ALAM JOURNAL OF MARITIME STUDIES

ISSN: 2590-4345 e ISSN: 2976-3843 Volume 5 Issue 1 Year 2024

Evaluating Hydrogen and Ammonia as Sustainable Alternatives for Marine Diesel Engines: Environmental, Technical, and Economic Perspectives

Mohamad Riduan Ramli[a*], Mohd Hirzan Mahamed[a], Nur Amirah Ishak[a]

[a] Faculty of Marine Engineering, Malaysia Maritime Academic

Abstract - The maritime industry is a notable contributor to global greenhouse gas (GHG) emissions, necessitating a transition to low-carbon alternatives to mitigate environmental impact. This study explores hydrogen and ammonia as potential alternative fuels for marine diesel engines, focusing on their environmental benefits, technical feasibility, and economic considerations. Hydrogen, with its high energy density and zero carbon emissions at the point of use, offers a promising solution for sustainable maritime operations. Ammonia, characterized by its high hydrogen content and renewable production capabilities, presents a viable alternative despite its associated challenges. The review assesses the current state of research and development, examining the comparative emissions profiles, storage and handling requirements, and combustion characteristics of these fuels. Technical barriers, such as advanced storage solutions for hydrogen and safety measures for ammonia, are discussed alongside economic obstacles, including high initial investment costs and fuel price disparities. Regulatory frameworks and policy support are highlighted as critical factors for successful adoption. Case studies of hydrogen and ammonia applications in maritime contexts underscore the practical feasibility and collaborative efforts necessary for broader implementation. The paper concludes by identifying future research directions to enhance the viability of hydrogen and ammonia as sustainable marine fuels, contributing to the maritime sector's transition towards reduced environmental impact and alignment with global climate goals.

Keywords: Alternative Fuels, Ammonia Fuel, Hydrogen Fuel, Marine Diesel Engines, Maritime Emissions, Sustainable Maritime,

*Corresponding Author. Email address: mriduan.ramli@alam.edu.my

1.0 INTRODUCTION

The maritime sector is a significant contributor to global GHG emissions, accounting for approximately 2.5% of the world's total emissions (IMO, 2021). To mitigate environmental impact, the industry must transition to low-carbon alternatives. Hydrogen and ammonia have emerged as promising candidates for alternative marine fuels due to their potential for reducing emissions and reliance on fossil fuels.

Hydrogen, with its high energy density and zero carbon emissions at the point of use, offers a viable solution for sustainable maritime operations (Ryu et al., 2023). Ammonia, on the other hand, provides a high hydrogen content and can be produced from renewable energy sources, making it an attractive alternative (Giddey et al., 2017). Both fuels, however, present unique challenges and opportunities that require detailed examination.

This review aims to assess the feasibility and impact of hydrogen and ammonia as alternative fuels. It will explore the environmental benefits, technical requirements, and economic considerations associated with their adoption. By examining the current state of research and development, this paper seeks to provide a comprehensive understanding of the potential of these fuels in achieving sustainable maritime operations.

2.0 ENVIRONMENTAL IMPACT OF HYDROGEN AND AMMONIA FUELS

The environmental impact of hydrogen and ammonia as alternative marine fuels is a critical consideration in their adoption. Hydrogen, when used as a fuel, produces only water as a by-product, eliminating CO2 emissions entirely (Lin et al., 2023). These characteristic positions hydrogen as a leading candidate for reducing the maritime industry's carbon footprint.

Ammonia, although not entirely carbon-free, can be produced using renewable energy sources through processes such as electrolysis, thereby minimizing its overall environmental impact (Smith et al., 2020). The combustion of ammonia in marine engines can produce nitrogen oxides (NOx), but advanced catalytic converters and selective catalytic reduction (SCR) systems can mitigate these emissions effectively (Zhu et al., 2022).

In addition to reducing GHG emissions, the adoption of hydrogen and ammonia fuels can significantly decrease sulfur oxides (SOx) and particulate matter (PM) emissions, contributing to improved air quality in port cities and coastal areas (Ni et al., 2020). Furthermore, the utilization of renewable energy for hydrogen and ammonia production aligns with global efforts to transition to sustainable energy systems (IEA, 2019). Table 1 showing Comparison of Emissions from Hydrogen, Ammonia, and Conventional Marine Fuels.

Fuel	LHV (MJ/kg)	HHV (MJ/kg)	Stoichiometric Air/FuelRatio (kg)	Combustible Range (%)	Flame Temp(°C)	Min. Ignition Energy (MJ)	Auto Ignitin Temp. (°C)
Methne	50.0	55.5	17.2	5-15	1914	0.30	540-630
Propane	45.6	50.3	15.6	2.1-9.5	1925	0.30	450
Octane	47.9	15.1	0.31	0.95-6	1980	0.26	415
Methanol	18.0	22.7	6.5	6.7-36	1870	0.14	460
Hydrogen	119.9	141.6	34.3	4-75	2207	0.017	585
Gasoline	44.5	47.3	14.6	1.3-7.1	2307	0.29	260-460
Diesel	42.5	44.8	14.5	0.6-5.5	2327	-	180-320

Table 1: Comparison of Emissions from Hydrogen, Ammonia, and Conventional Marine Fuels (Kumar et al., 2015).

Hydrogen and ammonia also offer the potential for reducing marine plastic pollution. Traditional marine fuels can contribute to plastic waste through leakage and spillage, whereas hydrogen and ammonia do not pose such risks. This aspect further enhances their suitability as sustainable alternatives.

3.0 TECHNICAL FEASIBILITY OF HYDROGEN AND AMMONIA AS MARINE FUELS

The technical feasibility of hydrogen and ammonia as marine fuels involves evaluating their storage, handling, and combustion characteristics. Hydrogen, due to its low density, requires advanced storage solutions such as compressed gas cylinders or liquid hydrogen tanks (Van Hoecke et al., 2021). These storage methods must ensure safety and efficiency, particularly in maritime environments.

Ammonia, with its higher energy density compared to hydrogen, presents fewer storage challenges. It can be stored as a liquid under moderate pressure or refrigeration, making it more practical for long-distance maritime transport (Duong et al., 2023). However, ammonia's toxicity necessitates stringent safety measures to prevent leaks and ensure crew safety.

Combustion characteristics also play a vital role in determining the feasibility of these fuels. Hydrogen can be used in internal combustion engines (ICEs) and fuel cells, each offering different advantages. Fuel cells provide higher efficiency and lower emissions, while ICEs offer easier integration with existing maritime infrastructure (Onorati et al., 2022).

Ammonia can be used in ICEs with modifications to address its lower flame speed and higher ignition temperature. Dual-fuel engines that use a combination of ammonia and conventional fuels can enhance combustion efficiency and reduce emissions (Cardoso et al., 2021). Figure 1showing Schematic Diagram of Ammonia Fuel Systems for Marine Engines

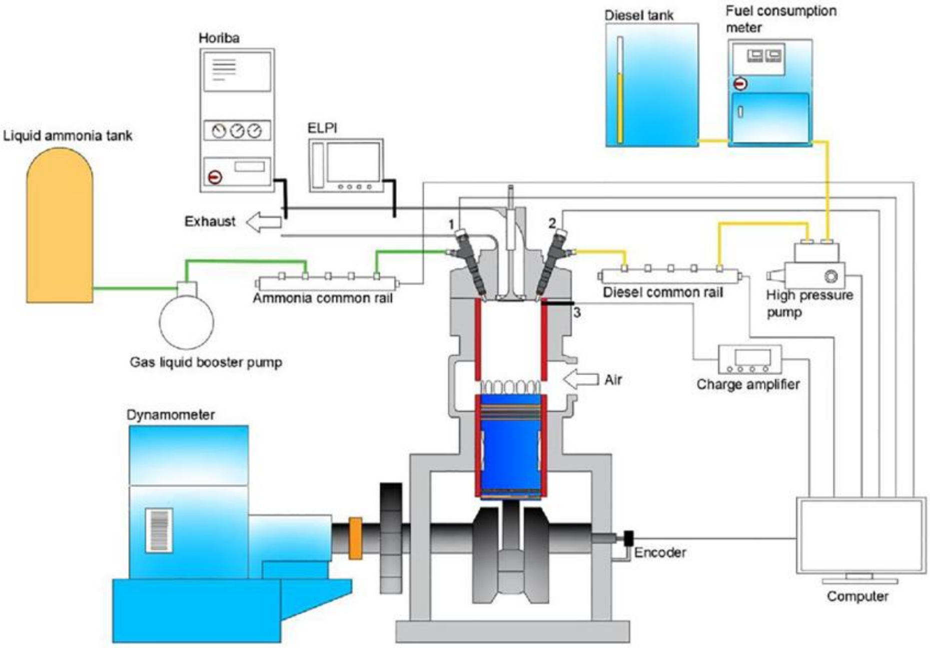

Fig. 1. Schematic Diagram of Ammonia Fuel Systems for Marine Engines (Zhang et al., 2023)

4.0 CHALLENGES AND BARRIERS TO ADOPTION

Despite the potential benefits, several challenges and barriers must be addressed to facilitate the adoption of hydrogen and ammonia as marine fuels. Technical challenges include the development of efficient storage and handling systems, as well as the optimization of combustion processes (Van Hoecke et al., 2021). Safety concerns, particularly regarding ammonia's toxicity, must be thoroughly addressed through stringent regulations and best practices (Duong et al., 2023).

Economic barriers, such as high initial investment costs and the current price disparity between alternative and conventional fuels, pose significant obstacles (Wang et al., 2021). Bridging this gap will require substantial financial incentives and support from governments and international organizations. Regulatory and policy challenges also play a critical role. Harmonizing international regulations and standards for alternative marine fuels is essential to ensure consistent implementation and compliance (IMO - Marine Environment Protection Committee, 2020). Furthermore, public acceptance and awareness are crucial for the successful transition to hydrogen and ammonia fuels.

Collaboration across the maritime industry, including shipbuilders, engine manufacturers, fuel producers, and policymakers, is vital to overcome these challenges. Research and development efforts must focus on innovative solutions to enhance the feasibility and competitiveness of hydrogen and ammonia fuels (Kim et al., 2020).

5.0 CASE STUDIES AND REAL-WORLD APPLICATIONS

Several case studies and pilot projects demonstrate the practical application of hydrogen and ammonia as marine fuels. The world's first hydrogen-powered passenger ferry, Hydro Ville, operates in Belgium, showcasing the feasibility of hydrogen for short-distance maritime transport. The Ship FC project in Norway aims to retrofit an offshore supply vessel with a large-scale ammonia fuel cell system, providing valuable insights into the challenges and opportunities associated with ammonia as a marine

ISSN: 2590-4345 e-ISSN: 2976-3843

fuel (Jafarzadeh et al., 2023). These initiatives highlight the potential of hydrogen and ammonia to transform the maritime industry.

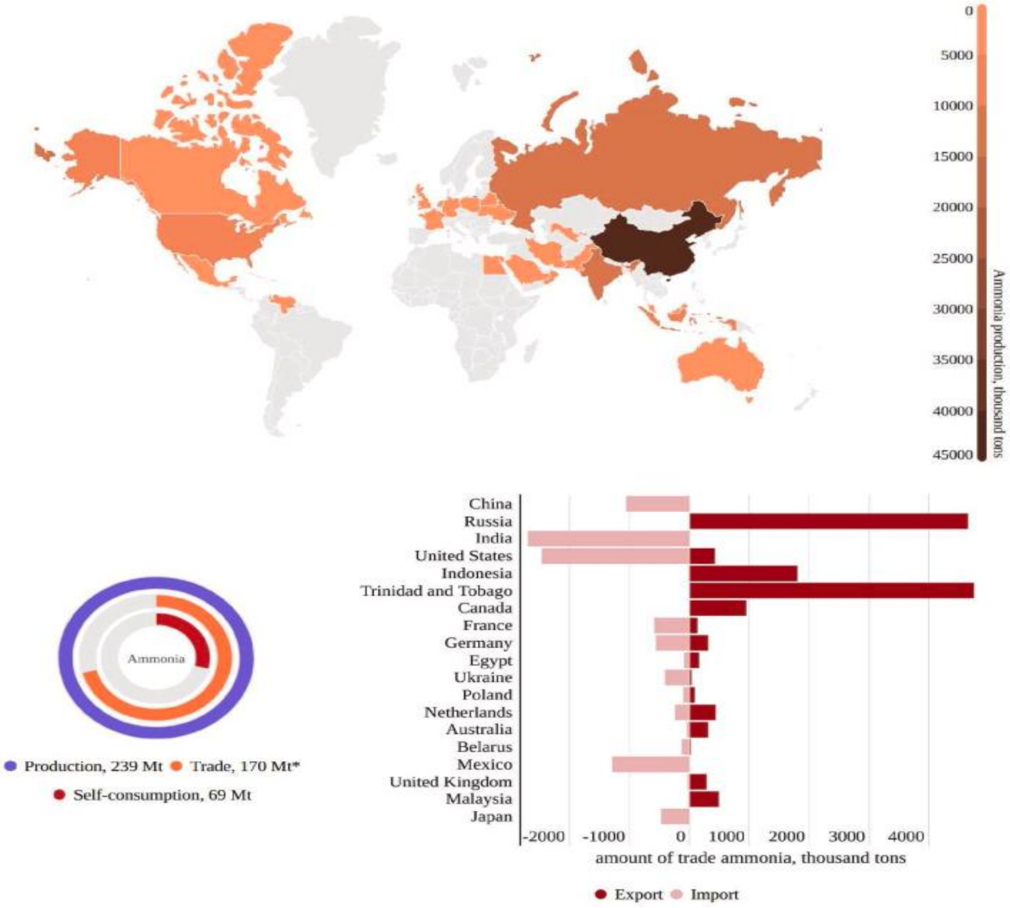

Fig. 2. Global ammonia production per country with import and export details (Machaj et al., 2022)

These case studies also underscore the importance of collaboration and knowledge sharing in advancing alternative fuel technologies. Lessons learned from these projects can guide future research and development efforts, facilitating the broader adoption of hydrogen and ammonia fuels in the maritime sector (Hansson et al., 2019).

6. FUTURE DIRECTIONS AND RESEARCH OPPORTUNITIES

Future research should focus on optimizing the production, storage, and utilization of hydrogen and ammonia fuels. Advances in electrolysis and other renewable energy-based production methods can reduce costs and improve sustainability (Marouani et al., 2023). Innovative storage solutions, such as metal hydrides and advanced tank designs, can enhance the practicality of hydrogen and ammonia for maritime applications (Bellosta von Colbe et al., 2019).

Policy and regulatory frameworks should continue to evolve to support the adoption of alternative marine fuels. Incentives for research and development, infrastructure investments, and early adopters can accelerate the transition to sustainable maritime solutions (IMO, 2021).

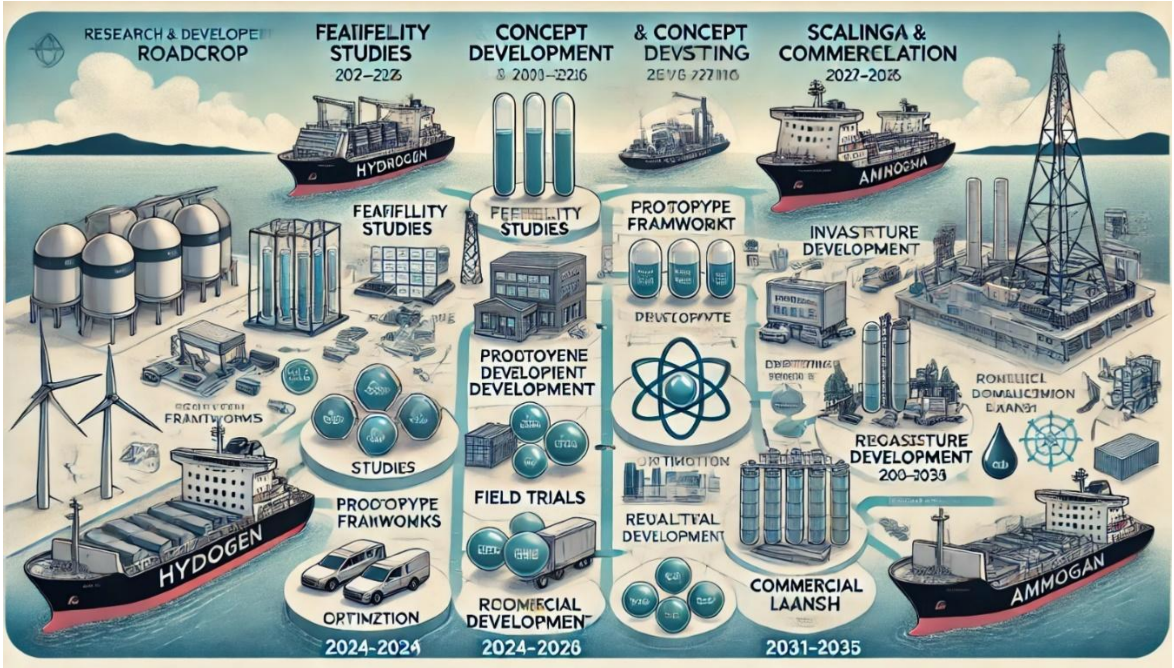

Fig. 3. Illustration Research and Development Roadmap for Hydrogen and Ammonia Fuels in the Maritime Industry

7. CONCLUSION

The transition to hydrogen and ammonia as alternative fuels for marine diesel engines offers a promising pathway to achieving sustainable maritime operations. While challenges remain, the environmental benefits, technical feasibility, and economic potential of these fuels make them viable options for the future of the maritime industry.

Continued research, innovation, and collaboration are essential to overcome the barriers and unlock the full potential of hydrogen and ammonia fuels. By embracing these alternative fuels, the maritime sector can significantly reduce its environmental impact and contribute to global efforts to combat climate change.

8. REFERENCES

Bellosta von Colbe, J., Ares, J. R., Barale, J., Baricco, M., Buckley, C., Capurso, G., Gallandat, N., Grant, D. M., Guzik, M. N., Jacob, I., Jensen, E. H., Jensen, T., Jepsen, J., Klassen, T., Lototskyy, M. V., Manickam, K., Montone, A., Puszkiel, J., Sartori, S., … Dornheim, M. (2019). Application of hydrides in hydrogen storage and compression: Achievements, outlook and perspectives. *International Journal of Hydrogen Energy*, *44*(15). https://doi.org/10.1016/j.ijhydene.2019.01.104

Cardoso, J. S., Silva, V., Rocha, R. C., Hall, M. J., Costa, M., & Eusébio, D. (2021). Ammonia as an energy vector: Current and future prospects for low-carbon fuel applications in internal combustion engines. In *Journal of Cleaner Production* (Vol. 296). https://doi.org/10.1016/j.jclepro.2021.126562

Duong, P. A., Ryu, B. R., Song, M. K., Nguyen, H. Van, Nam, D., & Kang, H. (2023). Safety Assessment of the Ammonia Bunkering Process in the Maritime Sector: A Review. In *Energies* (Vol. 16, Issue 10). https://doi.org/10.3390/en16104019

Giddey, S., Badwal, S. P. S., Munnings, C., & Dolan, M. (2017). Ammonia as a Renewable Energy Transportation Media. *ACS Sustainable Chemistry and Engineering*, *5*(11). https://doi.org/10.1021/acssuschemeng.7b02219

Hansson, J., Månsson, S., Brynolf, S., & Grahn, M. (2019). Alternative marine fuels: Prospects based on multi-criteria decision analysis involving Swedish stakeholders. *Biomass and Bioenergy*, *126*. https://doi.org/10.1016/j.biombioe.2019.05.008

IMO. (2021). Fourth IMO GHG Study 2020 Full Report. *International Maritime Organisation*, *6*(11).

IMO - Marine Environment Protection Committee. (2020). Reduction of GHG emissions from ships. Fourth IMO GHG Study 2020. MEPC 75/7/15. In *International Maritime Organization*.

Jafarzadeh, S., Ladstein, J., Ødegård, A., Sundseth, K., Ortiz, M. M., Høyli, R., & Zenith, F. (2023). Electrification Of The Coastal Fishing Fleet Using Hydrogen And Ammonia-Fed Fuel Cells. *Proceedings of the International Conference on Offshore Mechanics and Arctic Engineering - OMAE*, *5*. https://doi.org/10.1115/OMAE2023-101707

Kim, K., Roh, G., Kim, W., & Chun, K. (2020). A preliminary study on an alternative ship propulsion system fueled by ammonia: Environmental and economic assessments. *Journal of Marine Science and Engineering*, *8*(3). https://doi.org/10.3390/jmse8030183

Kumar, V., Gupta, D., & Kumar, N. (2015). Hydrogen Use In Internal Combustion Engine: A Review. *The International Journal of Advanced Culture Technology*, *3*(2). https://doi.org/10.17703/ijact.2015.3.2.87

Lin, C.-Y., Wu, P.-C., & Yang, H. (2023). Alternative Gaseous Fuels for Marine Vessels towards Zero-Carbon Emissions. *Gases*, *3*(4). https://doi.org/10.3390/gases3040011

Machaj, K., Kupecki, J., Malecha, Z., Morawski, A. W., Skrzypkiewicz, M., Stanclik, M., & Chorowski, M. (2022). Ammonia as a potential marine fuel: A review. In *Energy Strategy Reviews* (Vol. 44). https://doi.org/10.1016/j.esr.2022.100926

Marouani, I., Guesmi, T., Alshammari, B. M., Alqunun, K., Alzamil, A., Alturki, M., & Hadj Abdallah, H. (2023). Integration of Renewable-Energy-Based Green Hydrogen into the Energy Future. *Processes*, *11*(9). https://doi.org/10.3390/pr11092685

Ni, P., Wang, X., & Li, H. (2020). A review on regulations, current status, effects and reduction strategies of emissions for marine diesel engines. In *Fuel* (Vol. 279). https://doi.org/10.1016/j.fuel.2020.118477

Onorati, A., Payri, R., Vaglieco, B. M., Agarwal, A. K., Bae, C., Bruneaux, G., Canakci, M., Gavaises, M., Günthner, M., Hasse, C., Kokjohn, S., Kong, S. C., Moriyoshi, Y., Novella, R., Pesyridis, A., Reitz, R., Ryan, T., Wagner, R., & Zhao, H. (2022). The role of hydrogen for future internal combustion engines. In *International Journal of Engine Research* (Vol. 23, Issue 4). https://doi.org/10.1177/14680874221081947

Ryu, B. R., Duong, P. A., & Kang, H. (2023). Comparative analysis of the thermodynamic performances of solid oxide fuel cell–gas turbine integrated systems for marine vessels using ammonia and hydrogen as fuels. *International Journal of Naval Architecture and Ocean Engineering*, *15*. https://doi.org/10.1016/j.ijnaoe.2023.100524

Smith, C., Hill, A. K., & Torrente-Murciano, L. (2020). Current and future role of Haber-Bosch ammonia in a carbon-free energy landscape. *Energy and Environmental Science*, *13*(2). https://doi.org/10.1039/c9ee02873k

Van Hoecke, L., Laffineur, L., Campe, R., Perreault, P., Verbruggen, S. W., & Lenaerts, S. (2021). Challenges in the use of hydrogen for maritime applications. In *Energy and Environmental Science* (Vol. 14, Issue 2). https://doi.org/10.1039/d0ee01545h

Wang, Y., Wright, L., & Zhang, P. (2021). Economic feasibility of LNG fuel for trans ocean-going ships: A case study of container ships. *Maritime Technology and Research*, *3*(2). https://doi.org/10.33175/mtr.2021.248055

Zhang, Z., Long, W., Dong, P., Tian, H., Tian, J., Li, B., & Wang, Y. (2023). Performance characteristics of a two-stroke low speed engine applying ammonia/diesel dual direct injection strategy. *Fuel*, *332*. https://doi.org/10.1016/j.fuel.2022.126086

Zhu, Y., Zhou, W., Xia, C., & Hou, Q. (2022). Application and Development of Selective Catalytic Reduction Technology for Marine Low-Speed Diesel Engine: Trade-Off among High Sulfur Fuel, High Thermal Efficiency, and Low Pollution Emission. In *Atmosphere* (Vol. 13, Issue 5). https://doi.org/10.3390/atmos13050731