



REVIEW

Ammonia Bunkering—Infrastructure, Finance, Insurance and Regulatory Issues: A Review

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ABSTRACT

To comply with IMO Net Zero framework ammonia is emerging as a future fuel without carbon and sulphur products emission. Bunkering is a process of loading fuel on ships. Ships are not using ammonia as fuel at present. Engine makers are developing dual fuel engines to operate on ammonia. The prerequisite to use ammonia is a robust and safe infrastructure to supply green ammonia as fuel in ports worldwide. Fuel supply can be done by pipelines in ports, ship to ship transfer at anchorages or in ports, and truck to ship bunkering in ports. Ammonia being a corrosive and toxic chemical, and hazard identification and risk assessment needs to be carried out. Procedure for measurement of ammonia quantity and quality will need to be formulated. IGF Code will be applicable to Ammonia as fuel. All safety aspects will need to be included in a rigorous crew training and certification as per STCW convention. The methodology used for the paper is literature review, study of existing industry practices for bunkering of alternate fuels like LNG, Methanol and LPG and how it can be safely applied for ammonia bunkering. Key findings are that it will be safe to bunker ammonia by designing a robust system with inbuilt safety features similar to what is used for cryogenic fuel like Liquefied Natural Gas with stress on handling of toxic and corrosive properties and considering safety of crew and environmental protection.

Keywords: Bunkering Process; Toxicity; Corrosivity; Crew Training; Regulations; Methodology; Key Findings

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ARTICLE INFO

Received: 9 September 2025 | Revised: 13 October 2025 | Accepted: 17 October 2025 | Published Online: 13 November 2025
DOI: <https://doi.org/10.36956/sms.v7i4.2713>

CITATION

Bedekar, K., Oterkus, E., Oterkus, S., 2025. Ammonia Bunkering—Infrastructure, Finance, Insurance and Regulatory Issues: A Review. Sustainable Marine Structures. 7(4): 104–131. DOI: <https://doi.org/10.36956/sms.v7i4.2713>

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1. Introduction

Due to global warming caused by Greenhouse gases (GHG), shipping industry is under scrutiny for emission contribution which is almost 3% of the global measure. The emissions are caused due to the use of fossil fuels all these years. Now the hunt is on for a suitable fuel to reduce the GHG emission. The interim fuel in use has been Liquefied natural gas (LNG) for the last few years, recent addition of methanol, and the new entry ammonia which does not have any carbon content. Other contenders for suitable fuel are Bio Diesel and the holy grail of energy Hydrogen. It seems that the future marine industry will not use crude oil derivatives, fuel oil and diesel oil of different grades. For power generation there is also another alternative, fuel cells. So future marine industry will use aforementioned different multi fuels depending on the ship type, size, the trade route, ocean going or inland waterways, and also depending on the economics, availability, and infrastructure for supply. Shipping industry has a long history. Before industrial revolution wooden ships were powered by oars, wind, and sail. Steel ships came in to being after industrial revolution which were steam powered for propulsion. Coal was the fuel of the 19th century. Coal was used as fuel for boilers to produce steam, which were used in steam triple expansion engines, and turbines. After oil was discovered and production started in the 20th century from 1900 onwards ships' fuel was changed from coal to fuel. It contained hydrocarbons, its energy content was higher than coal, it was cleaner to handle as liquid and required lesser storage space which resulted in increment in cargo space. There was also reduction in crew members especially engine room as coal stokers were not required any more. Fuel oil was introduced initially for boilers to produce steam and later for internal combustion engines as they were more efficient than steam power. Heavy Fuel Oil (HFO) has been in use for the last seven decades in shipping due to its easy availability and low-cost and used in main engine, auxiliary engine and boiler. Discovery and development of internal combustion engines (ICE) led to replacement of steam reciprocating engines and turbines. Ships were powered by slow speed, 2-stroke

large, cross head type diesel engines for propulsion and 4-stroke medium speed auxiliary engines for electrical power. Marine diesel engines were more efficient than steam engines and turbines. For ship operating cost reduction heavy fuel oil was introduced in 1950 a product much lower in the refining process, containing many impurities like sulphur, ash, soot content, and various incombustible elements. Due to oil crisis and rise in oil prices, heavy fuel oil became the choice of ship owners. However, these fuels emit GHG and air pollutants like sulphur oxides (Sox) and Nitric and Nitrous oxides (Nox) and soot particles. Worldwide shipping industry consumes about 300M tons of fossil fuel per year for sea transportation of dry and wet cargo of 11 billion tons^[1]. Bunkering of fossil fuel like heavy fuel oil, diesel oil etc. is a well-established process in shipping and not considered dangerous with good measures to prevent environmental pollution and personal protection. Ships have been using fossil-based fuels like heavy fuel oil, intermediate fuel oil, and diesel oil since last hundred years. The procedures have been well established considering human safety and environmental protection. There is a robust infrastructure worldwide for fossil fuel supply. The crew is well trained to handle the bunkering with good co-ordination and support from the shore management. Written procedures and check list are in use as per the International Safety Management (ISM) guidelines and procedures are well documented in Safety Management System (SMS) of vessels. The methods for quality and quantity measurements are also well established. The shore establishment managing vessels is also well versed with supplying bunkers worldwide. The procedures for supply, quality and quantity measurements, fuel purification to make it suitable for use in ships engines and boilers are well documented, established and the crew is well trained in operation and procedures. There are shore establishment like Fuel Oil Bunkering Analysis and Advisory Service (FOBAS)^[2] which analyse the fuel, to ensure quality and specifications are maintained as per the standards. They also provide fuel quality guidance for smooth and efficient operation of the engines, boilers etc. For decarbonisation of shipping fossil fuel needs to be replaced, as it contributes almost 3% of world emis-

sion of GHG to the atmosphere ^[3]. The goal is to reduce pollution from shipping industry as per the “International Convention for the Prevention of Pollution from Ships, Marine Pollution (MARPOL) Annex VI” ^[4].

1.1. Alternative Fuels in Use

The alternative fuels in use are LNG, LPG and methanol (CH₃OH). All are derived from fossil fuels and have carbon content. At present there are dual fuel engines operating on these fuels, but these are transitional fuels. IMO goal is net zero emission by 2050 and as such carbon capture on board will be necessary for these fuels. All these fuels have a unique risk profile such as ammonia’s toxicity and corrosivity, LNG’s and hydrogen’s flammability and dispersion behaviour. Both are cryogenic fuels and very low temperature, or high pressure is necessary to keep them in liquid state. Methanol has a low flash point and near-invisible flame ^[5]. Methanol does not require cryogenic storage and is simpler to handle. The present dual fuel engine technology is suitable for green or blue methanol ^[6]. Methanol has low carbon content and is sulphur free. Ammonia

and methanol both have common challenges of lacking infrastructure for bunkering, cost and availability, combustion properties, and energy density. Marine engines can be retrofitted for using methanol as fuel ^[7]. IGF code governs the present interim guidelines for ships using alternative fuels such as methanol and ammonia is based on the safety principles of the IGF code (International Code of Safety for Ship Using Gases or Other Low-flashpoint Fuels). IMO’s risk-based AD&A process (MSC.1/Circ.1455) provides the basis for individual approvals. Till such time interim guidelines are adopted into the IGF code. A complete or partial alternative design and arrangements (AD&A) process will need to be undertaken for any alternative fuel project, depending on flag state requirements ^[8]. It will depend on the ship owner to use the most suitable fuel considering cost, availability and governing regulations.

Table 1 shows properties of different marine fuels in use other than ammonia. All these fuels have carbon content which will not be compatible with IMO’s goal of net zero carbon emission by 2050. Ammonia, a chemical compound, does not have any carbon element.

Table 1. Properties of different marine fuels in use ^[9].

Properties	Methanol	Methane	LNG	Diesel Fuel
Molecular Formula	CH ₃ OH	CH ₄	C _n H _m : 90–99% CH ₄	C _n H _{1.8n} ; C ₈ –C ₂₀
Carbon contents(wt%)	37.49	74.84	≈75	86.88
Density at 16 ⁰ C (kg/m ³)	794.6	422.5 ^a	431 to 464 ^a	833 to 881
Boiling Point at 101.3 kPa (°C) ^b	64.5	–161.5	–160(–161)	163 to 399
Net heating Value (MJ/kg)	20	50	49	42.5
Net heating Value (GJ/m ³)	16		22	35
Auto ignition temperature(°C)	464	537	580	257
Flashpoint (°C) ^c	11		–136	52 to 96
Cetane Rating	5		0	>40
Flammability limits (vol% in air)	6.72 to 36.5	1.4 to 7.6	4.2 to 16.0	1.0 to 5.0
Water solubility	Complete	No		No
Sulfur content(%)	0	0	<0.06	Varies, <0.5 or <0.1

Note: a for methane/LNG at boiling point; b to convert kPa to psi multiply by 0.145; c the lowest temperature at which it can vaporize to form ignitable mixture in air.

Sources: Jackson and Moyer, 2000 for LNG : Woodward and Pitblado, 2010; Hansson, 2015.

1.2. Abatement Technologies

Alternative fuels will require abatement technologies, especially ammonia. Its combustion will emit nitrous oxide N₂O with a global warming potential of 300

times higher than CO₂ which is a major challenge. However, the engine makers like Everllence (MAN), Wartsila, and WinGD have developed technologies to mitigate the emissions. The strategies used are improvement in engine design, combustion control, (EGR) Exhaust Gas

Recirculation, and use of Selective Catalytic Reduction (SCR). Ammonia, urea can be used to remove NO_x emissions. There are also specific proprietary chemicals like TOPSOEs TertiNO_x^[10] and YARA 58-Y1^[11] which can reduce / cutdown the No_x emissions to IMO standards.

Selective Catalytic Reduction (SCR) Reactor^[12]

is fitted in the exhaust manifold after the main engine turbocharger for NO_x emission abatement as shown in the **Figure 1**. Reactor contains chemicals like Urea and other proprietary chemicals like TOPSOEs TertiNO_x and YARA 58-Y1 which can reduce / cutdown the NO_x emissions to IMO standards.

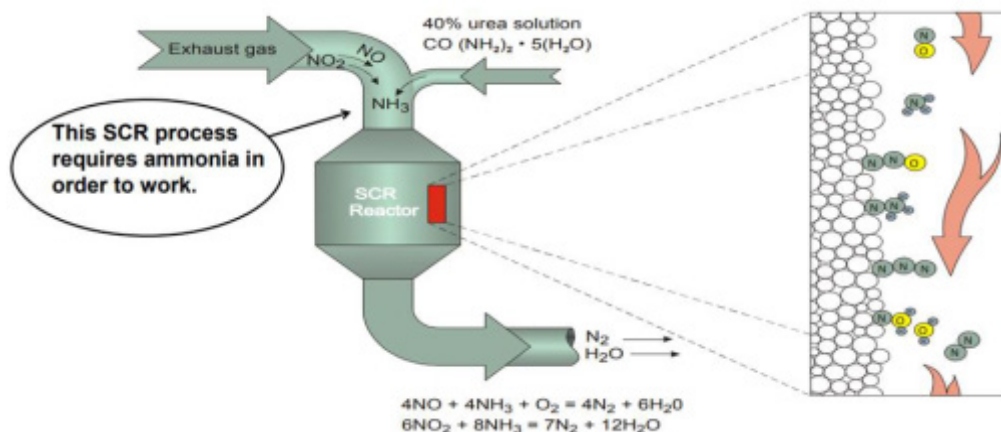


Figure 1. NO_x emission—ammonia^[12].

2. Methodology

The methodology used is literature review and study of existing industrial production of ammonia, properties of ammonia related to toxicity, its effect on humans and environment and combustion properties. Study also includes worldwide production and distribution of ammonia, existing industrial practise of handling ammonia during production and transport from the point of view of safety and how these practices can be modified and applied safely in shipping industry. The stress is on operational aspect of using ammonia as fuel on board and bunkering/fuel supply is the first step in the process.

3. Worldwide Ammonia infrastructure, Production and Transport

Ammonia is being produced by Haber Bosch process over a hundred years by synthesising Hydrogen and Nitrogen at high temperature and pressure using a catalyst. This process is energy intensive and polluting the environment due to GHG emission. Ammonia

is classified as brown / grey ammonia if the raw feed stock is coal and LNG. It's industrial use and transport is well established and regulated. There is a precedence of safely loading and discharging ammonia in bulk from the production units on to gas tankers and discharging in consumer ports all over the world. There are well over 200 ports involved in loading / discharging of ammonia as cargo.

However bunkering infrastructure is not developed yet since it will require a considerable investment ashore for storage tanks, pipelines, and associated pumping arrangements in a safe manner. In the initial stages, ship to ship transfer (STS) seems to be the most suitable as small tankers carrying ammonia can be used as bunker supply vessels. Bunkering ammonia on ships in fully refrigerated tanks at an atmospheric pressure as saturated liquid is considered the safest. The largest producers of ammonia are China, India, Russia, and US. Worldwide production of ammonia was estimated at 150 million metric tons^[13]. **Figure 2** below shows country wise production of ammonia^[14]. Worldwide there are about 122 seaports either exporting or importing anhydrous ammonia with specialised storage facilities. These ports could be used to build an infrastructure to supply ammonia as fuel by pipelines to ship addition-

ally, there will be a need to build specialised ammonia bunkering vessels, in the range of 2000–3000 m³ ca-

capacity to supply bunker at anchorage away from human populace.

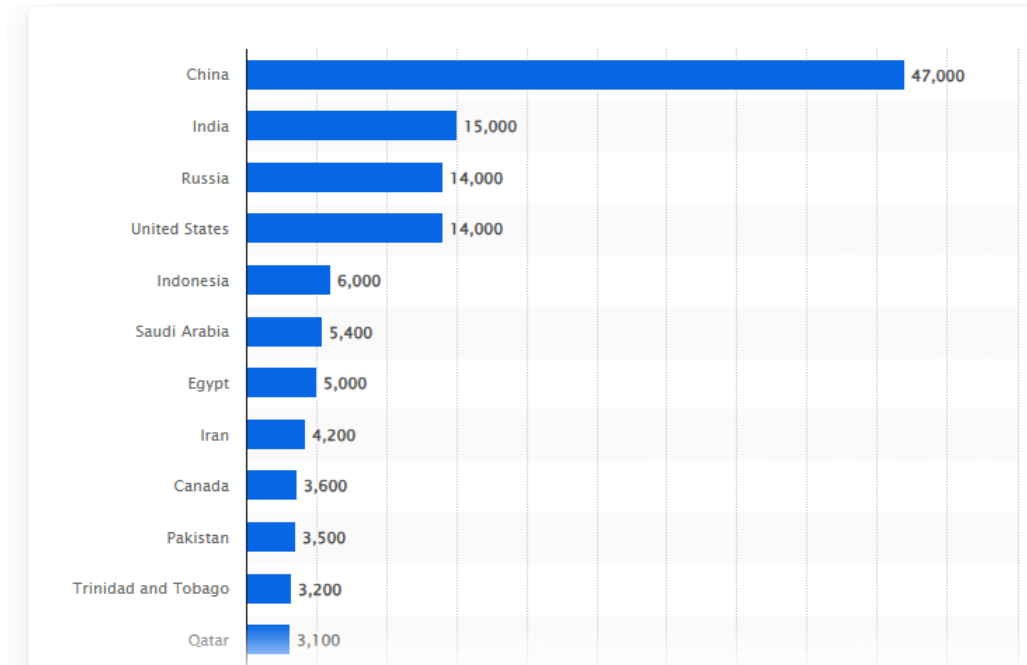


Figure 2. Ammonia production worldwide in 2024, country wise (in 1000 metric tons) ^[14].

Figure 3 shows worldwide ports. Gulf countries are major exporters with loading terminals, India and China are major importers. European Union (EU) is both importer and exporter. New infrastructure would be required in Gulf, China, Australia and EU. Compar-

tively South America lacks infrastructure. The International Transport Forum (ITF) forecasts that for 80% of carbon factor reduction, hydrogen and ammonia will contribute around 70% of the fuel market in the near future ^[15].

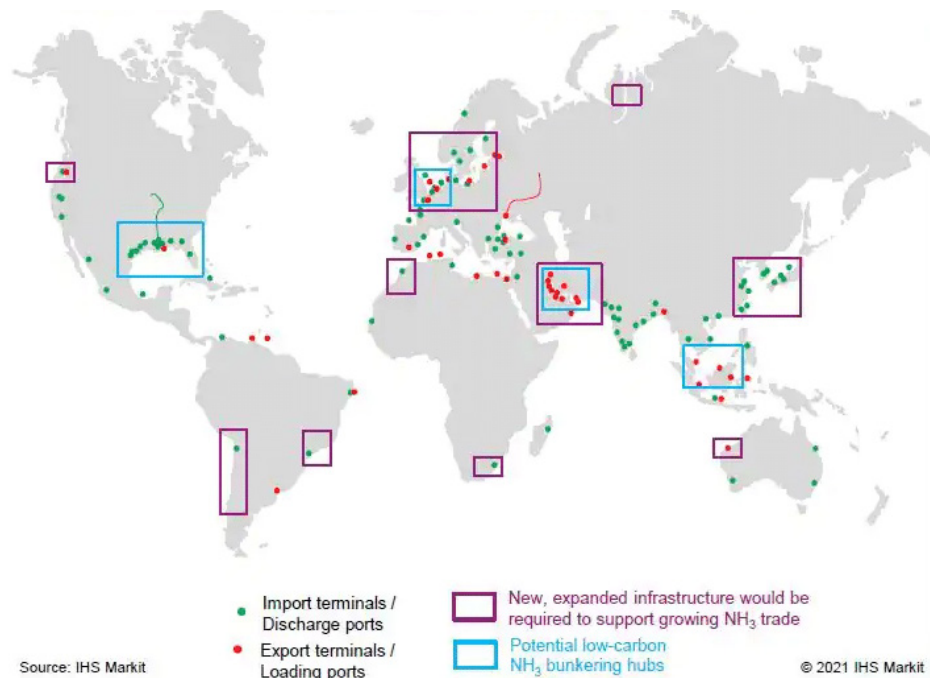


Figure 3. Global ammonia infrastructure: seaborne terminals ^[16].

3.1. Ammonia as Industrial Raw Material and as Fuel on Board Ships

Ammonia as a fuel will have a competition with ammonia as a raw material for industry. It is very likely that in the future marine engines can run on 100% ammonia as the fuel for decarbonisation of shipping industry. Ammonia can be used in gaseous or liquid forms. Due to its low energy density/unit volume at 12.7 MJ/L compared to fossil fuel like Marine Gas Oil (MGO) at 35 MJ/L, 2.8 times of MGO amount will be required for ammonia as the fuel. This will affect the vessels' operation range and cargo carrying capacity. For the new fuel, the regulatory regime is under development. A good ship design can make a simple fuel storage and delivery system when ammonia is used in its liquid form. This will also reduce the Operating expenses (OPEX). Today, a well-established global infrastructure of ammonia terminals and storage facilities exists. The same could be effectively used by small gas tankers working as bunker vessels with few modifications and use the existing storage infrastructure as a base to supply ammonia fuel to vessels in port and anchorage. The bunkering operation would be similar to supply other gaseous fuels like LNG, Liquid petroleum gas (LPG), and Methanol. The only difference is the toxic nature of ammonia detrimental to humans, aquaculture, and environment rather than flammability. A proper procedure needs to be developed for ammonia bunkering. There will also be a need for designing and building small ammonia tankers as bunker supply vessels.

Liquid petroleum gas tankers are capable of carrying ammonia as cargo. Out of 170 ships on liquified gas trade today 40 ships are carrying ammonia as cargo regularly ^[17]. Safety measures are in place for liquid gas carriers and crew is well trained. These measures include procedures for cargo loading / discharging, ballasting / deballasting, prevention and mitigation of leakage, tank cleaning and gas freeing, emergency and firefighting procedures. In addition, for carrying anhydrous ammonia as cargo, the ship requires toxic vapor detection ^[18]. Safety measures also include good vessel maintenance, use of Personal protective equipment (PPE), and guidelines for emergency responses. Loading / discharging process are well defined and

documented in SMS of the ships. Similar procedures for bunkering can be adopted like cargo loading. There are well documented and implemented personal safety measures for chemical tankers which carry dangerous and toxic chemicals. Similar procedures could be adopted for bunkering as well, e.g. liquid tight suits and overalls, chemical protective gloves, full face protection, and oxygen masks. There could be provision of shower, water curtain, and eye wash basins near the bunker station and accommodation. Present production of industrial ammonia is categorised as brown / grey ammonia. For brown / grey ammonia the CO₂ emission depends on the raw material used and plant efficiency. It varies between 1.6 and 2 tons of CO₂ per ton of ammonia and almost 3 tons of CO₂ per ton of ammonia when LNG and coal is used respectively as feedstock ^[19]. Worldwide projects are coming up with the aim of producing green ammonia. The production methods include water electrolysis to separate hydrogen from water and nitrogen separation by pressure swing adsorption and membrane nitrogen generation process from atmospheric air. Nitrogen separation technology exists and is in use on chemical tankers for inerting of different type of chemical cargos by nitrogen ^[20].

3.2. Why Ammonia

The main reason for ammonia use will be zero carbon and soot emissions complying with IMO regulations. Ammonia can also be transported in time and space. It's easily compressible and stored as saturated liquid at atmospheric pressure at -33.5°C or as liquid at 10–18 bar at atmospheric pressure. Storage on ships in bunker tanks will not pose any problem as gas carriers already carry ammonia as cargo in tanks. The current marine fuel consumption is about 230 million tons of fossil fuel ^[21]. By 2050 it can be expected that 25–50% of the fuel consumption is replaced by ammonia. The recent market price of industrial ammonia has been about 400 USD/Metric Ton in the Gulf region. The price is dependent on cost of raw material LNG and other factors. At present Low sulphur heavy fuel oil (LSHFO) is priced between \$460–\$568 ^[22], and Present brown / Gray Ammonia cannot compete with LSHFO in cost ^[23].

Figure 4 shows the free on board (FOB) and cost

and freight (CFR) annual prices of ammonia in Arabian Gulf, N.W Europe , Asia , Taiwan and India for last five years ^[24]. The shipping industry will be competing in future for ammonia with the fertiliser, chemical, refrigeration and energy industries.

Increasing green ammonia production will take time. At present about 300 projects are in the pipeline worldwide, about 261 green ammonia and 40 low carbon ammonia production facilities to be completed by 2030 ^[25].

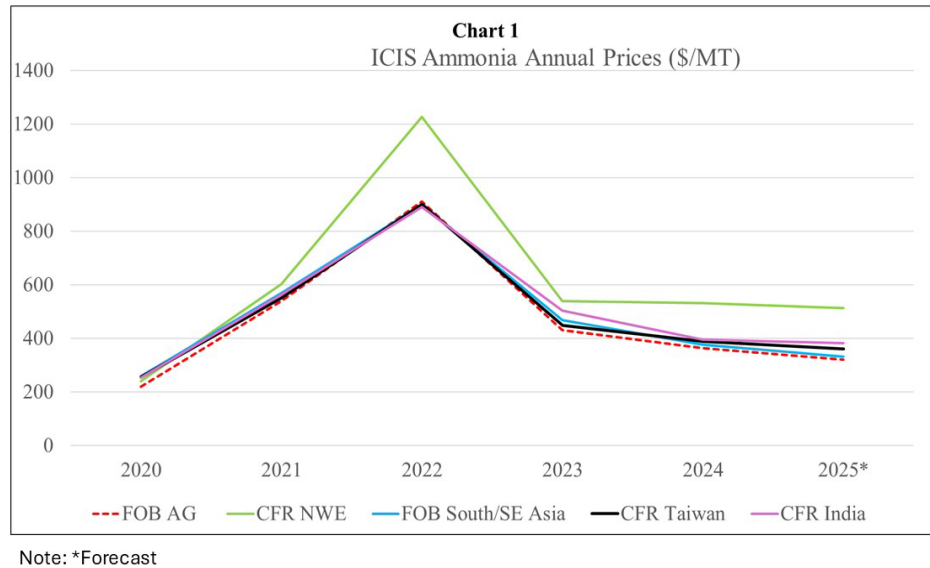


Figure 4. ICIS Ammonia annual prices (\$/MT) ^[24].

3.3. Factors Influencing to Switch to Ammonia as Fuel

Main factor is IMO's goal of net zero GHG emission by 2050. Further measures are a maritime GHG emissions pricing mechanism, adopted at the IMO (MEPC 83) session in April 2023 and will enter into force in 2027. There will be a fee of \$380/ton of CO₂ emission for vessels exceeding threshold value ^[26]. European Union is also introducing Emissions Trading System. Shipping companies will have to pay for their emissions corresponding to 40% of the total emissions in 2025 and rising to 100% by 2027 ^[27]. It will be economical for ship owner to change over to fuel without carbon emission. There is a general awareness about sustainable development in the society and consumer preference for green energy. Charterers are demanding action on GHG emissions from ship owners due to demand from consumers and pressure from regulators ^[28].

Figure 5 shows a comparison between emission pathway in line with IMO strategy and business as usual emissions and the emission gap. Year 2008 is considered as the base year. The green, red and blue lines

show the emission pathway as per IMO's revised strategy. Green shows net Zero by 2050, red shows pathway in line with IMO's 2018 GHG strategy and blue is business as usual emissions. There is a large emission gap between the green and blue line ^[29].

Figure 6 shows comparison of different types of ammonia in Tank to wake and well-to-wake GHG₂ emissions against VLSFO. Green Ammonia shows the lowest carbon emission compared to other fossil fuels.

Timeline of IMO regulatory action to cut GHG emissions from shipping (IMO, 2023) and IMO's regulatory action from 2011 to 2050 to achieve net zero emission by 2050.

Figure 7 shows initial mandatory actions and planned actions. Energy efficiency design index (EEDI) and Ship Energy Efficiency Management Plan (SEEMP) were introduced in 2013, to increase the engine efficiency thereby reducing emissions. Later Data collection system (DCS), Energy efficiency Existing ship index (EEXI), Carbon Intensity indicator (CII) were introduced and are still in force to reduce the carbon emission from shipping industry.

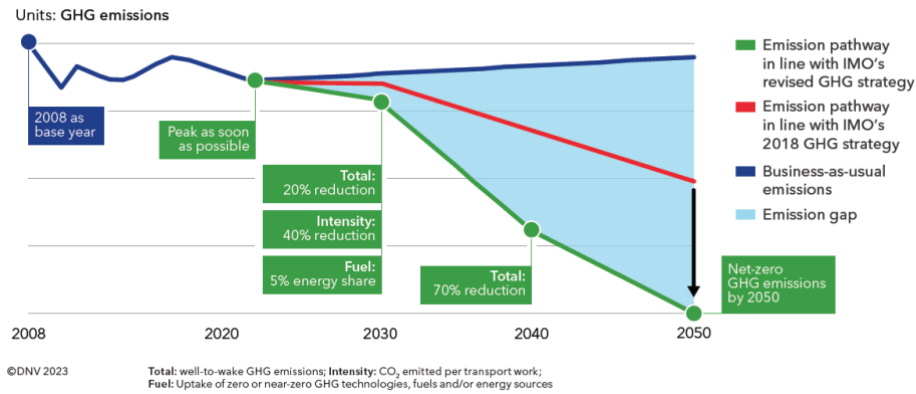


Figure 5. Well to wake GHG emissions throughout the years ^[29].

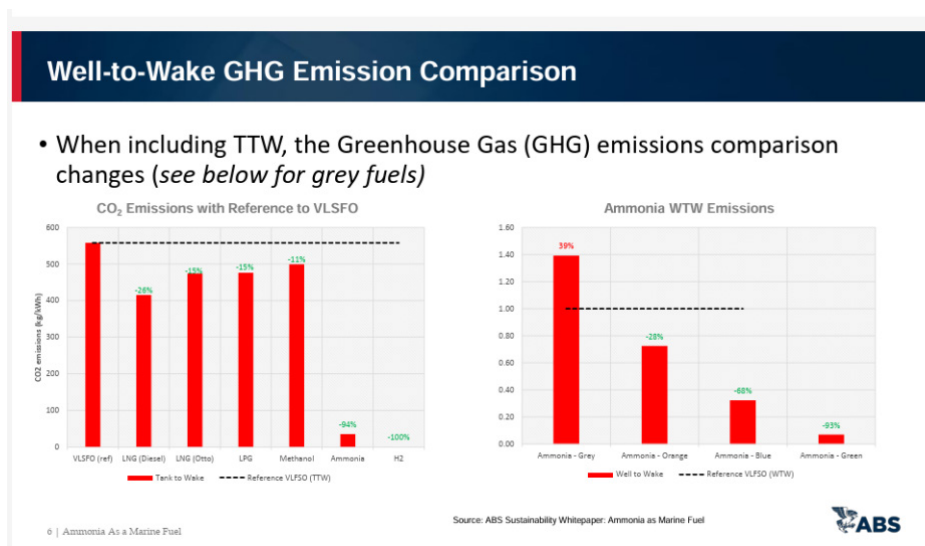


Figure 6. Comparison of different types of ammonia in Tank to wake and well-to-wake GHG2 emissions against VLSFO ^[30].

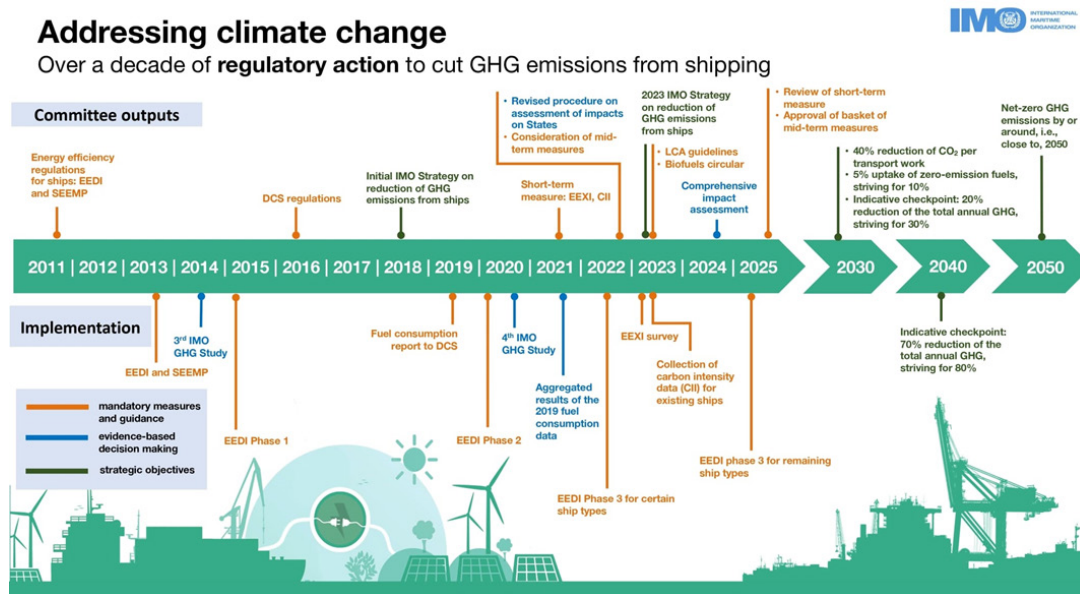


Figure 7. Regulatory action to cut GHG emissions from shipping ^[31].

3.4. Incentives to Use Ammonia as a Fuel

Government subsidies for producing green Ammonia will reduce the cost of ammonia. Department for Business, Energy and Strategy (BEIS-U.K.) has awarded £6.7 M to Tyseley ammonia for green hydrogen production to support development of technology to produce green ammonia using renewable energy^[32]. Hydrogen will be synthesised with nitrogen and ammonia will be produced with green energy with the availability of raw material from water and air. Financial institutes are also supporting the green initiative. “Poseidon Principles is a global framework for responsible ship finance.” This initiative was launched in June 2019 by a consortium of banks to measure the environmental footprint of their shipping investment and monitor the performance on a yearly basis. Their target has been derived from IMOs revised strategy of MEPC 80. “The Poseidon Principles establish a framework for assessing and. disclosing the

climate alignment of ship finance portfolios. They set a benchmark for what it means to be a responsible bank in the maritime sector and provide actionable guidance on how to achieve this”. The Poseidon initiative including Banks such as Citi, Societe Generale, and ING are part of the initiative for shipping finance. They will consider environmental and climate issues for ship financing. In simple terms, the decisions will support decarbonising of shipping. This will result in favourable financing conditions and lower the cost of borrowings benefiting the ship owners^[33].

Figure 8 shows the production methods of producing ammonia in categories of Grey, Blue and Green using green energy like wind and solar power. Grey ammonia can be produced from natural gas/coal whereas blue ammonia production includes carbon capture & storage. Green ammonia can be produced from carbon-free electricity^[34].

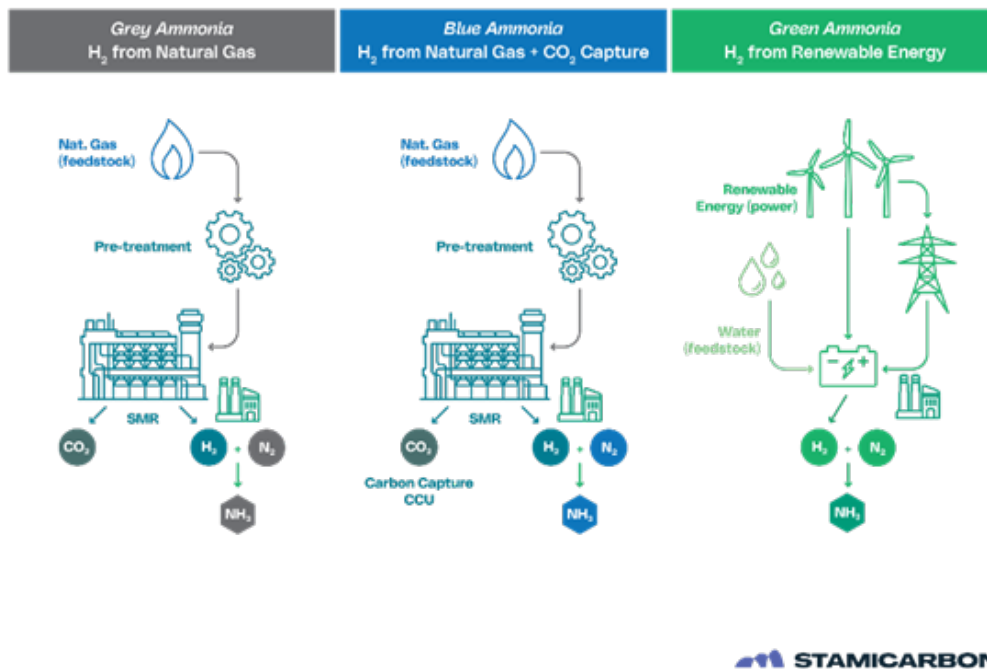


Figure 8. The production methods of producing ammonia in categories of Grey, Blue and Green using green energy like wind, solar power and carbon capture^[34].

Figure 9 shows Ports worldwide in EU, Africa, Gulf countries and S.E. Asia loading and discharging ammonia as cargo. Ammonia transport infrastructure is well established and operational in 130 ports worldwide^[35]. These ports could be used for ammonia bunkering. Ammonia

annual production is about 180 M Tons and capacity up-scale to 250 M tons is possible. It is expected that about 100,000 ships will need infrastructure in port to use ammonia as fuel. Green ammonia could power 30% of the world maritime fleet by 2050.



Figure 9. Worldwide Ports loading and discharging ammonia as cargo [35].

Figure 10 shows free on-board cost of industrial ammonia over a period of twenty years in the Black Sea, Middle east, and Caribbean region.

Figure 11 shows the gradual rise of green ammonia production worldwide over a period of last 25 years. The starting point is year 2025. By year 2050 it is expected that almost half the ammonia produced worldwide would be green ammonia.

As shown in Figure 12, it is expected that by

2030, 30.6 million tons (MT) capacity of low-emission and transitional ammonia will be operational. 3.5 MT transitional ammonia is already operational and expected to rise to 5.8 MT by 2025. Most of the low-emission ammonia capacity comes from gas reformation projects, totalling about 14.0 MT in 2030. By 2025/26 water electrolysis projects are expected to begin operating at scale and expected to reach 10.5 MT capacity by 2030^[37].

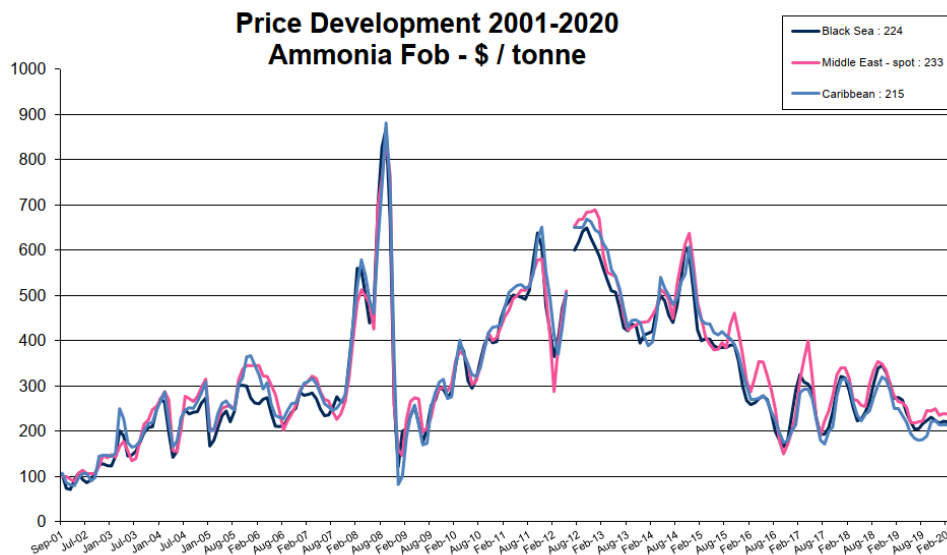


Figure 10. Price development between the years 2001–2020 (\$/tonne) [36].

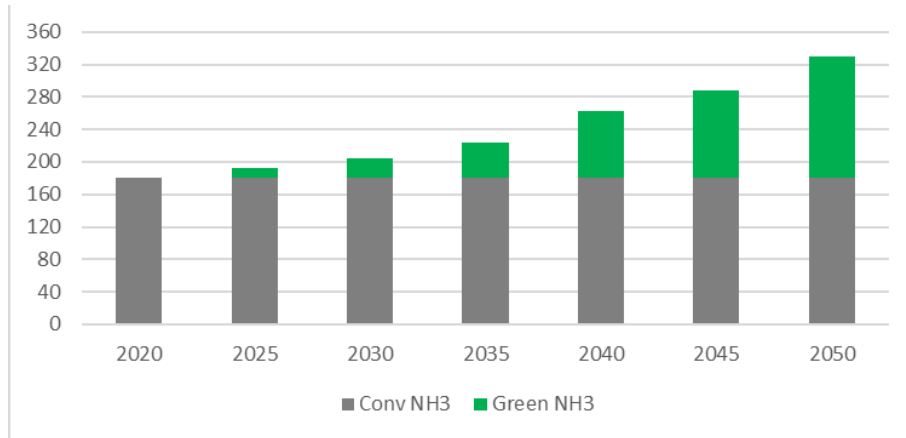
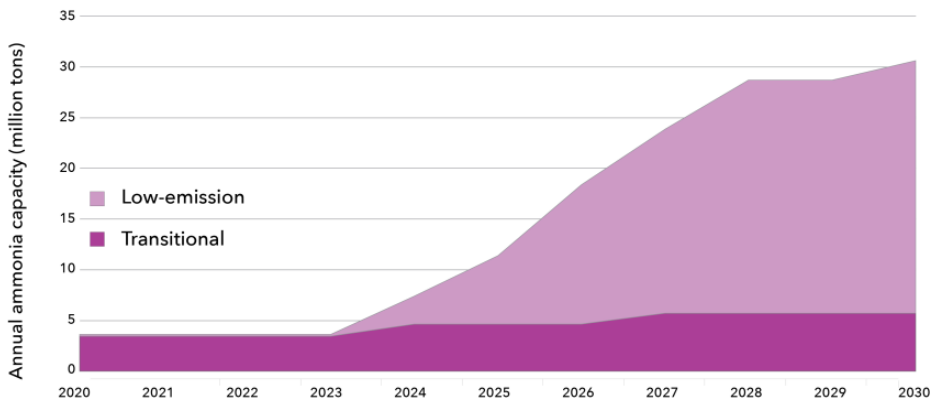


Figure 11. Projected ammonia production throughout the years (million tons)^[36].

Low-emission and transitional ammonia plants



By category (Operational, Firm, Mature): 30.6 million tons of ammonia by 2030



By technology pathway (Operational, Firm, Mature): 30.6 million tons of ammonia by 2030

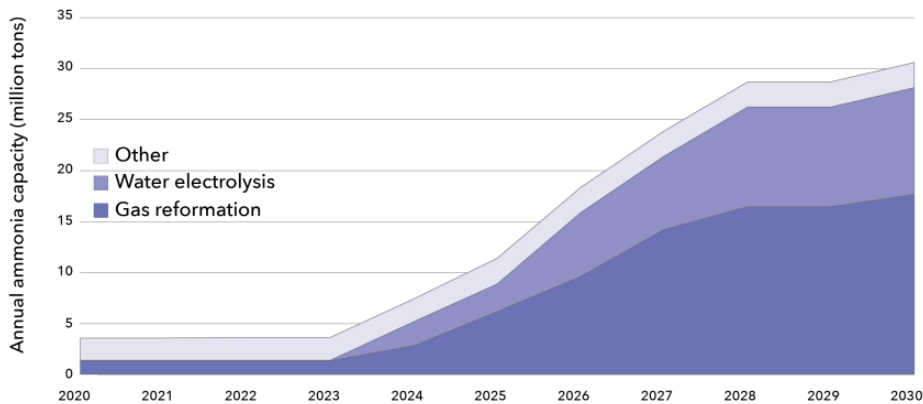


Figure 12. Annual ammonia capacity throughout the years^[37].

The worldwide capacity to produce low emission green ammonia is about 372.5 M Tons.

Figure 13 indicates ammonia production by gas reformation, water electrolysis and other methods^[38].

Figure 14 shows expected demand for ammo-

nia for fertiliser, in industry, in shipping as fuel, for power generation and as a hydrogen carrier. The graph indicates rise in ammonia demand from 200 MT from 2027 to 500 MT in 2050 for the shipping industry^[39].

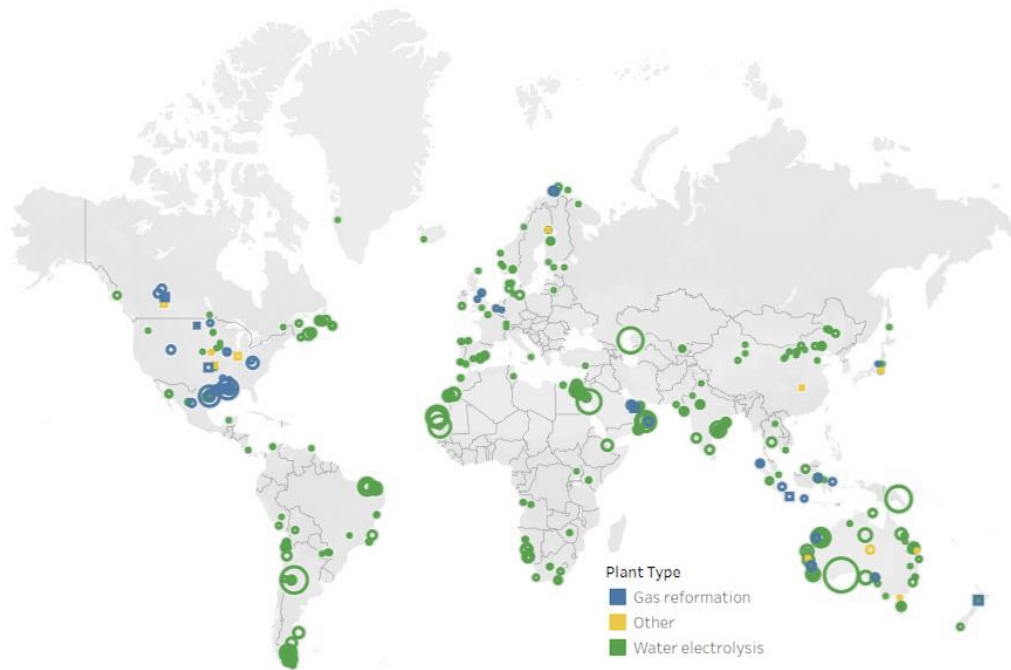


Figure 13. Ammonia production by gas reformation, water electrolysis and other methods ^[38].

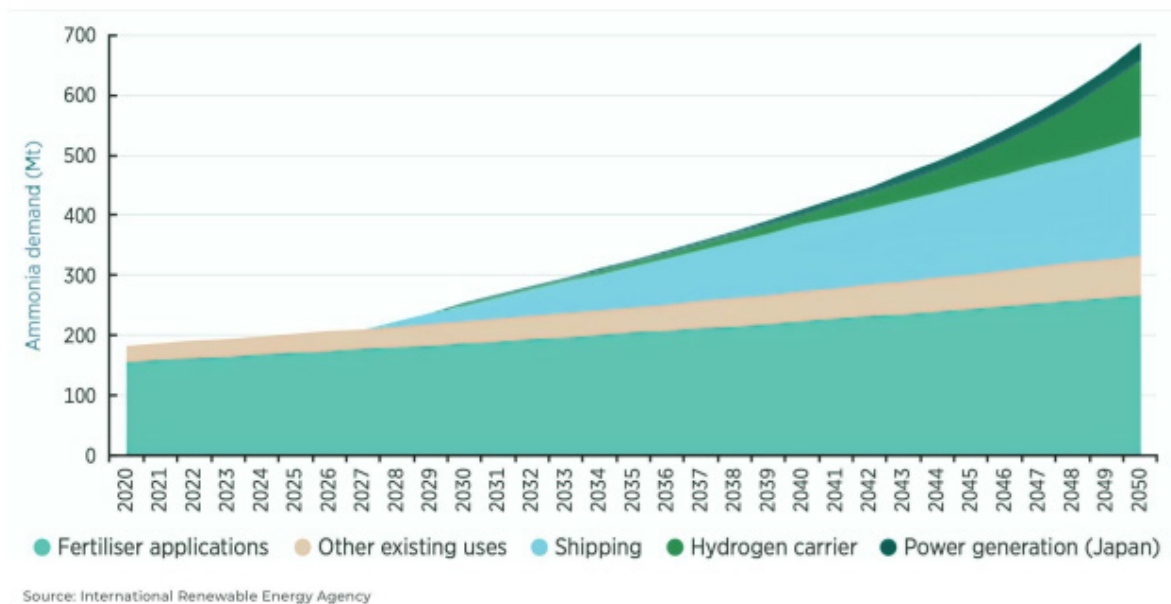


Figure 14. Expected ammonia demand to 2050 for 1.5°C scenario ^[39].

4. Methods of Bunkering

Ammonia bunkering process guidelines have been issued by IMO, EMSA, IACS members and other agencies like SIGGTO and SGMF. There is still work in progress until a proper code combining IGF and IGC is formulated by IMO for ammonia as a fuel.

Ships bunkering can be done in three different

manners:

1. Terminal to the vessel by using a pipeline directly from the storage tank to the vessel.
2. Road tanker to the vessel.
3. Ship to ship transfer (STS)

Ocean going large ships are supplied fuel in three different ways.

4.1. Truck to Ship

Trucks store pressurised saturated ammonia at ambient temperature at 10–15 bar. It is a low cost, convenient and well used existing method and bunkering is possible at berth. This method is not suitable for ammonia as large quantity is required, whereas supply quantity is available in small parcels, frequent connection and disconnections is not a safe practise. Port authority also may have certain restrictions.

4.2. Terminal-to-Ship

This is possible on tanker terminals where ammonia is stored in shore tanks that can be supplied from the terminal by pipelines connected to receiving vessels by a loading arm.

4.3. Ship-to-Ship

Ship-to-ship fuel supply is the most common method of fuel supply to large vessels, such as tankers, container vessels, and bulk carriers. These vessels need considerable quantity of fuel and same can be supplied by bunker tankers / barges. Ship-to-Ship transfer has been used for fossil fuel over the years. It is safe and convenient due to high bunkering rate and volume. Bunkering is possible at berth or at anchorage away from populace. Present drawbacks for ammonia bunkering are lack of storage infrastructure in ports and availability of bunker tankers. There will be initial capital cost for building the infrastructure. Only STS is considered in this study. This can be done at the port berth / jetty or at anchorage where both ship's crew are involved. Terminal to the vessel is not considered as container and bulk cargo terminals may not have the facility and bunkering may also interfere in port operations. This facility may be available at tanker terminals whereas STS is possible at all the berths. Road tanker is not considered as the quantity supplied will be too little against the higher demand due to low calorific value / energy content of ammonia. For bunkering ammonia, the main issues are toxicity and corrosivity. Bunkering frequency for ammonia will increase as more fuel is required in comparison to fossil fuel.

5. Bunkering Infrastructure for Ammonia

As of today, there is no established robust infrastructure worldwide for a regular supply of green ammonia as fuel. In the initial stages, brown/green ammonia can be used, and this will reduce the shipboard emission of GHG. Most of the ammonia production falls in the brown and grey ammonia category where LNG / coal is used as raw stock and the Haber-Bosch process is used for synthesis, which is energy intensive and emits GHG.

Worldwide there are three major bunkering hubs including Rotterdam, Fujairah and Singapore and these three ports have been supplying fossil fuels for few decades now. These same ports are now gearing up for supplying ammonia as fuel. As greater number of ships start using ammonia as fuel leading to higher demand and other major ports with ammonia loading / discharging facilities will also develop bunkering infrastructure.

5.1. Port of Rotterdam

Rotterdam is a major bunker port with about 10 M tonnes of fuel bunkered annually. The port has been involved in supply of LNG and methanol. The port readiness for ammonia is level 6. The recent STS of Gray ammonia in April 2025 between two OCI vessels Oceanic Moon and Gas Utopia, raises the port's readiness to level 7. The STS pilot project of transferring 800 Cu. Meters was executed between two vessels at -33°C . This signifies that port is ready to supply ammonia as bunker complying with all regulations related to safety. The findings of the pilot project and the procedures will be shared with EU and other ports. This established that the port has good safety framework for ammonia bunkering. This was a collaborative effort between the Port of Rotterdam Authority, OCI, owner and operator of the ammonia terminal. Other agencies involved were Fisher Fender care, APM Terminal and Victrola. The regulatory agencies involved were DCMR Environmental Protection Agency, Rijn Mond Safety Region (VRR), and the Joint Fire Service (GB) ^[40]. **Figure 15** shows Ship to Ship transfer in the port of Rotterdam ^[41].



Figure 15. Ship to Ship transfer in the port of Rotterdam ^[41].

5.2. Port of Fujairah

Port of Fujairah is exploring the possibility of developing ammonia bunkering infrastructure. It has been a hub for fossil fuel bunkering but compared to Singapore and Rotterdam there is no infrastructure for bunkering ammonia as yet ^[42]. At present, there is no demand for ammonia as fuel and hence no investment was made in ammonia bunkering infrastructure. However, Fujairah has been involved in B30—Biofuel bunkering (B30—Blend of 30% renewable biofuel and 70% conventional marine fuel).

5.3. Port of Singapore

Port of Singapore has been a major bunkering hub

for a long time for fossil fuel. Now it is trying to establish as a multifuel bunkering hub. With the introduction of alternate fuels like LNG, methanol, biofuels, ammonia will play a major role. MPA Singapore is planning to commit additional \$300 M towards the decarbonisation initiative. Terminal to ship bunkering of ammonia was carried out on the 'Fortescue Green Pioneer' during 2024 at Vopak's Banyan Terminal on Jurong Island ^[43]. It is predicted that the demand for ammonia as fuel will grow to 50 MT by 2050. Ammonia Powered vessel Fortescue Green Pioneer in Singapore anchorage is shown **Figure 16**.

Maritime Port Authority (MPA) of Singapore has committed \$ 300 million to support decarbonisation initiative over the next ten years as shown in **Figure 17** ^[44].

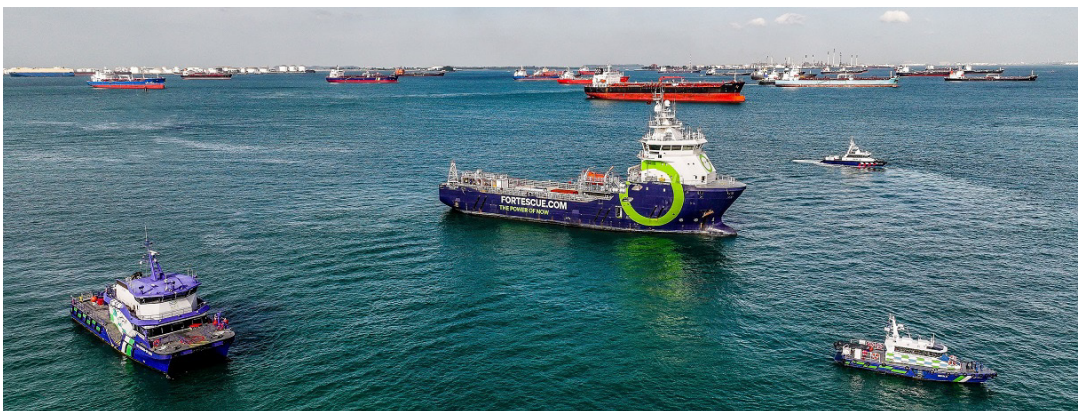
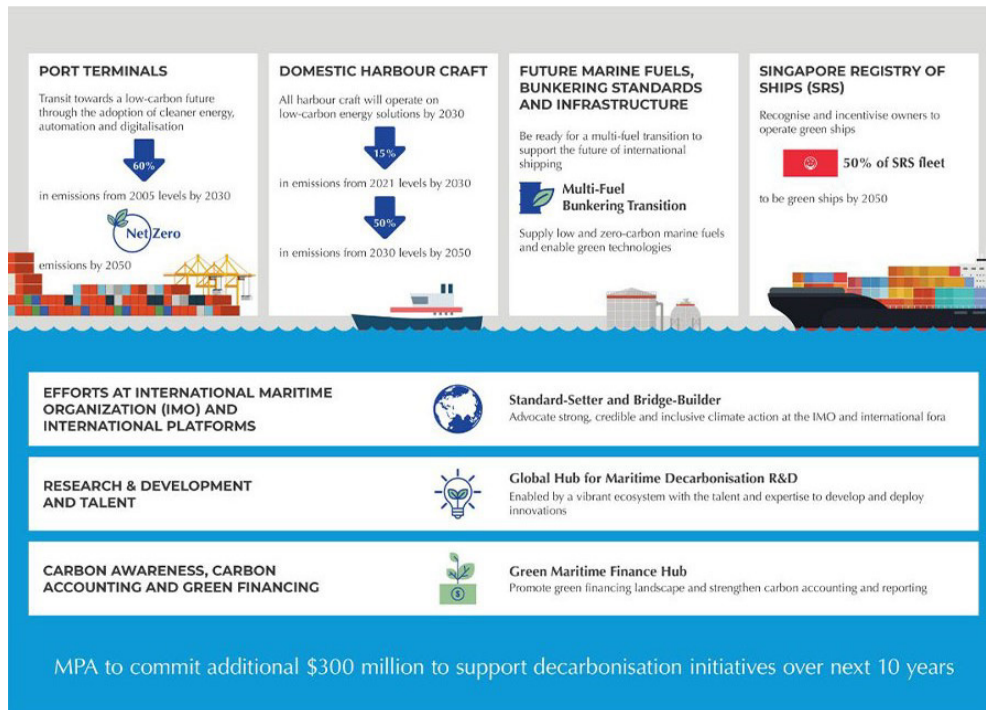


Figure 16. Fortescue Green Pioneer at Singapore anchorage.

Figure 17. MPA Singapore decarbonisation initiative ^[44].

6. Safety Concerns for Ammonia Bunkering

Any accidental leak of ammonia during bunkering operation either on board or in the sea will be detrimental to crew in the vicinity and the marine ecosys-

tem due to its toxic and corrosive nature ^[45]. This study looks at the overall operational and safety process of bunkering ammonia.

Risk matrix is prepared from normal bunker check list modified for Ammonia, emphasizing on Safety aspect due to Toxic and corrosive nature as shown in **Figure 18**.

		RISK MATRIX					
		Consequences	Minor	Appreciable	Major	Severe	Catastrophic
Risk Table		People	First Aid Cases E.g., Cuts / wounds / bruises. Minor discomfort or ill health	Medical Treatment Case Restricted Work Case Lost Workday Case. Short-term work-related illness	Permanent / Partial Disability Work-related health disorder	Permanent / Total Disability Fatality Severe / Life shortening diseases.	Multiple fatalities Severe illness to multiple personnel
		Environment	No impact on environment. Spills contained on board	Inconsequential impact on environment. Spills contained on board	Medium impact on environment Spills contained on board	Long Term impact on environment. Quantity not specified	Major Long-Term impact on environment. Quantity not specified.
		Assets	Financial Loss , cost not specified	Financial Loss	Financial loss	Financial loss	Financial loss
		Reputation	No effect on commercial venture	Minor effect on commercial venture Minor local public reaction	Loss to commercial venture Some local public reaction Minor media coverage	Threat to future commercial business Major media coverage	Severe threat to the company operation Prolonged international media coverage, public outcry
Likelihood	Remote	Has not occurred in the company in last 8 years.	Very Low	Very Low	Low	Low	Medium
	Unlikely	Has not occurred in the company in last 3 years.	Very Low	Low	Medium	Medium	High
	Possible	Has occurred in the company in the last year.	Low	Medium	High	High	Very High
	Likely	Occurs several times per year in the company.	Low	Medium	High	Very High	Very High
	Almost Certain	Occurs several times per year on each ship / location.	Medium	High	Very High	Very High	Very High

Figure 18. Risk Matrix.

Note: The risk levels for each of the four elements: People, Environment, Assets and Reputation considered for each hazard.

For Assets—No values are mentioned as it will depend on the incidence, location and kind of pollution caused by ammonia leak / spill.

7. Bunkering Process on Board

Bunkering process for fossil fuel has been well established worldwide with a robust infrastructure, logistics, supply chain, port regulations and it is in practise. MARPOL has formulated guidelines to prevent pollution from ships. Ship's crew are well trained, procedures for safe practises are well documented and implemented. There are associated hazards due to ammonia's toxic and corrosive nature. Only precedence is LNG bunkering which is a similar process that can be adapted to this cryogenic fuel for bunkering. Ships have been using LNG as fuel and have been bunkering. The bunkering operation is established and well tested in the industry. Ammonia is not volatile like LNG but highly toxic and dangerous to humans and environment. Since the required quantity of ammonia will be almost three times that of fossil fuel, required number of bunker manifolds and vapour lines will be more. This will depend on the ship type, size, and bunker tank capacity. The equipment size will also be larger as well as the hoses and higher pumping rates may be necessary. There will be additional features for human safety and environment protection like alarms for leak, ESD and dry breakaway couplings, hoses as specified by ISO standards, chemical resistant suits, water curtains to name a few.

Perceived Gaps—Bunkering process will have to be specific to the vessel depending on the storage system, tank type and configuration. Vessel will have to prepare procedure / checklist as per the ISM / SMS guidelines. For safe use of ammonia as fuel, regulations

are being developed. A good 'Ship and System design' will minimise chances of mishap.

Regulatory Bodies—IMO, SOLAS, IACS, EMSA, and port state controls.

7.1. Inherent Safety Features

Bunker line hoses are the starting point in the system; the hose will be supplied by the Bunker tanker / Barge. Ammonia is widely used in industry and transported regularly by road, rail and ships. Specialised hoses are used for liquid and gaseous anhydrous ammonia. These hoses are designed and made for dealing with the corrosive and toxic nature of ammonia. Occupational Safety and Health Administration (OSHA) regulation for ammonia hoses is specified in 29 (CFR) Code of Federal Regulation, 1910.111. The minimum working pressure for hose is 350 psi and test pressure of 500 psi. Commonly used hoses are stainless steel braided, and nylon braided. ISO specification for ammonia hoses is ISO 5771:2024 for a temperature range of -40°C to $+55^{\circ}\text{C}$ and working pressure of 2.5 MPa or 25 bar ^[46]. ISO specified flexible hose used for LNG may be used for anhydrous ammonia as well.

Figure 19 shows the breakaway coupling ^[47] designed in such a manner that the break pins shear off due to excessive force and activates the pistons (works like a spring-loaded disc valve to close of the connection swiftly) preventing leak/spill of the fluid medium. This ensures safety of the personnel around and loss of product.



Figure 19. Breakaway dry coupling Driplex Engitech ^[47].

7.2. Applicable Rules, Regulations for Bunkering

IACS—Classification societies unified rules

International association of classification society (IACS) has formulated unified rules for the use of ammonia as fuel and all related issues to safety and environment protection. Flag states normally delegate their work to classification societies from the new building phase to the end of the ship's life. All the surveys, inspections are done by the classification society on behalf of the flag state and statutory certificates are issued. Local port state control may have their own regulations for the safety of the environment. USA is one example where states have their own regulations mandatory for the vessels visiting ports in that state. California is one such state. EU ports and SECA will also have their own regulations in addition to IMO rules. Ammonia is being transported by ships as cargo regularly on gas carriers. SIGTTO and SGMF have their own guidelines for the safe operation of tankers. Oil Companies International Marine Forum (OCIMF) / Ship Inspection Report Programme (SIRE) inspections indicate the vessel condition. The charterers and insurance companies take into cognizance the reports for doing business with the ship owner.

7.3. Crew Training, Certification, Drills, PPE

Work is already underway to train the crew for handling ammonia as fuel. To start with first step should be "Train the Trainer". In shipping industry there are crews already trained to carry ammonia as cargo and shore training facilities exist to train the crew. Some shipping owner / management companies have already established training facility for bunkering LNG/ Methanol. The same training facility can be extended to train the crew to use ammonia as fuel. Guidelines are being developed by classification societies, IMO, flag state with input from shipping companies. Perhaps a separate certification will also be mandatory as per STCW convention to use ammonia as fuel. Ship's crew uses PPE for loading and unloading for ammonia and same concept can be used for handling ammonia bunkering and maintenance work on ammonia related

machinery. Ship staff should be trained and qualified as per the regulation V/3 of the STCW Convention and section A-V/3 of the STCW Code, considering ammonia's toxicity and corrosivity hazard.

7.4. Storage/ Bunker Tanks on Board

Ammonia energy density is less in comparison to fossil fuel and will need almost thrice the amount compared to fossil fuel leading to loss in cargo space. For engine room / machinery spaces forced ventilation will be required to prevent ammonia vapour accumulation. Fixed gas sensors will be required in specific areas including bunker stations. According to the ship type and size, the location of bunker tanks for ammonia should be decided. The availability of green ammonia as marine fuel will be the prerequisite for achieving the IMO decarbonisation target of 2050.

7.5. Ammonia Quality and Sampling

Fossil fuel quality and sampling procedure are well established. As ammonia being a new fuel, there are no guidelines available yet to show how the quality can be verified. Initially, the existing industrial standard will be used. In the future, specific ISO standards or internationally accepted guidelines considering ammonia's use as fuel can be considered. The documentation for supply and receipt of ammonia bunker can be based on similar lines as other gas fuels related to quantity and quality. The likely contaminants of anhydrous ammonia are water, oil and oxygen. According to IMO, on-board sampling is not applicable to gas fuels as per IMO MEPC 81 amendments.

7.6. Anhydrous Ammonia Industrial Sample Specifications

Ammonia unlike fossil fuel is a chemical compound of Nitrogen and Hydrogen. Both gases combine together to make an inorganic compound. At Normal Temperature and Pressure (NTP) it is in gaseous form but at -33.5 it converts to liquid. Unlike fossil fuel there are no complex hydrocarbon chains and other non-combustible elements. **Table 2** gives industrial specifications.

Table 2. Ammonia Sample Specifications.

Specification	Units	Value
Anhydrous Ammonia	% w/w	99.5 Minimum
Water Content	% w/w	0.2 Minimum
Oxygen	ppm	2.5 Maximum
Oil Content	ppm	5.0 Maximum
Lower Calorific Value	MJ/kg	18.6
Higher Calorific Value	MJ/kg	22.5
Density @16Deg.C	kg/l	0.62
Volume	Cu. Meter	-
Mass	Kg	-

The bunker calculations are normally done by the bunker supplier and ship's chief engineer and verified by the supplier and receiver. Company can also employ bunker surveyor in some cases. Quantity is verified by metering system and from tank soundings indicated in cubic meters and weight calculated by the given density. This is recorded in the Bunker delivery note (BDN). Fossil fuels have a very wide and complex range of properties depending on where it is sourced from, its viscosity, density, other non-combustible contents like aluminium, silica, vanadium, detrimental to engine components, with ash, and sludge content. They are also supplied as a blended fuel. This necessitates fuel processing like heating, centrifugal purification and clarification to make it suitable for combustion. Comparatively ammonia is a clean fuel consisting of only one compound of nitrogen and hydrogen. This simplifies the fuel sourcing, quality and analysis.

7.7. IMO Regulations for Bunkering Ammonia

For STS transfer IMO has given the guidelines MEPC 186(59) included in Chapter 8 to MARPOL Annex I. This is related to pollution prevention during transfer of oil cargo at anchorage and at sea while underway, the later will not be applicable to ammonia. The main requirements of the regulations are: Tanker must have an approved STS plan. As per the IMO guidelines—"Guidelines on the STS plan should be in accordance with the requirements of the IMO Manual on Oil Pollution Prevention, amended section 1 and Ship to Ship Transfer Guide which is jointly published by the

Chemical Distribution Institute (CDI), the International Chamber of Shipping (ICS), the Oil Companies International Marine Forum (OCIMF) and the Society of International Gas Tanker and Terminal Operators (SIGTTO)" ^[48]. Classification societies, SIGTTO, SGMF etc., are working on formulation of bunkering procedure and safe methods. There is precedence of bunkering of LNG and same can be modified for bunkering ammonia.

7.7.1. "International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IGC Code)"

Similar to ships using LNG as fuel, the IGC Code would be applicable to anhydrous ammonia bunkering ships which are subject to the SOLAS convention. Flag administration will have their own regulations for bunker tankers in ports under their jurisdiction. Case in point, Port of Singapore will have more stringent regulations for bunkering due to the close proximity of dense population near the proposed bunkering area in Singapore waters.

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

"IGF Code has the right framework for approving all gases and low-flashpoint fuels."

As of today, IGF code is applicable for ships using ammonia as fuel. IMO is developing the interim guidelines to deal with ammonia as a marine fuel until the SOLAS convention is amended to cover its application. Considering highly toxic and corrosive nature of the

fuel involved and the impact it will have in case of leak/spillage on humans and environment, guidelines will provide directives for safe operation of machinery and equipment.

8. Regulatory Structure for Ammonia Fueled Vessels

Various agencies are involved in developing unified requirements, interpretations and recommendations based on IGF code which can be adopted for ammonia. IACS members like ABS, BV, DNV, IRS, LR, NKK have the lead role and will provide guidance for ammonia fuelled vessels design, construction and survey. Flag states are responsible for the ships registered with them to comply with national and international regulations. Bunkering being a major operational part it is under their purview. Some flag states delegate their survey work and certification process to classification societies. Port state rules cover bunkering process and specify bunkering locations, procedures, restriction on time as per the weather conditions and traffic in port. Ships have to provide necessary documents and seek permissions accordingly related to procedure and risk assessment.

Other agencies involved are SIGTTO, SGMF, P&I clubs. SIGTTO share their experience of carrying anhydrous ammonia in bulk, loading and discharging of liquified gas cargo and STS. SGMF was established in 2013 and deals with marine gas fuels mainly LNG. SGMF published "Ammonia as Marine Fuel" covering system design, technical and operational issues, and also about bunkering^[49]. P&I Clubs monitor the vessel's health and has records of mishaps and related claims by the ship owners. They also advise the owners about safety procedures, training requirements of the crew under their cover.

8.1. Transport and Storage Conditions

Ammonia can be stored in liquid form and transported in three different modes: fully refrigerated in liquid state on gas tankers, semi-refrigerated and pressurised / non-refrigerated for road and rail transport in small parcels^[50]. **Table 3** shows ammonia storage conditions.

8.2. Ammonia Storage

Table 3. Storage Condition^[50].

Condition	Temperature	Pressure
Fully Refrigerated	−33° C	Atmospheric pressure
Semi-Refrigerated	−9° C to 4° C	2 to 4 bars
Non-Refrigerated (or pressurized)	Ambient temperature	7 bar up to 18 bars

Considering that ammonia is a cryogenic fuel it's either in gaseous or liquid state subject to its pressure and temperature. Ammonia transfer across similar storage conditions is in practise for cargo transfer. For fully refrigerated and semi-refrigerated transfer operational principles are the same. For transfer of non-refrigerated or pressurised state, storage tank and transfer system will need to be designed to withstand higher pressure.

9. Design of Bunker Stations

Bunker station location will be an important issue for ammonia considering its corrosive and toxic nature and consequences in case of spillage or leakage. For liquified or flammable gas fuels like LNG, LPG, Methanol are normally located on the open decks for providing adequate ventilation as per IMO requirements. For ammonia there may be requirement for enclosed or semi-enclosed bunker stations considering safety measures. These will require suitable systems like forced ventilation (blowers), gas detection and alarm systems. Water curtains will be more effective to control leakage of toxic gas or spill. Risk assessment and gas dispersion studies are being carried out for a safe design. Classification societies are providing guidelines / requirements for bunkering station design as per IMO requirements. Gas carriers use CCTV and air lock system with double doors for dangerous compartments like compressor and motor room. During STS bunkering sturdy mooring, fenders between the ships will be an important factor. The manifold will be subjected to external load due to relative motion of the vessels caused by wind, current, and ships passing by in the close vicinity. The brake away couplings are the weakest part of the transfer pipelines and designed to break off in case the load exceeds the design value. The coupling should be dry-disconnect type which is also self-sealing to pre-

vent any leakage.

Other safety precautions will be on similar lines for normal bunkering of any fuel like grounding to prevent build of static charge in the pipelines / hoses, isolation flanges required to break the electrical conductivity between the ship and the bunker vessel preventing arcs from passing between the two ships. The Society of International Gas and Tanker Operators (SIGTTO) has published detailed guidelines about the use of an insulating flange for LNG applications. Same can be adapted for ammonia^[51].

10.1 Mooring Equipment

Fenders are normally provided by the bunkering vessel. In most cases they are attached to the bunker

tanker / barge. For STS at anchorage / alongside normally Yokohama floating fenders are used. These are large sturdy cylindrical pneumatic rubber fenders as per ISO standard 17357. There are different types of fenders in use like pneumatic, solid, and foam type depending on where they are used. Most common for STS is aircraft tyre chain net type. Number of fenders can be used depending on the ship sizes^[52].

Figure 20 shows a Yokohama inflatable pneumatic fender. It's a robust construction with aircraft tyres held by chains covering the pneumatic cylinder to withstand the pressure exerted by the ships due to relative motion.

Figure 21 shows ship to ship transfer at sea / anchorage using Yokohama fenders.



Figure 20. Yokohama Inflatable Pneumatic Fender.



Figure 21. Ship to Ship Transfer at Sea / Anchorage using Yokohama Fenders.

11. Inerting, Purging and Boil Off Gas Management Systems

Ammonia bunkering will require inerting and purging by nitrogen on the similar lines like LNG. Purging lines and vent lines are included in the bunkering line and return vapour line. Unlike fossil fuel ammonia is a gaseous fuel similar to LNG, LPG etc. However, for bunkering it will be transferred as anhydrous ammonia in liquid state at -33 degrees. Due to its toxic nature after bunkering the lines and system will need to be purged of ammonia with inert gas like nitrogen. The toxic gas cannot be released to the atmosphere. The bunker line will have a return vapour line to the bunker supplier vessel. After completion of the bunkering operation all lines will need to be inerted by Nitrogen.

12. Communication

Ships are well equipped with handheld two-way radio communication devices commonly known as walkie-talkie. There are established VHF channels for communication between ships and port / harbour authorities, and all the portable electrical equipment's are intrinsically safe. The communication protocols are well established. Ships' officers are well versed with these walkie-talkies, used regularly for vessel arrival, departure, anchoring, loading, discharging and all vessel operational activities for a better coordination between crew members.

13. Risk Assessment and Gas Dispersion Analysis

Ammonia production and transport industry has well established guidelines for risk assessment and same can be adopted / modified and applied to shipping. Risk assessments are being conducted by various agencies to assess the associated risks and hazards of the bunkering operation. LNG and ammonia share the same cryogenic and high expansion ratio risk upon leak / release, in addition ammonia is highly toxic and corrosive. Various studies are ongoing in EU bunkering ports and Singapore about safety zones, hazardous ar-

reas, and security zones for safe bunkering of anhydrous ammonia in port areas in proximity to populace. The responsibility of risk assessment is with both the supply and receiving vessel.

14. Simultaneous Operations Study

Simultaneous operations are not considered in this study as it is for a specific type of vessel namely a gas tanker carrying ammonia as cargo. Also, only one mode of bunkering is considered that is STS at anchorage. So, any activity such as cargo handling, loading / discharging stores, provisions, water, and waste. Routine maintenance is also not considered and there are no activities related to port and terminal.

15. Vessel Compatibility

Bunkering and bunkered vessel should be compatible for safe transfer. Bunker supply vessels are normally smaller compared to the vessels they are supplying fuel to. For the vessels to be secured properly mooring equipment has to be compatible. Normally mooring ropes are provided by the bunkered vessel as they are wound on the ships mooring winches which can be operated and tension on the rope adjusted as required. During bunkering there is change in draft of both the vessels and mooring ropes tension has to be monitored properly. Bunker hose is normally provided by the bunkering vessel which must be certified for specific pressure test and should be sighted/verified prior bunkering. There should be proper securing arrangements for the cryogenic hose, normally the supply vessel has a crane / boom to secure the supply hose and adjust the height as required for a safe connection to the receiving vessel. The crane takes the load of the hose and the passing fluid. Bunkered vessel is equipped with different size of reducers and flanges to be connected to the hose. Vessels must have a well-established communication channel between them and language compatibility. Communication is normally by handheld two-way radio. There should be safe access for the crew of both vessels. IMO is developing guidelines related to

safety for ships using ammonia as fuel. Classification societies are also developing guidelines for safe bunkering^[53].

16. Firefighting Equipment / Water Spray System

For ammonia firefighting water in spray form is the most suitable medium. Ships are well equipped with CO₂, foam, dry powder extinguishing mediums. There are also high-volume firefighting sea water pumps to supply copious amount of sea water. Fog systems provide a protective cover to approach the open fire. Specific firefighting methods will need to be formulated depending on the location of fire. Fire fighters will require PPE chemical suits and Self-contained breathing apparatus (SCBA). Liquid ammonia is highly toxic. Exposure to ammonia vapour cause immediate irritation to the eyes, nose, throat and respiratory system. It can cause skin burn and longer exposure is fatal. Guidelines specify about requirement of a larger exclusion zone. Ammonia has a high relative density, resulting in a vapour cloud to sink and pool on the ships deck or water surface and it takes longer time to dissipate^[54].

17. Leakage Detection Systems

Fossil fuel bunkering station have always been open type. For ammonia bunkering stations it is proposed that they should be enclosed or semi enclosed type with all the connections alarm and control systems in a closed compartment on deck for containment purpose in case of leakage or spill during bunkering. Enclosed compartment will have their own safety design with leak detection and alarm systems, forced ventilation, firefighting arrangements and water curtain etc. Classification societies have suggested / proposed design as per the regulations considering safe distances from accommodation and normal working area.

18. Insurance and Legal Issues of Ships Using Ammonia as Fuel

Ammonia as a new fuel is not included in the

Bunker Convention for oil spills. This convention was adopted by IMO on 23rd March and enforced from 21st November 2008. "Adopted to ensure compensation is available to persons who suffer damage caused by spills of oil, when carried as fuel in ships bunkers. The convention applies to damage caused on the territory, including the territorial sea, and in exclusive economic zones of States Parties"^[55].

19. Bunker Convention for Hydrocarbon Fuels, including Lubricating Oil

The Bunker Convention, defines "bunker oil as any hydrocarbon mineral oil, including lubricating oil, used or intended to be used for ship propulsion and any residues of such oil." Bunker oil has various grades of Heavy Fuel oil depending on their viscosity and source, diesel oil, marine gas oil and different grades of lubricating oil for main engine cylinder lubrication, system oils for both main and auxiliary engines. Ammonia, like all other Alternate Fuels being considered by the industry, doesn't fall within this definition and the Bunker Convention therefore does not apply to Ammonia spills, when carried as bunkers during bunkering. It will depend on the affected coastal state if they are signatory to the relevant convention, and how to interpret whether a particular fuel meets the criteria.

Perhaps P&I club's position would be that it would continue to honour all its members' legal liabilities in the relevant state due to pollution incident regardless of whether the Bunker convention is applicable or not. P&I clubs will respond to ship owner's legal liabilities following a pollution incident affecting the jurisdiction in question. P&I club will provide cover to its ship owner members for liabilities arising from an ammonia bunker spill.

Not every state has signed up to the International Convention on Civil Liability for oil pollution damage (CLC) bunker or the HNS convention, whereas some states (for example the US and China) have their own local legislation dealing with liabilities flowing from a pollution incident. P&I clubs will however provide insurance cover for legal liabilities arising out of a spill in

all of these jurisdictions also. Due to the lack of applicability of the CLC or the Bunker Convention, there is no right of direct action against P&I Clubs and claimants will have to claim against the ship owner, as is the case for other type of claims. Even CLC is only applicable to Oil Pollution and not to ammonia as fuel ^[56]. There are no clear liability regulations covering ammonia spills. During bunkering fuel spill is likely, considering ammonia's toxic and corrosive nature it's a major hazard. Insurers are uncertain as to what could be the potential liabilities and cost in case of spill. Insuring ammonia powered vessels could be an expensive deal due to higher P&I premiums for the ship owner / operator. In all likelihood perhaps the premium for ships using ammonia as fuel will be higher than other fuels. It is something that the underwriters will consider when assessing the risk profile of an ammonia fuelled vessel.

19.1. HNS Implications (Hazardous and Noxious Substance)

Due to ammonia's hazardous and corrosive nature, it will also fall under the HNS convention. The HNS convention deals with safe transport of hazardous and noxious substances by sea. The convention ensures that "Those who have suffered damage have access to a comprehensive and international liability and compensation regime". The convention includes oils, liquids, chemicals defined as noxious and dangerous, liquified gases (applicable to Anhydrous ammonia), and liquids with a flashpoint below 60 °C. The current convention was adopted in 2010; however, it has still not entered into force awaiting the individual state's ratification ^[57].

19.2. Perceived Gaps

1. Lack of regulations for ammonia as fuel, as Bunker Convention only considers hydrocarbon-based fuels.
2. Insurers could face an unlimited liability as there is no liability cap defined as yet. Lack of regulations increases the risk for insurers.
3. Toxic and corrosive nature of ammonia is detrimental to crew safety and environment. Safety protocols, crew training and certification will af-

fect the insurance cost.

4. For ammonia as fuel the technological readiness is progressing fast however the international conventions and regulations are still lagging behind. This gap makes it difficult for an insurer to assess the risk and associated cost of insurance.

19.3. Present Status

Dual fuel engines using ammonia as fuel with diesel oil as pilot fuel are already under trial by Everllence, Wartsila, and WIN GD, both 2-stroke and 4-stroke versions. As per Everllence 3000 ships engines can be modified for ammonia operation ^[58]. Alfa Laval, a marine fuel system developer, has announced that it is exploring the next generation of fuel gas supply systems to accommodate LPG and eventually ammonia for engines ^[59].

There are 170 gas carrier ships in service that can carry ammonia, and about 40 of these ships regularly transport ammonia. Recent orders by ship owners for 50 very large ammonia carriers (VLACs) indicate that the ship owners are serious about using ammonia as fuel. In the initial stages these ships will be deployed as LPG carriers and will not carry ammonia as cargo. It will only happen once a proper infrastructure for ammonia bunkering is established and there is demand in the market for ammonia as fuel ^[60].

As per the report from "Hydrogeninsight", ammonia will be produced from green hydrogen. Almost 70% of planned green hydrogen production capacity around the world will be used to produce ammonia. Up to now 372 clean ammonia projects have been announced around the world. Two thirds of these projects would produce ammonia from green hydrogen produced from renewables-powered electrolysis, with the remaining one third using blue H₂ produced from natural gas as raw material with carbon capture and storage ^[61].

20. Conclusions

Ammonia is sans carbon, sulphur, and other pollutant free fuel that can achieve decarbonization of shipping as per the IMO regulations. Ammonia is a toxic and corrosive chemical, has lower calorific value compared to fossil fuels, but it is still more favourable than

hydrogen. A proper design / system will minimize the risk for bunkering of ammonia. Studies are being carried out for ammonia leakage / dispersion and its side effects. With proper safeguards in place, bunkering process should be safe for humans and the environment. Technical innovation and progress aside the ships' crew must feel comfortable handling toxic and corrosive fuel, a first in the history of shipping. With ammonia ready internal combustion engines and low-pressure fuel storage on board it will be an ideal fuel for large sea going ships. However appropriate safety measures need to be enforced in handling on board because of its high toxicity. Ammonia reacts with number of elements / metals like copper and alloys, zinc and galvanised steel. Carbon steel is also affected due to stress corrosion. Hence material selection for machinery and components using ammonia as fuel is of importance. There are also operational risks, such as fuel spills, vapor dispersion, and fires. The present international legal framework does not address these risks sufficiently. Unforeseeable damage to environment, human health, and property due to spillage of toxic ammonia has a legal aspect as well ^[62].

Author Contributions

K.B.: Conceptualisation, Methodology, Data Analysis, Original Draft Preparation; E.O.: Conceptualisation, Methodology, Data Analysis, Writing-Editing, Supervision; S.O.: Conceptualisation, Methodology, Data Analysis, Writing-Editing, Supervision. All authors have read and agreed to the published version of the manuscript.

Funding

This work received no external funding.

Institutional Review Board Statement

Not applicable.

Informed Consent Statement

Not applicable.

Data Availability

Data will be available upon request.

Conflicts of Interest

All authors disclosed no conflict of interest.

Abbreviations

ABS	American Bureau of Shipping
BEIS	Department for Business, Energy and Strategy
CAPEX	Capitol expenses
CFR	Cost and Freight (Charter party terms)
CFR	Code of Federal regulation
CO ₂	Carbon dioxide
DNV	Det Norske Veritas
ECA	Emission control area
EMSA	European Maritime Safety Agency
EU	European Union
FOB	Free on board (Charter party terms)
FOBAS	Fuel Oil Bunkering Analysis and Advisory Service (LR Service)
GE	General Electric
GHG	Greenhouse gases
HDPE	High density polyethylene
HFO	Heavy fuel oil
IACS	International association of Classification societies.
ICE	Internal combustion engine
IGC Code	Code for Construction and Equipment of Ships Carrying Liquefied Gases in Bulk
IGF Code	Code of Safety for Ships using Gases or other Low-flashpoint Fuels
IHI	Ishikawajima Harima heavy industries
IMO	International Maritime Organization
IRS	Indian Register of Shipping
ISM	International Safety Management
ITF	International Transport Federation
LNG	Liquefied Natural Gas
LPG	Liquid petroleum gas
LR	Lloyds Register
LSHFO	Low Sulphur heavy fuel oil

MAN	Maschinenfabrik Augsburg-Nürnberg
MARPOL	Marine Pollution
MEPC	Marine Environmental Protection Committee
MGO	Marine Gas oil
MPA	Maritime port administration
MT	Million tons
NO _x	Nitrous oxides
OCIMF	Oil Companies International Marine Forum
OPEX	Operating expenses
OSHA	Occupational safety and health administration (USA)
PPE	Personal protective equipment
PPM	Parts per million
PVC	Polyvinyl chloride
SCR	Selective catalytic reduction
SECA	Sulphur emission control area
SGMF	The Society for Gas as a Marine Fuel
SIGGTO	Society of International Gas Tanker and Terminal Operators
SIRE	Ship inspection report
SMS	Safety Management System
SOFC	Solid oxide fuel cell
SO _x	Sulphur oxides
STCW	Standard of Training, Certification and Watch-keeping
STS	Ship to ship transfer
UNCTAD	United Nations Conference on Trade and Development
VLSFO	Very low Sulphur fuel oil
WINGD	Winterthur Gas and Diesel

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