
- Developed a 5-year strategic plan, which included implementing an innovative environmental leadership strategy and support sustainable growth among others
- 72 ongoing activities related to environment, social, safety, and governance, and 27 new initiatives
- They are in business to develop alternative fuels, both for inland consumption and for maritime end-users
- Aim to grow their storage capacity for green ammonia but the total amount of storage is not yet known

## Facts

- Largest Gulf Coast container port, 7th ranked U.S. container port by total TEUs
- Largest petrochemical complex in the nation and 2nd largest in the world
- 10 000 vessels & 200 000 barges transits annually
- 44.5 million tonnes in 2021
- Ample truck, rail and air connections. No bunkering of ammonia, but could pivot quickly
- Hydrogen strategy, whereas grey ammonia availability of 30k MT

## Projects & Initiatives

- Sustainability partnerships, alternative fuels such as H2, development of future terminal, and implementing green shipping corridors are part of the ports action plan towards reaching carbon neutrality by 2050
- Initiatives included in the action plan include supporting industry partners to facilitate alternative fuel bunkering and infrastructure, such as LPG/LNG, Ammonia, Methanol, and Hydrogen
- The first greenfield terminal development in the port, a waterborne ammonia terminal, is now fully operational
- Conducting a feasibility study where they will investigate scaling challenges of hydrogen production, review policy and regulations, identify potential hydrogen users, evaluate resources and infrastructure, and help create a strategic plan for policymakers






Source: Port of Houston, Offshore-energy.biz, Forbes

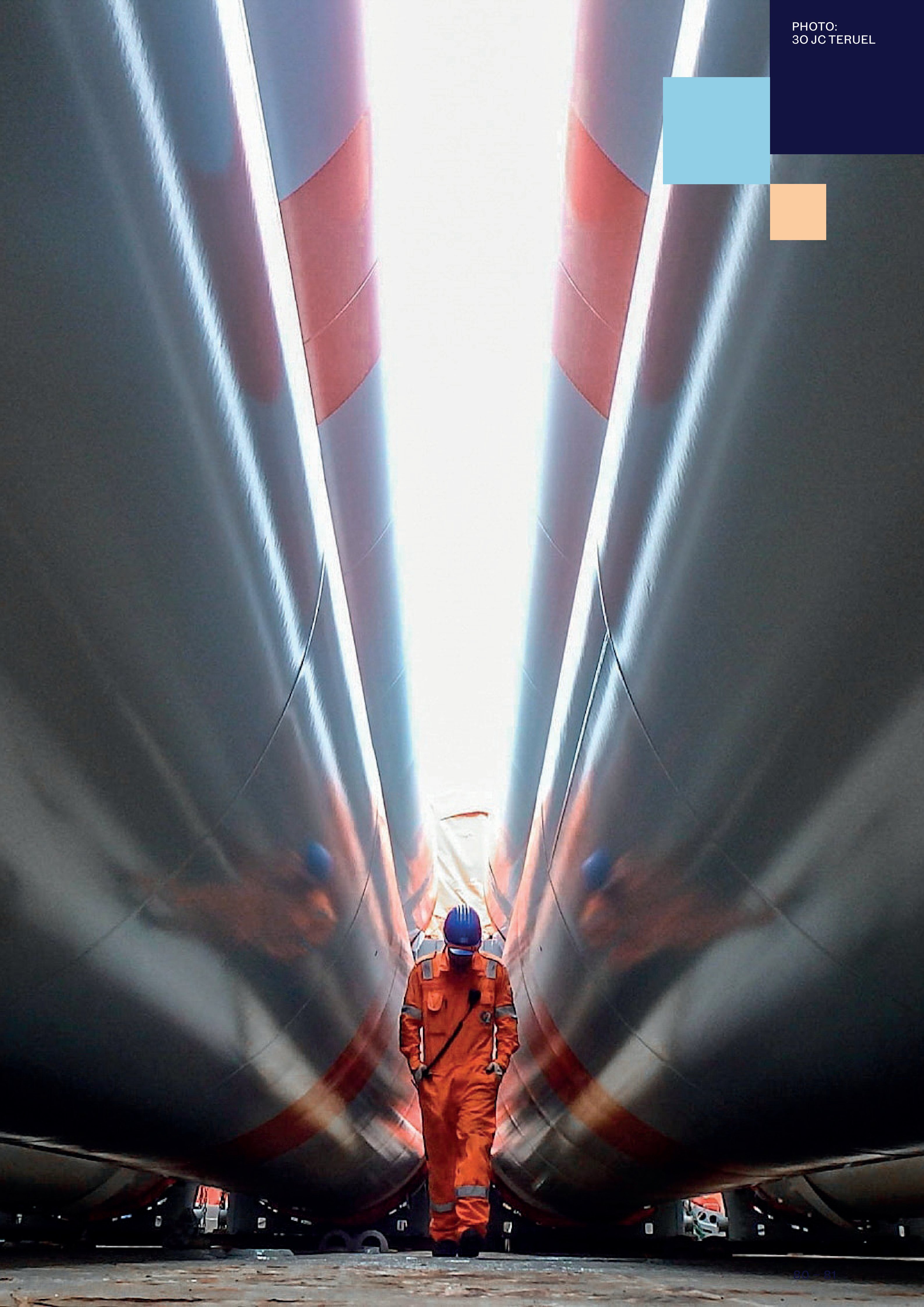


PHOTO:
3O JC TERUEL


GRIEG STAR

Green Shipping Programme