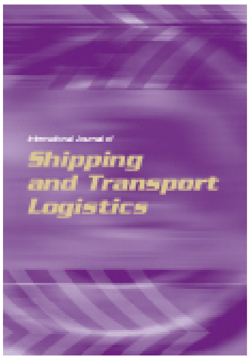

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Legal challenges and regulatory improvements regarding ammonia as an alternative marine fuel or cargo

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Legal challenges and regulatory improvements regarding ammonia as an alternative marine fuel or cargo

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Abstract: This study examines the regulatory challenges concerning ammonia-fuelled ships and the transportation of ammonia as cargo. It identifies gaps in the international safety standards and civil liability regimes for ammonia's dual role as fuel and cargo. The research highlights the need for revisions to the IGF and IGC codes to establish clear regulatory standards for ammonia-fuelled ships. It also proposes amendments to the HNS Convention to include ammonia-fuelled ships within its scope, to address the current lack of a comprehensive civil liability framework. The study emphasises the need to enhance compliance measures, train crew, and establish port safety procedures. In proposing these improvements, the study aims to provide a foundation for future discussions on revising international regulations related to alternative marine fuels, particularly ammonia. Such revisions would support the shipping industry's transition towards decarbonisation, while ensuring safety and legal predictability.

Keywords: decarbonisation; ammonia-fuelled ships; IGF Code; ICG Code; HNS Convention.

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1 Introduction

Global warming is intensifying issues related to climate change, such as rising sea levels, heatwaves, and water shortages, and this situation is causing a global crisis. Climate change directly affects the shipping industry. Port infrastructure is facing growing threats from rising sea levels, and extreme weather events increase the risks associated with operating ships.

In response to the global climate crisis, 195 countries have committed to reducing their greenhouse gas emissions under the Paris Agreement (UNFCCC, 2015). Accounting for approximately 2.89% of global carbon emissions, the maritime sector has become a critical focus for emission reduction initiatives [International Maritime Organization (IMO), 2020]. The IMO declared its aim to achieve carbon neutrality (net-zero) in the international shipping sector by 2050 through the IMO Strategy on Reduction of GHG Emissions from Ships, which was launched at the 80th Marine Environment Protection Committee (MEPC) meeting in July 2023. This strategy sets interim targets of at least a 20% reduction by 2030 and a 70% reduction by 2040, compared to 2008 levels. The aim is to gradually introduce a regulatory framework from 2027 to combine a goal-based fuel oil standard with a carbon pricing scheme (IMO Resolution MEPC.377(80), 2023).

As regulations regarding ship emissions become stricter, the shipping industry is shifting its focus towards alternative fuels to mitigate the greenhouse gas emissions (European Commission, 2025; Eide et al., 2011). As of 2025, 71% of newly ordered ships worldwide are set to adopt alternative marine fuels, in accordance with the global net-zero transition (Clarkson, 2025). There is a range of alternative marine fuels, and ammonia is emerging as a promising zero-carbon option that is well-suited for long range transportation (McKinlay et al., 2020). The World Bank and International Energy Agency (IEA) predict that ammonia will become a major alternative maritime fuel by 2050 (World Bank, 2025). The global ammonia market was valued at USD 74.7 billion in 2022, with green ammonia production expected to grow at an average annual rate of 90% until 2030 (IEA, 2024). Notably, ammonia has the advantage of being compatible with existing LPG transport infrastructure, which can ease the technological transition (IEA, 2021b).

In this context, the current study evaluates the regulatory challenges related to ammonia-fuelled ships as well as the transportation of ammonia as cargo and considers potential regulatory improvements. This research aims to systematically identify regulatory gaps by differentiating between the specific risks of using ammonia as a fuel and the risks associated with transporting ammonia as cargo. We critically evaluate how well the current civil liability regimes can handle the complex consequences of ships powered by alternative marine fuels, including topics such as environmental harm, property damage, and loss of life. To address these challenges, we then propose improvements related to implementing and revising the International Convention on Liability and Compensation for Damage in Connection with the Carriage of Hazardous and Noxious Substances by Sea, 1996, and its 2010 Protocol (the HNS Convention), as ammonia is classified as HNS cargo due to its toxic properties.

This study focuses on the following research questions:

1 What are the key characteristics of ammonia as an alternative marine fuel, and what are the global trends in its adoption within the shipping industry?

2 What are the current international safety standards for ships using ammonia fuel and transporting ammonia as cargo, including their limitations?

3 Under the existing civil liability regime for compensation, does the current framework adequately address ammonia-related incidents?

4 What improvements can be made to international regulatory and liability frameworks to better support the use of ammonia as an alternative marine fuel?

To address the research questions, we analyse the global trends and characteristics of ammonia as a marine fuel through a comprehensive literature review. We systematically examine regulatory gaps concerning the safety of ammonia in its dual role as both ‘cargo’ and ‘fuel’ under the IMO regulatory instruments. The research explores the current limitations of civil liability regimes under the International Convention on Civil Liability for Oil Pollution Damage (CLC), the International Convention on the Establishment of an International Fund for Compensation for Oil Pollution Damage (FUND), and the HNS Convention through a doctrinal analysis. We propose a new direction for international maritime law by advocating for a restructured civil liability system to address maritime accidents caused by ammonia fuel. The study emphasises the need to expand the scope of the HNS Convention and revise it accordingly. Given that ammonia’s toxicity risk differs qualitatively from that of conventional petroleum-based fuels, the proposed improvements to civil liability would enhance the legal predictability for adopting ships powered by alternative marine fuels. These suggestions provide a theoretical foundation for future discussions on revising the international regulations related to alternative marine fuels.

2 Literature review

2.1 Technical feasibility and environmental implications of ammonia as marine fuel

Ammonia has emerged as a prominent candidate for alternative marine fuel in the context of global shipping decarbonisation. Fullonton et al. (2025) provide a comprehensive analysis of the adoption potential of green ammonia in the shipping sector, highlighting both opportunities and challenges across the entire fuel supply chain. The authors emphasise key advantages such as the absence of direct CO_2 emissions when combusted, the ability to leverage established ammonia storage and transport infrastructure from the fertiliser industry, and recent advancements in dual-fuel engine technologies that allow for ammonia integration. However, the study also identifies significant challenges: the formation of nitrous oxide a potent greenhouse gas during combustion, high toxicity and associated safety risks for crew and marine ecosystems, and economic barriers such as infrastructure investment needs and first-mover risk. The authors stress that while green ammonia holds considerable promise, its successful adoption will require coordinated policy support, robust safety protocols, and substantial investment in both ship and port infrastructure.

Machaj et al. (2022) similarly reviews ammonia's potential as a marine fuel, underscoring its carbon-free combustion, existing production and transport infrastructure, and compatibility with renewable energy sources as major advantages. Nevertheless, they highlight technical barriers including lower energy density compared to conventional fuels, toxicity, and the necessity for new engine and storage technologies. The review also notes ongoing research, pilot projects, and the importance of regulatory and safety considerations, concluding that ammonia could become a significant marine fuel if technological and regulatory challenges are addressed.

2.2 Regulatory and legal considerations for ammonia as a marine fuel

Jang et al. (2023) analyses the current gaps in the international regulatory framework for ammonia-fuelled ships. While the International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IGC Code) and the International Code for the Construction and Equipment of Ships carrying Dangerous Chemicals in Bulk (IBC Code) provide safety standards for ammonia transport as cargo, there are currently only general provisions for low-flashpoint fuels in the International Code of Safety for Ships using Gases or other Low-Flashpoint Fuels (IGF Code), with no ammonia-specific regulations for its use as a fuel. Major classification societies have developed their own interim guidelines, but there is no unified international standard. The study emphasises the urgent need for the IMO to develop dedicated regulations and standards for ammonia as a marine fuel, as existing codes do not fully address its unique toxicity and corrosiveness. The lack of harmonised international regulation is identified as a major barrier to the safe commercialisation of ammonia-fuelled vessels. The European Maritime Safety Agency (EMSA, 2022) further highlights that green ammonia can achieve near-zero carbon emissions on both tank-to-wake and well-to-wake bases, making it suitable for long-distance shipping. However, EMSA identifies regulatory shortcomings: the IGC Code currently only covers ammonia as cargo, not as fuel; additional standards are needed for fuel applications; and there is a need for updated NOx Technical Codes and ISO bunkering standards. The agency calls for regulatory enhancements to ensure safe and effective ammonia fuel deployment. KR (2021a) notes that current IGC and IGF Codes are primarily designed for existing low-flashpoint fuels like LNG and methanol, and do not adequately reflect ammonia's specific hazards. KR recommends developing alternative design requirements based on IGC Code Chapter 7, mandating additional safety measures, and requiring NOx reduction technologies when applying the IGF Code to ammonia-fuelled ships.

Environmental impact studies, such as the joint research by Environmental Defense Fund (EDF) Lloyd's Register (LR) and Ricardo PLC (2023), have modelled ammonia spill scenarios and found that certain habitats such as estuaries, wetlands, and mangroves are particularly vulnerable due to ammonia's acute toxicity, especially to fish. While ammonia's persistence in the environment may be lower than oil, its toxicity is significantly higher, raising concerns about potential ecological damage in densely trafficked regions like the Strait of Malacca.

Regarding civil liability, Xu et al. (2015, 2017) discuss the regulatory and liability frameworks for alternative marine fuels, particularly LNG, and highlight the absence of comprehensive international legal instruments addressing pollution damage and compensation for incidents involving new fuels. However, their research primarily addresses the civil liability of LNG based on existing conventions, and thus does not provide a systematic framework or clear direction for civil liability issues related to environmentally friendly fuels such as ammonia.

Despite growing interest and research, there is currently a lack of comprehensive international regulatory and civil liability frameworks specifically addressing ammonia as a marine fuel. Given ammonia's toxicity and potential for significant environmental harm in the event of a spill, the literature underscores the urgent need for the development of harmonised international regulations and civil liability regimes tailored to ammonia's unique risks. This research aims to address these gaps by examining the international regulatory challenges associated with ammonia as both a marine fuel and cargo, and by proposing legislative improvements for civil liability, thereby contributing to the formulation of legal frameworks for ammonia as an environmentally friendly marine fuel.

2.3 Research gap

Existing literature consistently recognises ammonia's strong decarbonisation potential but also stresses the urgent need for harmonised regulations and liability regimes addressing its unique risk profile. Despite technological progress and increased academic attention, comprehensive international governance mechanisms for ammonia as marine fuel remain underdeveloped. Therefore, this study seeks to contribute to the development of a legal framework for ammonia-fuelled maritime operations by examining regulatory challenges and proposing improvements to civil liability systems.

3 Ammonia as an alternative marine fuel

3.1 Decarbonisation in the shipping industry

The international community's efforts to reduce greenhouse gas emissions from the shipping sector are gaining momentum. The IMO announced its plans to reduce emissions by between 20% and 30% by 2030 and by 70% to 80% by 2040 as intermediate checkpoints for greenhouse gas reduction. Europe and the USA are strengthening their regulations for shipping greenhouse gases, and the European Commission has established the FuelEU Maritime Regulation (EU Regulation 2023/1805, 2023). The latter regulation aims to reduce greenhouse gas emissions from maritime transport by gradually strengthening the greenhouse gas intensity limits for ships calling at EU ports, to promote the use of eco-friendly fuels (EU Regulation 2023/1805, 2023). The initiative sets a gradual reduction target, beginning with a 2% decrease in 2025 compared to 2020 levels, and aims to achieve an 80% reduction by 2050 (EU Regulation 2023/1805, 2023). Additionally, it mandates the installation of shore power supply devices on container ships and passenger ships as of 2030. In addition, the USA enacted the Clean Shipping Act and the International Maritime Pollution Accountability Act in May 2023 (US Congress Gov., 2023b). The Clean Shipping Act aims for net-zero by 2040 through vessel fuel regulations passed by the US Environmental Protection Agency, with targets of a 20% reduction by 2027, a 45% reduction by 2030, and a 80% reduction by 2035 compared to 2024 levels (US Congress

Gov., 2023b). The International Maritime Pollution Accountability Act imposes a pollution fee of USD 150 per ton of carbon dioxide on foreign vessels weighing more than 10,000 gross tonnage (US Congress Gov., 2023a).

To reduce carbon emissions in the shipping industry, alternative marine fuels such as biofuels, ammonia, and hydrogen must be used as primary fuels for ships. Major shipbuilding and shipping nations, including EU countries, the USA, South Korea, China, and Japan, anticipate a transformation in the industry, driven by increasingly stringent global emissions regulations for ships. These countries are actively developing and implementing policies to advance and promote green ship technologies.

Shipping companies have traditionally relied on bunker fuel to power their vessels. In response to stricter environmental regulations, they have adopted strategies such as switching to low-sulphur fuel oils, integrating scrubber systems, and increasing their investments in ships powered by liquefied natural gas (LNG). However, the industry is undergoing a rapid transformation. As global efforts to reduce greenhouse gas emissions accelerate, the shipping sector faces a turning point. It is now compelled to explore and adopt zero-emission alternative fuels. Hydrogen, ammonia, and methanol have emerged as key contenders for the future of maritime propulsion.

3.2 Global trend for ammonia-fuelled ships

Approximately 2.5% of global CO_2 emissions are attributed to the shipping industry. The strengthening of IMO emission regulations has led to the emergence of alternative marine fuels, including hydrogen, ammonia, and biofuels, as potential solutions for net-zero emissions. According to the 2021 Energy Outlook Report, the IEA predicts that the use of ammonia, hydrogen, and other alternative marine fuels will gradually expand; by 2060, over 60% of newly built ships are expected to adopt these fuels (IEA, 2021b). The report suggests that ammonia will account for nearly half of the market share, projecting that specifically for ships; ammonia will be more a prominent alternative marine fuel than hydrogen. Furthermore, in the IEA's net-zero 2050 scenario, it is predicted that ammonia's share in the ship fuel sector will expand from 8% in 2030 to 46% by 2050 (IEA, 2021a). Currently, LNG is the dominant alternative marine fuel, but methanol and ammonia are gaining prominence. Methanol faces uncertainties regarding the adequate supply of green methanol to meet future demand, as well as challenges in price competitiveness compared to LNG (Fullonton et al., 2025).

LNG-fuelled and methanol-powered vessels can be the dominant types of ships for next few years. However, once ammonia-fuelled ships are commercialised, they are likely to become the primary type of vessel. The evaluation of various fuel options in terms of the advantages and disadvantages of eco-friendly fuels and technological advancements is likely to continue for some years to come. Given the current lack of a definitive alternative fuel, it is probable that a future will emerge in which diverse eco-friendly fuel ships coexist. In 2014, the proportion of alternative-fuel ship orders was around 10% of all ship orders; this figure had increased approximately five-fold – to 50% – by 2024, just one decade later. The global eco-friendly ship order backlog stands at 1,377 vessels, with the top ten shipping companies accounting for 32.3% of the total. The top ten countries have ordered 446 ships (Clarkson, 2025), as follows: 258 container ships, 86 LNG carriers, 39 pure car carriers, and 23 LPG carriers. The container shipping company MSC leads in the number of orders for vessels that run on alternative marine fuels, at 85 ships, followed by CMA CGM at 81 vessels (Clarkson, 2025). These industry leaders are at the forefront of the maritime sector's push towards more sustainable shipping practices. This trend reflects the growing commitment of major shipping companies to reduce their environmental impact and comply with increasingly stringent emission regulations. Overall, the shift towards green ships represents a significant step in the industry's efforts to decarbonise and minimise its contribution to global CO_2 emissions.

Container ships are particularly affected by the economic implications of eco-friendly fuels, given their high speeds and substantial fuel consumption. It reveals that LNG-powered ships account for most of the orders, at 970 ships (73%). Methanol-fuelled ships follow, accounting for 226 orders (17%), and ammonia-powered vessels represent just 27 orders (2%). This breakdown highlights the industry's current preference for LNG as a widely adopted alternative fuel, whereas methanol and ammonia are gaining traction as emerging options for sustainable shipping (Clarkson, 2025). While LNG is the most widely used alternative fuel, methanol and ammonia are gaining popularity (Clarkson, 2025). Ammonia produces almost no CO_2 or SOx emissions, and the NOx generated during combustion can be reduced through abatement devices. Ammonia thus has strong potential to become a core fuel for achieving long-term carbon neutrality. Given this potential, ammonia is driving increased activity in the shipbuilding industry. The first commercial ammonia-powered ship is expected to launch in 2026 (Offshore Energy, 2024).

3.3 Characteristics of ammonia as marine fuel

Ammonia seems destined to become a popular alternative marine fuel because it is easier to store than hydrogen and can be easily transported at room temperature. The increasing demand for ammonia may also lead to the creation of new business opportunities (Huang et al., 2024).

In particular, ammonia poses a toxic hazard. Ammonia presents as a colourless, pungent substance that is toxic and has a strong odour under normal temperature and pressure conditions. Ammonia's physical properties contribute to its unique behaviour in air: it is lighter than air and thus tends to rise and concentrate in elevated areas such as ceilings. However, ammonia's strong affinity for water leads to rapid moisture absorption from the atmosphere upon release. This interaction can increase its density, potentially causing it to become heavier than air. In such cases, ammonia may form a distinctive white cloud near ground level. These characteristics highlight the importance of understanding ammonia's behaviour for proper handling and safety measures in maritime and industrial settings (Moon et al., 2023). Periodic exposure to ammonia odour can desensitise a person's sense of smell, potentially leading to an inability to detect concentrations as high as 300 ppm. Ammonia dissolves easily in water and can be absorbed through body fluids – such as sweat, tears, and saliva – and can potentially cause severe chemical burns (US Centres for Disease Control and Prevention, 2025). The safety of seafarers and other personnel on board, as well as the emergency equipment in ammonia handling areas, must cater to these characteristics (NIH, 2004). For example, water spray is an effective means of absorbing ammonia from the air during a leak. To prevent injuries to personnel who are in contact with ammonia, emergency showers and eyewash stations should be installed in ammonia handling areas. Ventilation systems in people's living quarters and work areas should also be designed to prevent ammonia ingress.

Technologies exist to detect potential leak points in ammonia fuel systems, such as bunkering manifolds, fuel tanks, and engine connections, while ensuring that any leaked ammonia remains within safe limits (Akturk and Seo, 2023). Engine rooms, where gas leaks pose a significant risk, can combat leakage through the use of double-walled pipes for fuel supply lines, combined with gas detection systems and automatic fuel supply shutdown mechanisms. This safety approach has long been used in LNG-powered vessels and has proven effective in leak prevention (Jeong et al., 2024). Accommodation must be isolated from toxic zones, and gas discharge sources such as ventilation outlets and fuel pipe vents should be equipped with treatment facilities to keep the ammonia concentration within safe limits. In emergencies such as fires, it is not practical to safely manage a large ammonia release from fuel tank pressure-relief valves.

Therefore, onboard shelters with predefined crew safety protocols are essential. Protecting crew members requires not only robust ship safety systems but also strict management and operational procedures for ammonia equipment. Training and awareness are also essential. Given this context, additional requirements must be added to The International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW) Code A-V/3 (training standards for IGF ship personnel) that are specifically adapted for ammonia fuel (Duong et al., 2024).

3.4 Risks and damage from using ammonia as a marine fuel

3.4.1 Potential damage

Some alternative marine fuels, such as hydrogen and ammonia, possess characteristics and risks including flammability, explosiveness, and toxicity. In the event of a spill or marine pollution incident, the quantity and toxicity of the released fuel can have severe impacts on the environment and ecosystems. Pollution and spills affect social and economic systems as well as human health and safety (Lee et al., 2024). In particular, there is a risk of ecosystem eutrophication due to ammonia leaks (Khan and Mohammad, 2014). Ammonia is not only toxic to humans but also has adverse effects when released in large quantities into the ecosystem. Eutrophication occurs when excess nutrients, such as phosphorus and nitrogen, are supplied to water, causing excessive algae growth, which in turn reduces the level of dissolved oxygen and leads to the death of organisms.

Ammonia marine pollution incidents can release substances that exceed the lethal dose for organisms. However, dilution in seawater and the atmosphere may reduce these concentrations to below a lethal level. Even so, the widespread dispersion of pollutants can critically impact marine life across large areas (Lee et al., 2024). Pollutants such as organic chemical compounds spread through biological pathways and food chains, which potentially affect ecosystems globally. When pollutants enter an organism via exposure or ingestion, and resist excretion, they accumulate over the organism’s lifespan (Soler et al., 2021). This bioaccumulation induces sublethal or lethal effects, which ultimately leads to a population decline among species and communities (Lee et al., 2024). Such effects extend to fish, algae, marine mammals, and even apex predators like humans.

Ammonia marine pollution incidents have both short-term and long-term negative impacts on the local economy. Ammonia released in marine accidents can cause fin damage and deformities in commercially valuable fish, reducing the commercial value of marine resources. The contamination of commercial fish and shellfish can lead to the closure of fisheries and aquaculture farms, further to expand expanding the damage

(Edwards et al., 2024). Spilled ammonia can pollute beaches, bathing waters, and recreational waters, to diminish the amenity value for tourism and other local economic drivers. Such incidents can also negatively affect public perceptions, to reduce visits to the affected areas and purchases of related consumer goods (fish, shellfish, etc.).

3.4.2 Cases of ammonia spills at sea

A number of ammonia spill cases have highlighted persistent safety and regulatory challenges over time. In 1966, the gas carrier Mundogas Oslo collided with the Finnish ship Sara near Grundkällen in northern Sweden and sank with 2,000 tonnes of liquid ammonia on board. Salvage was delayed due to bad weather, sea ice and fog, and after the sinking, the hull chronically leaked ammonia, causing long-term pollution of the marine environment. Estimates suggest that around 940 tonnes still remain in the hull, with more than half having been released into the ocean since the accident (Cedre, 2025).

In 1976, in the Swedish port of Landskrona, the Belgian gas carrier René 16 broke a pipe during unloading due to unsuitable materials, releasing 180 tonnes of ammonia in 50 minutes. The ammonia cloud travelled to a nearby shipyard, killing two people and requiring firefighters to respond in protective gear. The incident highlighted not only the acute toxicity of ammonia, but also the shortcomings of ship safety design and emergency response systems (Cedre, 2025).

On 10 December 1979, the Iraqi cargo vessel Sindbad lost 51 steel cylinders containing one tonne of solution chlorine to a depth of 30 metres on the seabed 20 nautical miles west of Iwemaouden, Netherlands, in bad weather. The Dutch authorities developed a special response strategy in 1984, using sonar and a remotely operated vehicle (ROV) to locate and locate the cylinders, which were then detonated under controlled conditions by divers using explosives. Within an hour, a cloud 300 metres wide, 3,000 metres long and 300 metres high formed as the chlorine rose to the surface, and the white cloud of ammonium chloride could be visually identified by the release of ammonia from ships upstream. Some seabirds were observed entering the cloud and immediately falling to the surface, but no serious ecological damage was reported. The cost of the response to this incident was approximately €700,000 (Cedre, 2025). In 2013, an LPG tanker anchored in the Straits of Malacca suffered an ammonia leak that killed one person and left three others in critical condition. This, together with the direct risk to crew health, highlights the importance of a rapid and organised emergency response (Cedre, 2025).

More recently, the Government of Western Australia reported that on 21 July 2018, an ammonia release occurred at the Kwinana Beach Jetty during a ship-to-shore unloading operation. The incident was caused by a hydraulic shock in the loading arm, which generated a puff cloud that drifted approximately 800 meters across the water to Wells Park, where it was detected by a person sitting in a car. As a result of ammonia spill, five personnel from the ship and facility were taken to hospital. This incident highlights the critical importance of designing and operating systems to prevent hydraulic shock, especially during the start-up and final purging of liquid transfer pipelines (Government of Western Australia, 2018).

On the morning of 11th July 2022, an ammonia leak occurred on a Russian-flagged fishing vessel (1,315 t) docked at Gamcheon Port, Busan, South Korea. During the transfer of ammonia used as a refrigerant to an external tank, a hose ruptured, releasing approximately 100 L of ammonia. At the time, the vessel contained around 1,000 L of ammonia, and the transfer was part of routine maintenance operations. About 20 crew members evacuated safely, and fortunately, no injuries were reported (Yonhap News, 2022).

These examples suggest that the maritime transport of ammonia and hazardous chemicals can have a significant impact on both human life and the environment. In particular, chronic leaks from sunken ships and the spread of toxic gas clouds in the atmosphere can cause long-term and widespread damage to marine ecosystems and coastal states.

4 Analysis of the international regulatory framework for the safe operation and transport of ammonia

As the previous section explored the technical characteristics and inherent hazards of ammonia when used as a marine fuel, this section turns to the corresponding international regulatory framework. It examines the existing safety standards applicable to ammonia in its dual role as both fuel and cargo, while identifying current regulatory gaps. Given the operational and environmental risks associated with ammonia, its use must be governed by strict international safety standards to ensure the safety of ship sand the marine environment.

4.1 The SOLAS convention

The international regulations concerning the safe use of alternative marine fuels and cargo transportation are governed by the International Convention for the Safety of Life at Sea (SOLAS). The SOLAS Convention is one of the most important IMO conventions and establishes minimum standards for ship safety, equipment, and structure. The SOLAS Convention comprises 14 chapters, with detailed regulations organised into independent codes. The international regulatory framework for using ammonia as a marine fuel and transporting it as cargo encompasses several codes, namely, IGF Code, the International Maritime Dangerous Goods (IMDG) Code, IBC Code, and IGC Code (EMSA, 2022).

Table 1 Codes and mandatory regulations in SOLAS

Codes	*Mandatory regulations*
IMDG Code	• SOLAS Chapter VII
IBC Code	• SOLAS Chapter VII • MARPOL Annex II
IGC Code	• SOLAS Chapter VII
IGF Code	• SOLAS Chapter II-1 • MARPOL Annex I, Reg.12 • STCW Convention Reg. V/3 and Section A-V/3

Source: IMO Korea, Mandatory IMO Documents (https://www.imokorea.org)

IMO instruments typically fall into two categories: codes and resolutions (IMO Korea, 2020). While these are generally considered non-binding, they can become mandatory when incorporated into existing IMO conventions, such as SOLAS; STCW; and the International Convention for the Prevention of Pollution from Ships, 1973, as modified by the Protocol of 1978(MARPOL 73/78). As shown in Table 1, these specific examples of codes and resolutions serve as mandatory regulations to prevent vessel-source pollution and improve navigational safety in the global shipping industry by being incorporated into existing IMO conventions.

The SOLAS Convention and its associated codes employ a distinctive amendment process characterised by a four-year implementation cycle. This approach recognises the convention's broad scope and complexity while ensuring legal stability and predictability, which enables the shipping industry to plan and implement changes effectively. The tacit acceptance procedure provides an efficient mechanism for implementing regulatory amendments to ensure that the SOLAS Convention can accommodate frequent updates (Shi, 1998). While there is no general definition of the tacit acceptance procedure, it typically refers to an amendment process with the following characteristics. First, the tacit acceptance procedure is a method by which the treaty's operating body proposes treaty amendments. Unless they explicitly object within a specified period, contracting parties are considered to have implicitly consented to and be bound by the amendments. The amendments do not apply to contracting parties that object to them (König, 2013). This procedure is designed to facilitate the amendment process. It enables prompt responses to developments in marine environment and shipping technology. It ensures legal stability and predictability by automatically adopting amendments unless there are explicit objections. It safeguards consistency in IMO regulations and promotes the safety and efficiency of global shipping.

Currently, the applicable regulation for the use of alternative marine fuels is the IGF Code. The IGF Code provides essential criteria for the arrangement and installation of machinery for propulsion and auxiliary purposes, tailored to the characteristics of the fuel to minimise the risks to the ship, its crew, and the environment. The IGF Code has been incorporated into Chapter II-1 of the SOLAS Convention, which addresses the construction standards for ships – including their structure, subdivision, and stability, as well as machinery and electrical installations. Regulations concerning the maritime transport of cargo are addressed in Chapter VII of the SOLAS Convention. Chapter VII deals with the carriage of dangerous cargoes, encompassing regulations for the transport of dangerous goods in packaged form and solid bulk; it also provides specifications for the construction and equipment of ships that carry dangerous liquid chemicals and liquefied gases in bulk. It outlines special requirements for the carriage of packaged irradiated nuclear fuel, plutonium, and high-level radioactive waste. These comprehensive regulations ensure the safe maritime transport of various hazardous materials. Currently, there is a need for international safety standards regarding the use and maritime transport of ammonia fuel; this situation requires amendments to the SOLAS Convention (Jang et al., 2023). Once these standards are established, regulatory revisions will become necessary through the implied acceptance procedure.

4.2 Current regulatory framework for the use of ammonia as an alternative marine fuel

4.2.1 IGF Code

In 2004, Norway initiated the development of international regulations for natural gas-fuelled ships by submitting a proposal to the 78th MSC. In 2009, six years after the initial proposal, this effort culminated in the adoption of Resolution MSC.285(86), the Interim Guidelines on Safety for Natural Gas-Fuelled Engine Installations in Ships (IMO Resolution MSC.285(86), 2009). The IGF Code was finally adopted at the 95th MSC in June 2015 and came into effect on 1 January 2017. This code applies to all ships of 500 gross tonnage and above that are engaged in international voyages and use low-flashpoint fuels in their propulsion systems (IMO Resolution MSC.391(95), 2015). Ships using gas or low-flashpoint fuels must comply with the IGF Code as per the SOLAS regulations II-1/56 and 57.

The IGF Code applies to cargo ships such as container ships, bulk carriers, oil tankers, car carriers, and passenger vessels; it excludes ships that are subject to the IGC Code, mainly LNG carriers (IMO Resolution MSC.391(95), 2015). The IGF Code covers all necessary standards for using gas or low-flashpoint fuels. Specifically, it provides essential criteria for the arrangement and installation of machinery for propulsion. Based on accumulated experience, the IGF Code incorporates goals and functional requirements for design, construction, and operation using a goal-based standard approach (IMO, 2025d). To address rapidly evolving alternative-fuel technologies, the IMO Sub-Committee on the Carriage of Cargoes and Containers (CCC) regularly reviews and revises the IGF Code. While the general provisions of the IGF Code were developed with consideration for various fuels such as LNG, LPG, and ammonia, the detailed regulations focus primarily on LNG. The current IGF Code does not include specific safety regulations for handling the toxicity and corrosiveness of ammonia, nor does it provide dedicated provisions for containment, detection, escape, and mitigation (CDEM) related to such hazards (Jang et al., 2023). The increased adoption of non-binding guidelines through MSC circulars for alternative fuels such as LPG, methanol, and ammonia shows that the international community recognises the need to integrate these into mandatory regulations. In response, the IMO must amend and expand the IGF Code to include these alternative fuels.

4.3 Current regulatory framework for transporting ammonia as ship cargo

4.3.1 IGC Code

The IGC code was developed to establish design and construction standards for vessels transporting liquefied gases in bulk. Its primary objective is to mitigate potential risks to the ship, crew, and environment associated with the hazardous nature of these cargoes (IMO Resolution MSC.5(48), 1983). Since 1 July 1986, the IGC Code has been mandatory under SOLAS Chapter VII. It applies to ships of all sizes, including those under 500 gross tonnage, that transport liquefied gases with a vapour pressure exceeding 0.28 MPa absolute at 37.8°C, as well as to other substances listed in Chapter 19 when carried in bulk. Regarding ammonia carrier ships, independent cargo tanks specified by the IGC Code have been used successfully, which suggests that similar tanks could be suitable for ammonia fuel storage (Würsig, 2024). On 1 July 2016, the IGC Code was amended to allow the use of cargo gases other than LNG as fuel, provided that an equivalent level of safety to that of natural gas is ensured and approved by the relevant administration (IMO Resolution MSC.370(93), 2014). Historically, the use of toxic cargo as fuel was prohibited. However, in 2023, at the 108th session of the MSC, the IGC Code was amended to allow toxic cargo including anhydrous ammonia to be used as ship fuel. These amendments are set to take effect on 1 July 2026 (IMO MSC 109/22/Add.1, 2025).

Until that date, although ammonia as cargo falls under the scope of the IGC Code, its use as a fuel will remain restricted. If ammonia-fuelled ships carrying ammonia cargo will be prohibited from using the ammonia cargo itself as fuel. The IGC Code classifies ammonia as a toxic substance, and paragraph 16.9.2 currently prohibits toxic cargo from being used as fuel.

4.3.2 IBC code

The IBC Code establishes global standards for the safe transport of hazardous chemicals and noxious liquid substances in bulk by sea, as listed in Chapter 17 of the code. The code is incorporated into SOLAS Chapter VII, which governs the carriage of dangerous goods, and MARPOL Annex II, which regulates pollution control for noxious liquid substances transported in bulk. To mitigate the risks to vessels, crews, and the environment, the IBC Code outlines specific design and construction requirements for ships, as well as the necessary equipment, taking into account the unique properties of the substances being transported (IMO, 2025a). In December 1985, by resolution MEPC.19(22), the code was extended to cover marine pollution aspects and applies to ships built after 1 July 1986. In October 2004, IMO adopted the revised MARPOL Annex II Regulations for the control of pollution by noxious liquid substances in bulk. This annex incorporates a four-category categorisation system for noxious and liquid substances, and it entered into force on 1 January 2000 (IMO, 2025a).

Ammonia is included in the list of hazardous chemicals specified in Chapter 17 of the IBC Code. It is classified as a noxious liquid substance and must comply with the regulations of SOLAS Chapter VII and MARPOL Annex II. SOLAS Chapter VII requires ship designs that meet special requirements for ammonia transport. MARPOL Annex II applies to all ships carrying noxious liquid substances in bulk. Under this annex, noxious liquid substances are classified into categories X, Y, and Z. Ammonia is classified as a Category Y cargo, according to the IBC Code, and is subject to strict regulations regarding its discharge into the sea. When it is transported as cargo, appropriate procedures for tank cleaning and residue handling must be followed. Ships carrying noxious liquid substances in bulk must undergo regular or intermediate inspections and obtain the International Pollution Prevention Certificate for the Carriage of Noxious Liquid Substances in Bulk (NLS Certificate). However, the IBC Code does not directly apply to the maritime transport of ammonia. Ammonia transport by sea is primarily governed instead by the IGC Code (International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk). Due to its properties, ammonia is gaseous at room temperature and is transported in liquefied form. Although the IBC Code primarily regulates liquid chemicals, ammonia is typically transported as a liquefied gas on carriers subject to the IGC Code. Safety measures related to toxicity such as cargo tank design, ventilation requirements, and spill containment are mainly addressed by the IGC Code. However, in specific situations involving liquid-phase handling, relevant IBC Code guidelines may also be referenced. When developing guidelines for ammonia-fuelled ships, the IMO should carefully compare and integrate relevant requirements from both the IGC Code and the IBC Code.

4.4 Regulatory gaps in IMO regulations

IMO regulations have become increasingly diverse and complex, and this trend extends to both the IGC Code and the IGF Code. Some provisions within these codes are ambiguous or intricate, leading to challenges in their application. The IGC and IGF codes address different risks in transport operations. The IGC Code regulates the transport of ammonia as cargo, focusing on the risks associated with bulk storage and handling, whereas the IGF Code governs its use as fuel, addressing the risks related to fuel systems and combustion. Given these distinct purposes, the regulations within these two codes cannot be identical. Safety measures must therefore be tailored to the specific risks of ammonia, whether it is used as cargo, fuel, or both.

The IGF Code was initially developed for ships using natural gas as fuel and applies to vessels of 500 gross tonnes and above that utilise gas or low-flashpoint fuels. However, it excludes ships covered by the IGC Code, such as LNG carriers. Ammonia has a flashpoint of approximately minus 33°C or lower. While it does not readily combust under normal conditions, the potential for combustion exists and it is classified as a low-flashpoint fuel. Consequently, ammonia-fuelled ships fall under the scope of the IGF Code. The IGF Code provides detailed specifications or requirements only for LNG, and there are currently no international regulations addressing ammonia-fuelled ships.

By contrast, the IGC Code applies to ships carrying ammonia as cargo (KR, 2021b). Although the IGC Code was recently amended to allow cargo other than LNG to be used as fuel under equivalent safety standards, toxic cargo, including ammonia, is still prohibited as fuel. Namely, while vessels carrying ammonia as cargo are subject to the safety requirements of the IGC Code, the current IGC Code prohibits them from using ammonia from their cargo tanks as fuel. The IGC Code sets the safety standards for ammonia carriers but does not explicitly mandate any safety equipment that is specifically developed for ammonia leak detection and management. In practice, ammonia carriers are not equipped with dedicated leak detection and mitigation systems. Given the toxicity of ammonia, appropriate protective equipment such as respirators and safety goggles should be provided, along with eyewash stations and emergency showers on deck. Ammonia leaks on ammonia carriers are extremely rare, as the substance is securely contained within cargo tanks. The only potential leak source is the pressure-relief valve outlet, which is designed to remain closed except in emergencies such as a fire on the tank top. As a result, specialised ammonia leak safety equipment is not typically required for these vessels (Duong et al., 2024).

For ships that are fuelled by ammonia rather than merely carrying it, the risk of leaks must be proactively managed. Ammonia’s toxicity is highly potent: exposure to 20 ppm can cause eye and nasal discomfort, exposure to 700 ppm for over an hour can lead to blindness, and exposure to 5,000 ppm for just a few minutes can cause asphyxiation (Safety4Sea, 2025).

4.5 Current progress of the IMO

Given ammonia's physical properties, transport methods, safety requirements, and international regulations, the IGC Code rather than the IBC Code governs the maritime transport of ammonia cargo. Currently, the only applicable regulation for the use of environmentally friendly fuels is the IGF Code. After the development of the IGF Code for natural gas was completed, discussions began in earnest on ships using methanol and ethanol as fuel; such debates included topics such as tank arrangement, materials, joints, and fire-extinguishing systems. Regulations for ships using methyl and ethyl alcohol as fuel were initially excluded from priority development in 2012 at the 17th BLG meeting to expedite the implementation of the IGF Code (IMO Sub-Committee on BLG, 2013).

The interim guidelines for the safety of ships using methyl and ethyl alcohol as fuel were completed after the 4th IMO Sub-Committee on CCC meeting in 2017. At the 102nd MSC, held in December 2020, the interim guidelines were adopted. They enact safety regulations for using methyl and ethyl alcohol as ship fuel, which can reduce nitrogen oxides by up to 80% and greenhouse gases by up to 25% (IMO MSC.1/Circ.1621, 2020). Unlike LNG stored at cryogenic temperatures, methanol and ethanol can be stored at room temperature and under normal atmospheric pressure, which means they are easier to transport. Bunkering can be facilitated by simple modifications to existing port fuel facilities. The interim guidelines for safety regulations of ships that use methyl and ethyl alcohol were implemented in the form of an MSC circular, rather than being incorporated into the IGF Code (IMO MSC.1/Circ.1621, 2020). At the 7th IMO Sub-Committee on CCC meeting held in 2021, a document proposing the development of safety regulation guidelines for hydrogen and ammonia fuels was submitted. This document stated that additional consideration for hydrogen safety is necessary, because reformed secondary fuels contain high concentrations of hydrogen regardless of the primary fuel used for fuel cells (IMO Sub-Committee on CCC, 2021). It also proposed that the development of safety regulations should be expedited, considering the technological advancement of using hydrogen or ammonia as fuel for internal combustion engines.

To expedite the development of safety regulations for alternative fuels in maritime decarbonisation efforts, the IMO has established a comprehensive work plan. The plan incorporates the creation of interim guidelines for hydrogen and ammonia fuels as key topics for discussion at the IMO Sub-Committee on CCC meeting. The 10th IMO Sub-Committee on CCC meeting, held on 16 September 2024, focused on the urgency of establishing safety standards for ammonia-fuelled ships. At the meeting, the IMO adopted the Safe Use of Hydrogen and Ammonia as Fuel interim safety guidelines. These were approved at the 109th MSC meeting in December 2024 (IMO MSC.1/Circ.1687, 2025). The fundamental purpose of these interim guidelines is to provide regulations on the arrangement, installation, control, and monitoring of ship machinery, equipment, and systems to minimise risks that may arise from using ammonia as fuel. The aim is to ensure the safety of ships, crew, and the environment, considering the characteristics of the fuel. The guidelines provide comprehensive coverage of all aspects requiring special consideration for the use of ammonia as a marine fuel. When applying these guidelines to specific ship designs, flag states must consider the relevant provisions of the IGF Code.

However, it is important to note that the interim guidelines are advisory in nature, as they are based on recommendations rather than legally binding instruments. Their current non-binding nature highlights the need to transition the recommendations into mandatory regulations under the IGF Code.

5 Legal challenges in civil liability for ammonia-fuelled ships and ships carrying ammonia

5.1 Scope of application of the current civil liability regime

As the shipping industry moves towards decarbonisation, the number of ships powered by LNG, liquid hydrogen, methyl and ethyl alcohol, and ammonia is likely to grow. This point raises an important question regarding whether the existing international civil liability framework is adequate to address potential environmental damage arising from spills involving these alternative fuels. Currently, the CLC and FUND provide compensation for pollution damage that occurs within the territorial waters and exclusive economic zones of contracting states, but only for tankers that carry persistent oil as cargo. These conventions cover not only oil spills from cargo but also spills of bunker by oil tankers. The compensable pollution damage includes loss or damage caused outside the ship by contamination that results from the release or discharge of oil from the ship, irrespective of where such discharge occurs. Compensation for environmental damage is limited to the loss of profit and the cost of reasonable measures taken (or to be taken) for environmental restoration. The costs of preventive measures and further loss or damage caused by such preventive measures are also subject to compensation (Jacobsson, 2016; Soyer and Tettenborn, 2018).

The principle of strict liability applies, making shipowners responsible for any pollution damages (Jacobsson, 2016). Shipowners are required to maintain mandatory liability insurance up to a limited amount, and victims are granted direct claim rights (Jacobsson, 2016). The FUND was established for oil pollution compensation; it covers the difference between actual damage and the liability limit and provides full compensation if shipowners are entirely unable to pay. The International Convention on Civil Liability for Bunker Oil Pollution Damage (Bunker Convention), which came into effect in 2008, stipulates liability limitations related to pollution from bunker oil. The convention covers pollution damage caused by bunker oil spills from non-tanker vessels, including persistent and non-persistent oils. This convention applies to all types of seagoing vessels and seaborne craft except oil tankers that are covered by the CLC. It addresses shipowners' liability for personal injury, property damage outside the ship, environmental pollution damage, and costs of preventive measures. Unlike the CLC, the Bunker Convention does not have a secondary international fund for compensation (Soyer, 2009). Therefore, it extends liability to bareboat charterers, ship managers, and operators in addition to shipowners. The Bunker Convention also differs from the CLC in that it does not establish its own liability limitation system, instead deferring to the 1976 Convention on Limitation of Liability for Maritime Claims or to national laws (IMO, 2025b).

If no international civil liability regime exists for alternative fuels, liability would have to be determined under domestic law. This could result in forum shopping, and claimants may not be adequately compensated, particularly if shipowners are not required to maintain compulsory insurance (Røsæg, 2000). Moreover, the LLMC would apply through national legislation, allowing shipowners to limit their liability, and there is no second-tier fund available for claims that exceed the applicable limits. The establishment of a global civil liability regime for alternative fuels is therefore essential. Such a regime would reduce uncertainty regarding liability and compensation, thereby encouraging shipowners, operators, insurers, and financiers to support the wider adoption of alternative fuels needed for maritime decarbonisation.

5.2 Do alternative-fuel ships or ships carrying ammonia and liquid hydrogen fall under the HNS convention?

Ships transporting hazardous and noxious substances (HNS) as cargo are not covered by the CLC, FUND, or Bunker Convention. This exclusion is due to HNS not falling under the categories of persistent crude oil from tankers or ship bunker fuel, which are the primary focus of those conventions. In the absence of a specific international civil liability regime for HNS, incidents involving such substances typically fall under the Convention on Limitation of Liability for Maritime Claims (LLMC) (Jacobsson, 2013). This regulatory gap indicated the need for a dedicated international treaty to address the unique risks associated with HNS transportation. In recognition of this need, after extensive global discussions, the HNS Convention was adopted in 1996 (HNS, 2025). The HNS Convention aims to ensure adequate, prompt, and effective compensation for damage to persons and property, costs of clean up and reinstatement measures, and economic losses resulting from the maritime transport of HNS. It addresses risks not covered by CLC (HNS, 2025).

The substances covered by HNS Convention include approximately 5,500 types of HNS cargo as defined in various IMO regulations, including the MARPOL73/78, the IMDG Code, the IBC Code, and the IGC Code. These encompass oils (both persistent and non-persistent), LNG, LPG, and various chemical substances. Specifically, HNS cargo includes the following: oils carried in bulk, as defined in regulation 1 of Annex I to MARPOL73/78; noxious liquid substances carried in bulk, falling under categories X, Y, or Z according to regulation 6.3 of MARPOL73/78 Annex II; dangerous liquid substances carried in bulk, as listed in chapter 17 of the IBC Code; dangerous, hazardous, and harmful substances, materials, and articles in packaged form, which are covered by the IMDG Code; liquefied gases as listed in chapter 19 of the IGC Code; liquid substances carried in bulk with a flashpoint not exceeding 60°C; and solid bulk materials possessing chemical hazards, covered by the International Maritime Solid Bulk Cargoes Code, as amended.

Ammonia is classified as a Class Y cargo under the IBC Code, whereas ships carrying ammonia in gas form fall under the IGC Code. Such vessels are covered by the HNS Convention; however, the convention has yet to be ratified. The 2010 HNS Convention was adopted to resolve the practical and legal obstacles that prevented the 1996 HNS Convention from entering into force and to ensure prompt and adequate compensation for damage caused by hazardous and noxious substances transported by sea. Based on the 2010 HNS Convention, initially, shipowners and insurers cover damages up to a set liability limit, with additional compensation provided by the HNS Fund. Liability limits range from 10 million to 100 million Special Drawing Rights (SDR), depending on the vessel’s tonnage. Despite these amendments, the revised protocol has not yet met the requirements for entry into force. Ratification requires at least 12 countries, including four with a deadweight capacity of at least 2 million tonnes and a cargo volume of at least 40 million tonnes for the HNS Fund. The convention will take effect 18 months after these conditions are met. By March 2025, only five countries, namely Norway, Turkey, Canada, Denmark, and South Africa, had ratified the convention (HNS, 2025).

Table 2 LLMC and HNS compensation limits

Regime	*Claim type*	*Ship size (GT)*	*Compensation limit (SDR)*
LLMC 1976	Personal injury	≤ 2,000 GT	2 million SDR
		2,001–30,000 GT	2 million SDR + 800 SDR/ton
		30,001–70,000 GT	+ 600 SDR/ton
		> 70,000 GT	+ 400 SDR/ton
		Maximum	59.7 million SDR
	Property damage	≤ 2,000 GT	1 million SDR
		2,001–30,000 GT	1 million SDR + 400 SDR/ton
		30,001–70,000 GT	+ 300 SDR/ton
		> 70,000 GT	+ 200 SDR/ton
		Maximum	29.85 million SDR
LLMC 1996 protocol	Personal injury	≤ 2,000 GT	3.02 million SDR
		2,001–30,000 GT	3.02 million SDR + 1,208 SDR/ton
		30,001–70,000 GT	+ 906 SDR/ton
		> 70,000 GT	+ 604 SDR/ton
		Maximum	126.14 million SDR
	Property damage	≤ 2,000 GT	1.51 million SDR
		2,001–30,000 GT	1.51 million SDR + 604 SDR/ton
		30,001–70,000 GT	+ 453 SDR/ton
		> 70,000 GT	+ 302 SDR/ton
		Maximum	63.07 million SDR
HNS (shipowner liability)		≤ 2,000 GT	10 million SDR
		2,001–50,000 GT	10 million SDR + 1,500 SDR/ton
		> 50,000 GT	+ 360 SDR/ton
		Maximum	100 million SDR
HNS Fund			250 million SDR

Given that the HNS Convention has not yet been ratified, pollution incidents involving HNS are currently regulated under the general liability framework of the LLMC. Under the LLMC, shipowners' liability is capped; however, this system has been criticised as providing insufficient compensation to protect the victims of pollution incidents. The LLMC 1996 protocol allows shipowners to limit their liability regarding loss of life or personal injury claims. For vessels up to 2,000 gross tonnes, the liability cap is SDR 3.02 million. For ships exceeding 2,000 GT, liability is calculated using a tiered system; the limit is SDR 1,208 per ton for ships between 2,001 and 30,000 GT; it is SDR 906 per ton for ships between 30,001 and 70,000 GT; and the limit is SDR 604 per ton for ships exceeding 70,000 GT. Concerning property claims, the liability cap for ships up to 2,000 GT is SDR 1.51 million. For larger vessels, liability follows a similar tiered structure, with limits of SDR 604 per ton for ships between 2,001 and 30,000 GT; SDR 453 per ton for ships between 30,001 and 70,000 GT; and SDR 302 per ton for ships exceeding 70,000 GT (Griggs et al., 2020).

Furthermore, the 2010 HNS Convention implements a two-tier system for incidents involving HNS at sea. The first tier holds shipowners strictly liable, with limits ranging from SDR 10 million to SDR 100 million, based on the ship's size. The second tier, the HNS Fund, provides additional compensation of up to a total of SDR 250 million per incident. This comprehensive framework ensures robust coverage for various types of damages, balancing the responsibility between ship operators and cargo interests while prioritising victim compensation. This system ensures comprehensive coverage for various types of damages, including loss of life, personal injury, property damage, and environmental damage (Jacobsson, 2016).

There is a significant disparity in the liability limits of the LLMC versus the proposed HNS Convention. With the shift towards decarbonisation, the use of cleaner fuel ships and the transport of cleaner fuels are likely to rise. To support this transition, the ratification of the HNS Convention should be expedited to ensure its liability limitation system is in place. Currently, the HNS Convention covers ammonia cargo ships but does not extend to ships that are powered by ammonia. The convention currently defines HNS as substances, materials, and articles transported as cargo. Therefore, the HNS Convention should be reconsidered to also apply to ships that use HNS as fuel.

5.3 The need to revise the HNS regime

Vessels transporting ammonia as cargo fall under the IGC Code. These ships are subject to the HNS Convention. However, ammonia-fuelled ships may be not covered by the HNS Convention. Furthermore, the CLC, FUND, and the Bunker Convention do not apply to these vessels, creating a regulatory gap (Table 2). At the 108th session of the IMO MSC in 2023, amendments to the IGC Code were approved to permit the use of toxic cargo, including anhydrous ammonia, as ship fuel. Under the revised IGC Code, ammonia-fuelled ships carrying ammonia as cargo will be allowed, as an exception, to utilise their cargo as fuel (IMO MSC 109/22/Add.1, 2025). Since ammonia-fuelled ships are not subject to the Bunker Convention, there is no liability framework for environmental damage, property loss, or personal injury caused by ammonia accidents.

Given that no international regulation provides compensation for damages caused by ammonia-fuelled ships, including toxic leaks and explosions, there is a pressing need for a liability regime regarding ships that use ammonia as fuel. To address the legal gap, the scope of the HNS Convention should be expanded beyond 'HNS carried on board as cargo' to include 'HNS used or intended for ship operation or propulsion'. Rather than creating a separate regime (similar to the Bunker Convention), it would be more effective to amend the existing HNS Convention. The HNS Convention can be amended by incorporating the provisions of 'low-flashpoint fuels used or intended for ship operation/propulsion' under Article 5(a)(vii).

With regard to the application of the HNS Fund in relation to ammonia, ammonia cargo is covered under Chapter III, titled Compensation by the HNS Fund (Articles 13 to 35) of the 2010 HNS Protocol. According to Article 19, the HNS Fund maintains separate accounts for oil, LNG, and LPG. Other hazardous substances, including ammonia, are classified under Article 18(c) as 'other substances'. Importantly, the HNS Fund does not maintain contribution to separate accounts for ammonia. There are raises significant concerns regarding ammonia-fuelled vessels unlike the CLC and FUND. The existing liability and contribution framework focuses on transporting hazardous cargo, rather than its use as fuel. Ammonia used for fuel purposes is not considered as transporting cargo, and thus falls outside the intended scope of contribution to the HNS Fund. It is essential not only to actively consider covering incidents arising from the use of ammonia fuel on ammonia-fuelled ships, but also to recognise the compelling rationale for allocating such contributions to a separate account, similar to those for oil, LNG, and LPG.

Table 3 Scope of application by fuel type and ship category under the existing civil liability regime

Classification	*CLC*	*FUND*	*HNS Convention*	*Bunker Convention*
Application of Fuel	Pollution damage caused by the discharge of persistent oil (such as crude oil, heavy fuel oil, etc.) from oil tanker	Pollution damage caused by the discharge of persistent oil (such as crude oil, heavy fuel oil, etc.) from oil tanker	Pollution damage caused by the carriage by sea of hazardous and noxious substances (HNS)	Pollution damage caused outside the ship by contamination resulting from the escape or discharge of bunker oil from the ship
Application of ship's type	Oil tankers	Oil tankers	Ships carrying HNS cargoes	All ships

In 2023, a few number of states including Canada, Denmark, Estonia, France, Norway, South Africa, Slovakia, and Türkiye – have ratified the 2010 Protocol to the HNS Convention (IMO, 2025c). Although the formal conditions for its entry into force have been satisfied, the Convention still lacks ratification by a sufficient number of states. This delay can be attributed to several interrelated factors: the broadened scope HNS covered by the Convention, the potential financial burdens imposed on shipowners and cargo interests, and administrative challenges associated with securing insurance certification and ensuring compliance with enhanced safety regulations. In response, international community such as the IMO, the IOPC Fund, and EU have sought to encourage wider participation by providing guidelines, technical assistance, and policy incentives (IMO, 2025c). Importantly, there is now a growing consensus within the international community that the Convention's entry into force should be expedited. Once operational, the Convention will require vessels engaged in the carriage of HNS cargoes to maintain appropriate insurance and carry corresponding certificates, while restricting the operation of ageing, non-compliant vessels. At the same time, the strengthening of port state control (PSC) and the more rigorous enforcement of safety requirements are expected to enhance accident prevention and the demand for new buildings will further improve safety standards. Within this framework, cargo interests will be liable for contributions to the HNS Fund, while shipowners will face increased P&I Club premiums.

In particular, the introduction of alternative fuels emphasises the importance of ratifying the convention. While alternative fuels may generate less environmental harm than fossil fuels, their elevated levels of toxicity and flammability present considerably greater risks to human life and property. These risks reinforce the necessity of an effective civil liability regime capable of delivering adequate and assured compensation to victims, in line with the liability structure envisaged by the HNS Convention. Consequently, it should be revised and supplemented to account for the distinct risks associated with disorganisation trend in shipping industry (Zografakis et al., 2024).

Similarly, it is necessary to further assess the sufficiency of liability limitation amounts for personal injury under the convention, as well as to establish a definition of shipowner liability that aligns with the existing CLC regimes. The convention cannot operate effectively without coordinated international cooperation and the swift amendment and ratification of its provision. For instance, the liable party must be clearly and consistently defined in line with the CLC Convention as ‘shipowner, meaning the person registered as the owner of the ship or, in the absence of registration, the person or persons owning the ship’. Such clarification would enable the HNS Convention to provide a stable and predictable liability regime across a wide spectrum of incidents, including those involving vessels powered by alternative fuels, while preserving coherence with the broader liability and compensation regime.

6 Future regulatory improvements

As an alternative marine fuel, ammonia is attracting attention as a zero-emission fuel. Since it liquefies at minus 33°C under atmospheric pressure, low-pressure tanks with low-temperature maintenance technology can be used, making tank design and fabrication easy. The technology for mass production, transport and handling is already mature. Even in the 2050 scenario, the IEA forecasts that ammonia’s share of the marine fuel sector will increase to 8% in 2030 and 46% in 2050 (IEA, 2024). There is currently no international standard for the safety and civil liability of ammonia-fuelled ships.

First, while the IGC Code applies to the carriage of ammonia cargoes, it is necessary to develop independent safety standards for the use of ammonia cargoes on ammonia-fuelled ships. The compatibility with the application of the IGF Code will need to be discussed by international shipping community. In particular, the IGC and IGF codes address the hazards of ammonia under the different conditions of ‘carriage as cargo’ and ‘use as fuel’, which means the regulations are not identical. At the recent 10th IMO Sub-Committee on CCC meeting in 2025, interim guidelines for ammonia as fuel were finalised as part of the IGF Code (Part C-1 Guidelines). They establish functional requirements for all safety systems and align with the IGF Code principles for low-flashpoint fuels (IMO MSC.1/Circ.1687, 2025). These guidelines, while non-mandatory, provide a crucial pathway for equivalency approvals by flag states. They include important amendments, such as the designation of toxic zones with specific ammonia detection thresholds, the adoption of revised ventilation and emergency shutdown protocols, and harmonisation with risk assessment methodologies under MSC.1/Circ.1212 (IMO MSC.1/Circ.1212/Rev.1, 2019). Concurrently, Chapter 16 of the IGC Code (Part C-2 Guidelines) has been amended to permit the use of ammonia cargo as fuel on gas carriers as long as it demonstrates a safety equivalence to natural gas. Key revisions in this area include the removal of prohibitions on toxic cargo-fuel use, updated requirements for LPG and ethane fuel systems, and new material specifications for cargo piping in corrosive environments. The implementation timeline for these changes is structured to allow for a gradual adoption. The IGF Code interim guidelines for ammonia fuel take effect voluntarily from 2025, with expected mandatory application by 2028. The IGC Code amendments adopted at the MSC 109 in 2024 will enter force on 1 January 2028, with provisions for early voluntary compliance via the MSC circular (IMO MSC 109/22/Add.1, 2025). Based on the revised IGC and IGF Codes, member states must implement domestic regulations regarding the construction, design, equipment, and maintenance of ammonia-powered ships and the safe transport of ammonia as cargo.

Second, in accordance with international standards, flag states must strengthen their compliance and verification measures to ensure the effective implementation of the IGC, IGF, and ISM Codes. This requires states not only to enhance inspection regimes, provide specialised training for seafarers, conduct rigorous documentation reviews, and perform operational audits (Kim et al., 2022), but also to incorporate procedures that specifically address the unique risks posed by ammonia. Given ammonia's high toxicity, corrosiveness, and potential to cause fatal inhalation injuries even at low concentrations, flag states should mandate additional onboard safety management elements, including emergency ventilation procedures, continuous gas monitoring systems, and enhanced personal protective equipment (PPE) protocols. Shipowners should ensure that the existing ISM Code incorporates a clear requirement for crew education and training programmes that reflect ammonia's hazardous properties, toxic exposure thresholds, rapid dispersion behaviour, and appropriate response techniques in the event of leaks or accidental releases. These measures will ensure that all crew members fully understand both the operational characteristics of ammonia and the protective equipment necessary for safe handling.

Currently, there is no international civil liability regime for alternative-fuel-powered ships, and these vessels are governed by the LLMC for matters related to property loss, loss of life, or personal injury. If they were to fall under the HNS Convention, the liability limits could increase to SDR 100 million. Considering the toxicity, environmental impact, and potential risks of ammonia to human health, liability limits may need to be differentiated according to specific fuel types. To enhance the financial assurance, the owners of ships that are 3,000 GT or more and are fuelled by ammonia or carry ammonia as cargo must obtain compulsory insurance. Accordingly, the HNS Convention should be amended so that its scope explicitly encompasses ammonia when used as a ship fuel. Such a comprehensive approach would not only support the safe operation of ships using alternative marine fuels but would also encourage their adoption as the shipping industry moves toward decarbonisation.

7 Conclusions

Ammonia is set to play a significant role as an alternative marine fuel during the decarbonisation of the shipping industry. However, ammonia poses challenges due to its toxicity and corrosiveness; in addition, it is less combustible than fossil fuels, which means fuel efficiency and combustion technology needs further development. Addressing these technical hurdles and ensuring safe handling will be crucial for the successful commercialisation of ammonia as an alternative marine fuel.

The study found that international safety standards for ammonia, both as a fuel and as a cargo, remain incomplete, with legal inconsistencies leading to regulatory gaps. While the IGC Code includes ammonia as a cargo, no compatible regulations exist under the IGF Code to enable vessels transporting ammonia to simultaneously employ it as an alternative marine fuel. Further, the IGF Code lacks clear application criteria for its use as fuel. This regulatory ambiguity creates uncertainty in the design and operation of ammonia-fuelled vessels and necessitates further discussion and revision at the IMO level. A significant legal challenge arises from the fact that ammonia-fuelled ships fall outside the scope of existing civil liability regimes, such as the CLC, FUND, and Bunker Convention. The shipping industry provides compensation frameworks for crude oil and bunker fuel spills, but no clear civil liability regime exists for spills of alternative marine fuels (such as ammonia, hydrogen, and LNG). This gap is particularly concerning given ammonia's potential to cause eutrophication and severe harm to marine ecosystems and fisheries, with no compensation regimes in place.

Given that ammonia can be both a cargo and a fuel, this study recommends the following improvements. First, the IGF Code and IGC Code should be revised to establish clear regulatory standards for ammonia-fuelled ships and ships carrying ammonia as cargo. Currently, the IGF Code is primarily designed for LNG and does not account for the unique characteristics of ammonia as a fuel. Based on revised global safety standards, each state should standardise and regulate its ports and bunkering infrastructure. Port authorities must also implement bunkering facilities and safety protocols to support the safe operation of ammonia-fuelled ships.

Second, the HNS Convention should be amended to clarify the liability regime for ammonia incidents. Currently, while the HNS Convention may apply to ammonia being transported as cargo, it does not cover ships using ammonia as fuel. The HNS Convention should be revised to include ammonia-fuelled ships and establish a corresponding compensation regime. This step will contribute to legal certainty and predictability by providing an international civil liability regime for ships using alternative marine fuels.

Third, flag states must enhance their compliance and verification measures to ensure the effective implementation of the IGC, IGF, and ISM Codes. Shipowners should add crew education requirements into the existing ISM Code to ensure that all crew members have a thorough understanding of ammonia's characteristics and the necessary equipment. Additionally, the special training requirements for personnel onboard ammonia-fuelled ships or ships carrying ammonia as cargo should be adopted under the STCW Convention.

Our proposed improvements would enhance the legal stability and predictability of introducing ammonia fuel. This research provides fundamental ideas for exploring international cooperation to support the sustainable development of the shipping industry and the introduction of green ships.

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Declarations

All authors declare that they have no conflicts of interest.

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