Current Development Status and Future Prospects of Ammonia-Powered Vessels Under the Green Shipping Goals

Hongyi Cao*

Institute of International Education, Lappeenranta University of Technology, Lapakatu 2C 39, Lahti, 15240, Finland

*Corresponding author's e-mail: 2964930249@qq.com

Abstract. As carbon emissions from the global shipping industry continue to rise, the urgency for low-carbon development has intensified. At the policy level, the International Maritime Organization (IMO) and the European Union have implemented increasingly stringent carbon reduction targets for shipping. Technologically, the adoption of clean marine fuels has become essential, with green ammonia emerging as a zero-carbon fuel that holds significant potential for decarbonization in the shipping sector. Nevertheless, ammonia-powered vessel technology remains in its infancy, making it imperative to conduct in-depth studies on its current applications and future prospects to facilitate the green transformation of the shipping industry. This paper thoroughly examines the development background, significance, technical advancements, and economic analysis of ammonia-powered vessels within the context of green shipping goals, thereby providing valuable insights for future decarbonization pathways in the sector.

Keywords: Shipping industry; low-carbon development; green ammonia; economics; development prospects

1 Introduction

Currently, global shipping carbon emissions have surpassed 1 billion tons, representing approximately 12% of the total carbon emissions from the transportation sector. Data published by the European Environment Agency indicates that the shipping industry is one of the "least regulated sources of air pollution." Without appropriate regulation, the carbon emissions from this sector are projected to increase by 50% by 2050. In light of the urgent need for global decarbonization, the push for low-carbon development in the shipping industry has gained significant attention[1].

At the policy level, both the International Maritime Organization (IMO) and the European Union have developed policies aimed at reducing carbon emissions in the shipping sector. In July 2023, the IMO convened the 80th meeting of the Marine Environment Protection Committee (MEPC 80) to discuss revisions to the greenhouse

W. He et al. (eds.), *Proceedings of the 2024 10th International Conference on Advances in Energy Resources and Environment Engineering (ICAESEE 2024)*, Atlantis Highlights in Engineering 36,
https://doi.org/10.2991/978-94-6463-708-3_11

gas reduction strategy for shipping adopted in 2018, as well as to establish more rigorous carbon reduction targets for the industry. The meeting made it clear that international shipping greenhouse gas emissions should reach their peak as soon as possible and aim for net-zero emissions by 2050[2]. Furthermore, MEPC 80 established two "indicative checkpoints": by 2030, annual greenhouse gas emissions from international shipping should be reduced by at least 20% compared to 2008 levels, with an aspiration to achieve a 30% reduction; by 2040, annual emissions should decrease by at least 70% compared to 2008 levels, aiming for an 80% reduction[3]. The European Union is at the forefront of global efforts to establish green shipping regulations, which have the most direct and urgent implications for the shipping industry. The EU has enacted a comprehensive package of climate legislation and policies known as "Fit for 55," which includes key regulations closely related to the shipping sector, such as the EU Emissions Trading System Directive (EU ETS) and the FuelEU Maritime Regulation. Overall, the EU has integrated the shipping industry into its carbon emissions trading system. On one hand, concerning penalties, the EU is progressively imposing carbon emission levies on shipping companies, starting January 1, 2024, with 40% of shipping carbon emissions to be included in the EU ETS, increasing to 70% in 2025 and 100% in 2026[4]. On the other hand, through the FuelEU Maritime Regulation, limits on the carbon intensity of fuels are established, and fuel types that exceed these limits will not be permitted for use. Consequently, in the context of tightening shipping emission reduction policies, identifying strategies to foster the green transformation of the shipping industry and achieve decarbonization goals is of considerable practical significance.

At the technical level, marine clean fuels play a critical role in the emissions reduction process of the shipping industry and are essential for achieving medium- to long-term carbon reduction goals. In recent years, numerous scholars have conducted research and practical investigations into various clean fuels, identifying multiple potential pathways for the industry to meet its greenhouse gas reduction targets[5]. Nonetheless, the low-carbon transformation of ship fuels represents a long-term and complex systems engineering challenge. Assessing the prospects for clean fuel applications necessitates a comprehensive consideration of factors such as economics, availability, and environmental sustainability. As a zero-carbon fuel, green ammonia is anticipated to play a significant role in the future decarbonization of shipping[6]. However, while research and application of green ammonia technology are progressing globally, its utilization in the powered vessels sector remains in the early stages, with the first large ammonia-powered ship engine yet to be delivered. Therefore, a thorough examination of the current status of green ammonia applications in powered vessels, along with an exploration of future trends and prospects for ammonia fuel propulsion technologies, is crucial for advancing the green transformation of the shipping industry[7].

2 The Comprehensive Positioning of Ammonia-powered Vessel

Guided by global carbon neutrality goals, the pursuit of low-carbon and zero-carbon alternative fuels for shipping has emerged as a critical issue. A comprehensive assessment of various factors indicates that the currently preferred clean fuels for marine applications primarily include LNG, methanol, ammonia, and hydrogen (see Table 1). In the future, the shipping industry's transition to new fuels will rely on the replacement of vessels and the expansion of fleets. A complete transition to renewable zero-carbon fuels will necessitate a transitional phase, during which LNG and methanol will undoubtedly play significant roles as alternative fuels.

Table 1. Comparison of Different Shipping Fuels.

Fuel Type	Carbon Reduction Potential	Advantages	Disadvantages
LNG	20%	Large reserves, relatively low cost, relatively mature technology with widespread application	it emits a large amount of CO_2 after burning and there is a risk of methane leakage
Carbinol	30%	Wide sources, relatively clean, easy storage and transportation	It is a non-zero carbon fuel and has a certain level of corrosiveness
Hydrogen	100%	Zero carbon emissions, with policy support	Hydrogen has a low energy density, making storage and transportation difficult and less economical
Ammonia	100%	Zero carbon emissions, mature industrial chain, with relatively high energy density	It is toxic, requires ignition, and incomplete combustion can emit N_2O

However, similar to liquefied natural gas (LNG), fossil-based methanol is insufficient to meet the future carbon reduction targets for the shipping industry. The future development of methanol as a shipping fuel should focus on biomass synthesis or the production of electrolytic green methanol. Currently, global methanol production capacity approaches 200 million tons, with an output exceeding 100 million tons; however, the production of green methanol constitutes only 1% of this total (see Figure 1). Moreover, the anticipated increase in green methanol production will encounter at least two significant constraints: first, the availability of raw materials for biomass-based green methanol (such as straw) is limited; second, the certification processes for carbon sources in electrolytic green methanol are stringent, resulting in unfavorable economic viability.

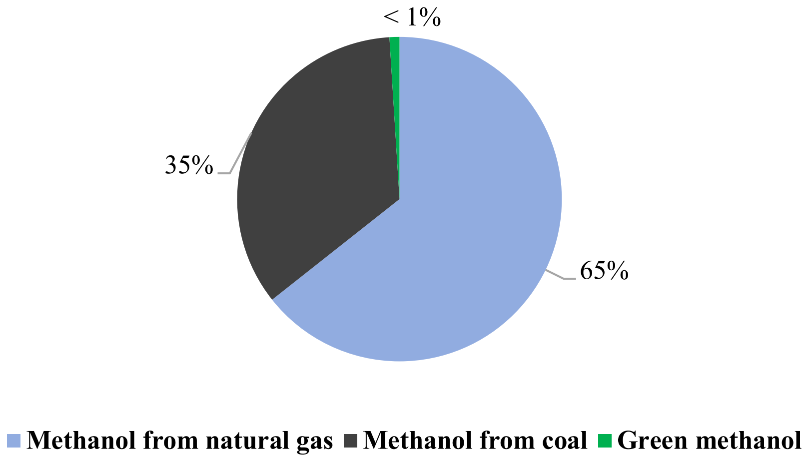

Fig. 1. Proportion of Global Green Methanol Production Capacity.

Green ammonia is anticipated to become one of the primary options for decarbonizing the shipping industry in the future. Firstly, as a zero-carbon fuel, green ammonia contains no carbon atoms, which enables the shipping industry to transition toward a zero-emission era. Secondly, the nitrogen required for synthesizing green ammonia can be directly extracted from the air, ensuring a plentiful supply with minimal risk of raw material shortages; this aligns with national energy security strategy requirements in the current context. Although the process of producing green ammonia from green hydrogen requires energy input, the industry maintains a generally optimistic outlook regarding green ammonia's potential as an alternative fuel for shipping. On one hand, the physical properties of liquid ammonia render it more suitable for storage and transportation. Liquid ammonia produced from hydrogen has a higher volumetric energy density than liquid hydrogen, resulting in reduced cargo space loss for ships. Additionally, ammonia is easier to liquefy than hydrogen, with a liquefaction temperature of -33°C at atmospheric pressure compared to -253°C for hydrogen. Moreover, liquid ammonia contains at least 60% more hydrogen per unit volume than liquid hydrogen. On the other hand, the established industrial and supply chains provide robust market support for promoting ammonia fuel. As a common chemical, ammonia benefits from mature storage and transportation facilities, and existing LNG bunkering stations can be easily converted into ammonia bunkering stations. Nevertheless, utilizing green ammonia as a ship fuel presents challenges, including toxicity and N2O emissions resulting from incomplete combustion. Both academia and industry are collaborating to address these issues from institutional and technological perspectives, thereby accelerating the integration of green ammonia into the decarbonization process of the shipping sector.

3 Green Ammonia Marine Engine Technology and Progress

3.1 Development Progress of Ammonia Fuel Engines

Ammonia engines are essential for the commercial application of ammonia-powered ships. Currently, numerous organizations worldwide are actively engaged in the research and development of ammonia engines. Ammonia-powered marine engines can be classified into three categories based on their operational speeds: low-speed engines, medium-speed engines, and high-speed engines (see Table 2).

Table 2. Classification of Marine Engines.

Type	Low-speed Stage	Medium-speed Engine	High-speed Engine
Speed / r·min	60-120	600-1500	600-2250
Cylinder diameter / mm	350-900	195-225	98-185
Single-cylinder power / kW	567~3855	195~255	95~127
Cycle stroke	2	4	2 or 4
Power source	Mainly heavy oil	Mainly heavy oil	Mainly light diesel
Main characteristics	High power, high efficiency, long lifespan	Quick starting, good maneuverability	Fast sailing speed, compact size
Applicable ship type	Large ocean-going vessels	Fishing vessels, tugboats	Small yachts, government vessels

Both two-stroke low-speed engines and four-stroke medium-speed engines have demonstrated research and development progress in ammonia-fueled ship engines that exceeds industry expectations. In February 2024, IHI Power Systems in Japan delivered the world's first four-stroke ammonia-fueled medium-speed engine to Nippon Yusen, intended for installation on a tugboat currently undergoing conversion. The completion of this project was originally scheduled for June 2024, and the vessel is anticipated to become the world's first commercially operated ammonia-fueled ship. Additionally, driven by the research and development efforts of leading global companies such as MAN and WINGD, the low-speed ammonia-fueled engines are projected to be delivered by the end of 2024, with commercial operation expected to commence in 2026-2027 (see Table 3).

Table 3. Progress in the Research and Development of Ammonia Fuel Engines.

Research and Development Institution	Type	Application Vessel Type	Expected Delivery Status
MAN Energy solutions	Two-Stroke Low-Speed Engine	Large Ocean-Going Ship	First unit expected to be delivered in 2024
Wartsila	Four-Stroke Medium-Speed Engine	Coastal Bulk Carrier	Expected delivery in early 2025
IHI	Four-Stroke Medium-Speed Engine	Tugboat	Expected to be applied to tugboats in 2024
WINGD	Two-Stroke Low-Speed Engine	Large Ocean-Going Ship	First unit expected to be delivered in 2025
Crrc Dalian Co. Ltd	Four-Stroke Medium-Speed Engine	Tugboat	Expected to be applied to the country's first ammonia-fueled tugboat in 2025

3.2 Progress of Handheld Orders for Ammonia-Fueled Vessels

The first order for an ammonia-fueled oil tanker was placed in the second quarter of 2022, resulting from a collaboration between a subsidiary of China Shipbuilding Group Co., Ltd. and the South Korean shipbuilding company K Shipbuilding (KSB) to develop an ammonia-fueled Aframax oil tanker. On February 14, 2024, Belgian shipping company CMB. TECH, in collaboration with Norway's Yara Clean Ammonia (YARA) and North Container Line (NCL), ordered the world's first ammonia-powered container ship from Qingdao Shipyard, which is scheduled to be operational by 2026. The design of the vessel is overseen by the Shanghai Shipbuilding Research Institute, another subsidiary of China Shipbuilding Group, with special attention given to the toxicity and corrosiveness of ammonia fuel to minimize its harmful effects. According to data from Clarksons, as of April 23, 2024, there are 17 orders for ammonia-fueled vessels worldwide, of which 15 are new builds (see Figure 2).The primary vessel types include bulk carriers and medium-sized gas carriers, while two other orders are retrofits, one being a tugboat and the other a platform supply vessel. Furthermore, as the green shipping initiative accelerates, the number of vessels designated for alternative fuels is also on the rise. If ammonia-fueled reserve vessels are included in this analysis, the total number of ammonia-fueled vessels (including orders) could reach 348, comprising 249 ordered vessels and 99 existing vessels.

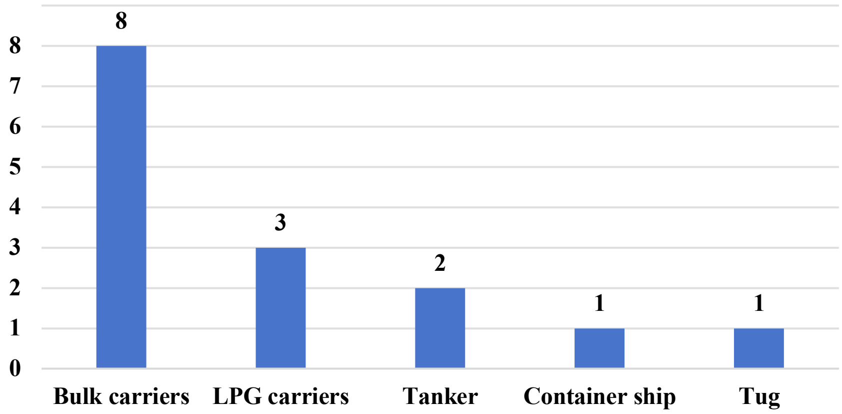

Fig. 2. Data on Newbuild Orders for Ammonia-Fueled Vessels.

4 Application Prospects and Economic Analysis

4.1 Prospects for Green Ammonia in Shipping

Driven by global carbon neutrality objectives, green ammonia is increasingly recognized as a crucial pathway for decarbonizing the shipping industry, functioning as a clean and efficient energy carrier. The International Energy Agency (IEA) stated in its 2023 report, "Net Zero Emissions Roadmap," that ammonia fuel will be pivotal in the global shipping industry's decarbonization efforts. By 2050, as international shipping activities are anticipated to more than double, ammonia's share of final energy consumption is projected to increase significantly to 44%, suggesting that the shipping industry could consume up to 233 million tons of green ammonia annually. Additionally, Lloyd's Register (LR) predicts in its report "The Future of Marine Fuels" that green ammonia will emerge as the most promising and widely adopted alternative fuel for shipping. By 2050, blue and green ammonia are expected to collectively account for 20-60% of the shipping fuel market, with an average share of 46% across all scenarios. The Norwegian classification society DNV has also forecasted that by 2050, green ammonia will comprise 35% of the total demand for alternative fuels in shipping. These findings indicate that green ammonia fuel will play a significant role in the future decarbonization efforts of the shipping industry [8].

4.2 Economic Analysis of Green Ammonia Fuel

The cost of green ammonia is primarily influenced by the cost of green hydrogen, which constitutes 80%-90% of the total ammonia production cost. Consequently, the potential for reducing the cost of green ammonia arises from several key factors: a decrease in the cost of electrolysis equipment for green hydrogen, lower prices for clean electricity, and the optimization of ammonia synthesis processes. Currently, the global average production cost of green ammonia varies between $720 and $1,400 per ton. With anticipated declines in green electricity prices and advancements in production processes contributing to a reduction in the overall cost of green ammonia, it is projected that this cost may decrease to between $310 and $610 per ton by 2050[9].

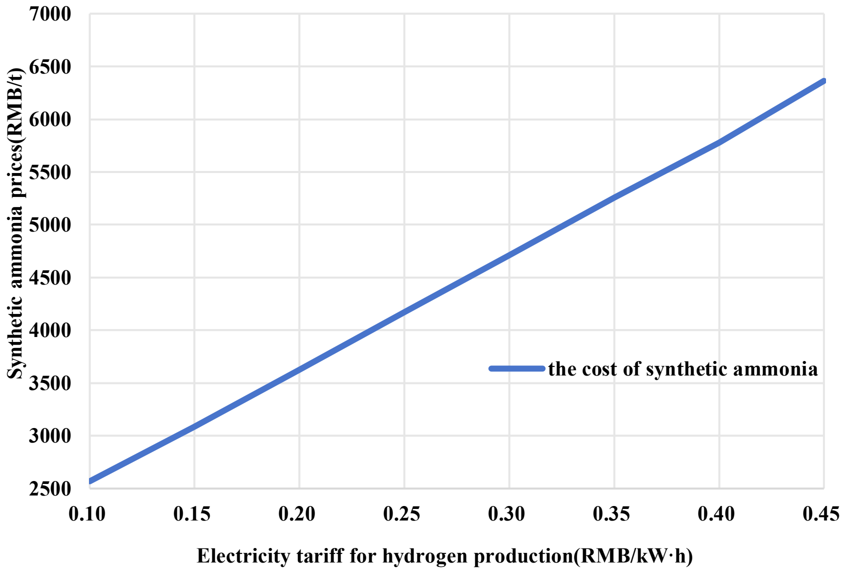

Fig. 3. Relationship between Hydrogen Electricity Prices and Ammonia Synthesis Costs.

Synthetic ammonia requires a stable power supply, typically sourced from grid electricity or a combination of renewable energy and grid power. Significant regional differences in electricity prices can affect ammonia production costs; as illustrated in Figure 3, a price variation of 0.1 yuan/kW·h can lead to an approximate cost fluctuation of 1,000 yuan per ton of ammonia. If the electricity price for hydrogen production is set at 0.25 yuan/kW·h, the cost of hydrogen as a raw material is approximately 19 yuan/kg, contributing about 3,300 yuan per ton to the overall cost of synthetic ammonia. The electricity price for ammonia production is set at 0.35 yuan/kW·h. Considering factors such as overall energy consumption, depreciation, financing, and maintenance costs, the total production cost of synthetic ammonia is approximately 4,100 yuan per ton.

Currently, the cost of hydrogen production limits the competitiveness of green ammonia in the market, and achieving economic viability for large-scale production of green hydrogen from renewable electricity will require time. However, in regions under significant pressure to consume renewable energy, utilizing stranded wind and solar power for hydrogen production demonstrates preliminary economic feasibility. To enhance the economic viability of the hydrogen production system based on green electricity, further reductions in the cost of green electricity and optimization of hydrogen production capacity should be prioritized. Furthermore, special attention should be given to the flexible control model of the "Electricity–Hydrogen–Ammonia" system to optimize energy consumption and production costs associated with hydrogen. With the establishment of standardized systems for green hydrogen and green ammonia, breakthroughs in key technologies, and gradual improvements in supportive industrial development policies, the green ammonia industry is poised for rapid growth.

5 Conclusion

This study examines the current development status and future application prospects of ammonia-powered vessels in light of global green shipping targets. Carbon emissions in the shipping industry continue to rise, prompting the International Maritime Organization and various countries and regions, including the European Union, to implement stringent carbon emission policies. These initiatives establish clear objectives and timelines for the shipping industry's low-carbon transition. This research offers a comprehensive analysis of the stringent policy requirements and the pressing demand for clean marine fuels at the technological level, distinctly positioning green ammonia as a zero-carbon fuel within the shipping sector's decarbonization process. Due to its advantages, including zero carbon emissions, a well-established industrial chain, and ease of storage and transportation, green ammonia is poised to emerge as a leading option among various potential clean fuels. It is projected that by approximately 2050, its share in final energy consumption will significantly increase to 44%, positioning it as a mainstream clean fuel for vessels. Although ammonia-fueled ships remain in the early stages of development, ongoing research and demonstration projects by several major global marine engine manufacturers are anticipated to expedite the commercialization of ammonia-powered vessel technology. Economically, the current production cost of green ammonia ranges from $720 to $1,400 per ton; however, with declining prices for green electricity and advancements in production processes, this cost is expected to decrease to between $310 and $610 per ton by 2050. In conclusion, this paper presents an in-depth analysis of the current application status and development trends of green ammonia in the field of powered vessels, highlighting its significant role in promoting the green transformation and sustainable development of the shipping industry.

References

1. Liu Lei. (2022) Current Status and Development Prospects of Clean Fuels for Vessels. J. Ship Materials and Market, 30 (12): 7-10.
2. Liu Wei, Wang Cong, Guo Ya, et al. (2021) Research on the Application of Ammonia Fuel and Standard Requirements in the Shipping Industry. J. China Standardization, (18): 39-43.
3. Prospects for Low-Carbon Development in Shipping (2023). China Classification Society. J.

4. Li Yintao. (2023) Development Trends and Future Prospects of Green Low-Carbon Ships. J. China Ship Inspection, (04): 63-73.
5. Chen Gong, Zhu Yu, Han Bing. (2023) Analysis of the Current Status and Development Trends of Green Shipping Energy Technologies. J. Transportation Information and Safety, 41 (02): 168-178.
6. Li Xincheng, Wan Junjie, Lv Liang, et al. (2024) Progress Analysis of Internal Combustion Engine Applications for Zero-Carbon and Low-Carbon Fuels. J. Engine for Vehicles, (03): 1-9.
7. Zhang Xiaoping, Wang Xiaoliang, Wei Zhihao, et al. (2024) Analysis of the Application Prospects of Ammonia Fuel in the Shipping Industry. J. Shandong Chemical, 53 (07): 79-82+86.
8. Chen Keyu, Xu Jinxin, Wu Guibo, et al. (2024) Current Status and Development Prospects of the Green Ammonia Industry. J. Chemical Industry Progress, 43 (05): 2544-2553.
9. Li Weidong, Li Yilong, Teng Lin, et al. (2023) Research Progress on Ammonia Energy Technology and Economic Viability under the "Dual Carbon" Goals. J. Chemical Industry Progress, 42 (12): 6226-6238.