Overcoming Challenges in the Alternative Fuels Transition

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Abstract

The maritime industry is at crossroads as we are facing the transition from traditional heavy fuel oils to alternative fuels like LNG, methanol, ammonia and hydrogen. Very strict environmental regulations and efforts to control greenhouse gas (GHG) emissions make this transition obligatory. Yet it has a host of challenges, both technical, economic, regulatory as well as human. This paper aims at examining the barriers through analysis of current literature and empirical studies in order to propose ways forward. At the center of our discussion is the question: What are some of the effective ways that can be used by maritime industry to overcome these constraints? Our analysis shows that even though the maritime industry has made strides over the past years in adapting to new regulations, there are numerous difficulties concerning adoption of alternative fuels due to their complexity related to activities of the maritime industry. In contrast to prior works only concentrated on potential cost and GHG benefits, this study will take a wider outlook by including both approaches from technical perspective as well as views from a general perspective.

Introduction

The maritime sector is the cornerstone of global trade, handling 80-90% of international goods transport (Hoffmann et al., 2018). Despite its energy efficiency (fuel per unit distance) compared to other forms of transport, it contributes about 3% of global greenhouse gas (GHG) emissions (Makitie et al., 2022; Prussi et al., 2021; Foterich et al., 2021; Wang & Wright, 2021). The International Maritime Organization (IMO) has set a goal to reduce these emissions by 50% by 2050 compared to 2008 levels through a multiphase approach (Anderson et al., 2020; Wang & Wright, 2021). Therefore, meeting these goals necessitates switching to alternative fuels such as Liquefied Natural Gas (LNG), methanol, ammonia and hydrogen. However, this shift comes with several challenges that need to be resolved for a sustainable and effective maritime industry.

The aim of this review is to answer the question, "How can the maritime industry effectively overcome the challenges with regard to the transition to alternative fuels?" by examining relevant literature and giving a high-level overview of the current problems in implementing alternative fuels. The main difficulty that we have observed in existing literature is that it dwells

on economic or technical barriers and GHG saving potential only. The paper complements the current body of knowledge by presenting other technical and non-technical aspects, in line with other researchers (e.g Prussi et al., 2021; Foretich et al., 2021). By synthesizing these qualitative findings, we are able to develop strategic decision support tools, guide technical direction and set priorities for maritime stakeholders and scientific community. In the first section, we will discuss these challenges, including technical, economic, regulatory, and infrastructural barriers. In the second section, we will explore strategies and solutions the industry can employ to overcome these obstacles, emphasizing the role of innovation, policy support, investment in human capital and collaborative efforts.

Review on Current Challenges in the Adoption of Alternative Fuels

In this section, several challenges in the implementation of the use of the alternative fuels in the maritime sector will be described. We have analyzed recent publications in journals as well as technical papers from classification societies' websites, and industry updates. This broad literature review therefore seeks to unravel the narrative on the challenges that have to be crossed to enable 'the green fuels transition' within the maritime framework. This review will allow forming an informed understanding of the present situation and define the areas to address to achieve the adoption of the alternative fuels.

Technical Challenges – The technical viability of alternative fuels in maritime shipping varies considerably. LNG, while relatively mature, remains a capital-intensive product that requires substantial investments in infrastructure and technological adaptations (Prussi et al., 2021; Turcanu et al., 2021). A key concern is the potential of "methane slip", which can nullify LNG's environmental benefits since methane is a potent greenhouse gas (Curran et al., 2024). Thus, LNG is more broadly accepted by the industry as "*the first step towards decarbonising the maritime industry*" (Wartsila, 2024).

Methanol and ammonia present distinct challenges related to storage, handling, and combustion properties. Methanol has lower energy density compared to conventional fuels (much like other alternative fuels) and poses toxicity risks (Prussi et al., 2021; Turcanu et al., 2021). However, the Shipping Industry Safety Coalition "Together in Safety" (2022) has produced a risk analysis report that assesses methanol as the safest option compared to other conventional fuels and specifically points out ammonia as high risk, due to a number of ammonia's risk factors characterized as "intolerable". A similar study outcome by an MIT research group highlighted that "*NO_x, NH_3 and N_2O from ammonia combustion could impact air quality and climate*" in such way that could lead up to 668 100 additional premature deaths yearly, if controls and regulations remain as of today (Wong et al., 2024). Concurrently, hydrogen is promising in emissions reduction, challenges in cost, generating, storing, and using hydrogen onboard are still a major concern (Wang and Wright, 2021).

The use of these types of fuels in conventional marine engines also requires research and development efforts to ensure compatibility. New engine technologies have to be designed for using these fuels as they have different fuel combustion patterns as compared to conventional fuels. This means substantial investment in RD and time to build and test these technologies and then implement them (Foretich et al., 2021).

The lack of widespread expertise in handling and maintaining new engines designed for alternative fuels is a significant barrier. Alternative fuel engines require specialized knowledge for troubleshooting and repairs, which many shipyards and marine engineers currently lack (Bourboulis et al., 2022; LR, 2023).

Another aspect that in many cases is neglected is the fact that finding replacement components for new alternative fuel engines can be challenging. The supply chains for parts specific to alternative fuel engines are not as well established as those for traditional marine engines, leading to longer downtimes and increased operational costs when parts are needed (Marine Log, 2023). This issue is compounded by the limited physical capacity of shipyards to handle the retrofits or repairs needed for these engines, creating potential bottlenecks (Bourboulis et al., 2023).

Economic Challenges – The high cost of alternative fuels compared to conventional fuels remains a significant barrier. Initial investments in retrofitting ships and developing the necessary infrastructure are substantial (Hyungjui et al., 2020; Prussi et al., 2021). Furthermore, the economic viability of these fuels depends on fluctuating market prices and the development of a stable supply chain (Prussi et al., 2021; Foretich et al., 2021). The cost dynamics are even more complex when considering the operational expenditure (OpEx) and capital expenditure (CapEx) associated with each fuel type (Hyungju et al., 2020). For example, hydrogen and ammonia may have higher OpEx because of their storage and handling requirements (Karvounis et al., 2022).

Regulatory and Policy Challenges – International and national regulations are also a very influential factor when it comes to the adoption of alternative fuels. The IMO's regulations, such as MARPOL Annex VI, mandate reductions in sulfur oxides (SOx) and nitrogen oxides (NOx) emissions, driving the need for cleaner fuels (Kim et al., 2020; Prussi et al., 2021). However, the regulatory landscape is complex and remains dynamic, requiring ship operators to monitor the changes regularly and effectively (Foretich et al., 2021). Compliance with these regulations often involves additional costs and operational changes, which can be demanding for shipping companies (Makitie et al., 2022).

Adding to the complexity is the fact that there is much ambiguity within the industry on how these changes should be implemented. Ship operators frequently struggle to understand and comply with the numerous and sometimes contradictory regulations issued by various international, regional, and national authorities. This confusion is exacerbated by the fact that some regulatory frameworks are not yet fully developed, leaving companies uncertain about future compliance requirements (Maritime Professionals, 2023).

These issues are further confounded by the lack of a harmonized global regulatory framework. Different regions may have varying standards and requirements, leading to a fragmented regulatory landscape. In this case one may observe the fact that such fragmentation may lead to severe operational and financial implications for the shipping companies who operate in an international environment, since they are required to observe and adhere to a broad set of requirements and standards (Foretich et al., 2021).

Infrastructure Development – Another major challenge is building up the infrastructures for supporting the use of alternatives fuels. Ports need to be equipped with refuelling stations for

LNG, methanol, ammonia, and hydrogen. Of course, this demands considerable capital inputs and cooperation between various parties: port states, fuelling agencies, and shipping companies. Additionally, the integration of alternative fuel infrastructure must consider the environmental and safety regulations at both local and international levels. For instance, the installation of hydrogen refuelling stations entails compliance with high safety standards due to the fuel's high flammability (Prussi et al., 2021; Wang and Wright, 2021; Turcanu et al., 2021).

Human Element and Crew Readiness – Human factor can be considered as one of the most main components in the adoption of alternative fuels. Crew readiness and comprehensive training programs are essential to handle new types of fuels safely and efficiently. Lack of adequate training can result in increased safety hazards and diminished organizational performance (Prussi et al., 2021; Turcanu et al., 2021). Moreover, the transition to alternative fuels necessitates changes in standard operating procedures and emergency response protocols, which require ongoing education and adaptation (Foretich et al., 2021; Percic et al., 2021).

Given the complexity and variety of alternative fuels, proper knowledge and skills must be embraced by the crews to handle such fuels with competence and safety. This includes understanding the unique properties of each fuel, the potential hazards, and the specific handling and storage requirements. For example, LNG requires cryogenic storage, which poses unique challenges compared to traditional fuels. Similarly, ammonia is highly toxic, requiring strict safety protocols to prevent exposure and contamination (Turcanu et al., 2021).

Needless to say, there are significant gaps in the knowledge base required to handle alternative fuels, leading to the dissemination of confusing or incorrect information to seafarers. The rapidly evolving nature of fuel technologies means that training programs need to be continuously updated to reflect the latest best practices and safety protocols. Unfortunately, the pace at which these updates are implemented can lag behind technological advancements, leaving crews inadequately prepared.

Solutions to overcoming the challenges of adoption of Alternative Fuels

In the previous section, we explored various challenges associated with the adoption of alternative fuels in the shipping industry. In regards to these challenges, this part will feature solutions with a focus on technical possibilities, economic aspects, regulation, and structural factors.

Overcoming Technical Challenges

The technical challenges of adopting alternative fuels in shipping are significant and varied. LNG, while relatively advanced, still demands substantial infrastructure investments and technological modifications. For example, the MV Wes Amelie, the first container ship powered by LNG, faced considerable supply chain issues, underscoring the need for reliable and sustainable LNG infrastructure (Maritime Professionals, 2023). Methanol, despite its challenges, offers several advantages that make it a promising alternative fuel. Methanol's simpler design requirements lower the capital expenditure (CAPEX) for new builds or retrofits, as there is no need for pressurization or cryogenic fuel tanks (DNV, 2023). Moreover, methanol engines are less complex, and retrofitting existing ships to run on methanol is relatively straightforward,

significantly reducing conversion costs (DNV, 2023). Methanol's lower storage and handling requirements also make it more attractive for various ship types. The growing order book for methanol-fuelled vessels, including Maersk's 25 methanol-enabled vessels, highlights the industry's confidence in methanol's technical and economic viability (SeaTrade Maritime, 2023).

As for the technical barriers, solutions such as increases in modular and scalable fuel storage means' capability can improve the flexibility of fuel managing processes. This approach is most helpful for addressing issues of varied storage of different alternative fuels as seen also in methanol (Hellenic Shipping News, 2023). Additionally, developing hybrid propulsion systems that can switch between alternative and conventional fuels offers a transitional pathway towards full adoption, providing operational flexibility and reducing the immediate financial burden associated with transitioning to new fuel technologies (Clarksons, 2022).

Finally, accelerating technological advancements necessitates extended collaborative research and development partnerships among academic institutions, industries, and governments (Wang and Wright, 2021; Prussi et al. , 2021). Developing adaptive engines capable of utilizing multiple types of alternative fuels is a very promising concept but requires further research, since at the moment it might be far from implementation from a technological perspective. Nevertheless, there are some auspicious adaptive technologies already developed, such as the Adaptive Combustion Control (ACC 2.0) developed by MAN, which allows the 49/60DF engine to adapt automatically to changing ambient conditions, varying fuel qualities, and engine wear.

Economic Incentives & Support

As we pointed out in the first section, the relatively high price of these fuels as compared to conventional fuels is another problem area. Initial investments required for retrofitting ships and developing the necessary infrastructure are considerable. Additionally, fluctuating market prices and the stability of supply chains impact the economic viability of alternative fuels (Karvounis et al., 2022; Foretich et al., 2021).

Overcoming economic challenges means that governments need to play a more active role, since governments and international bodies should provide financial incentives such as subsidies, tax breaks, and funding for research and development. These incentives can help offset the high costs associated with alternative fuels and encourage their adoption (Foretich et al., 2021).

Establishing a carbon pricing mechanism could also make alternative fuels more competitive compared to traditional VLSFO. This approach can create a financial environment that favors cleaner fuels and supports the industry's transition towards sustainability (Heine et al, 2019). This approach aligns with EU's current initiatives and specifically the EU Emissions Trading System (ETS). This carbon pricing mechanism creates a financial environment that incentivizes the switch to cleaner fuels by making the use of traditional fossil fuels more expensive. It effectively supports the maritime industry's transition towards sustainability by encouraging the adoption of alternative fuels such as LNG, methanol, and hydrogen (European Commission, 2023). Furthermore, the FuelEU Maritime initiative complements the ETS by setting targets for reducing the greenhouse gas intensity of the energy used by ships. This regulation incentivizes the use of low-carbon fuels and technologies, thus promoting further reductions in maritime emissions (Lloyd's Register, 2023; European Commission, 2023). However, the trading system

introduced through FuelEU is something that we should closely monitor as a possible new market can emerge through the trading of surplus and deficit volumes (Lewis & Eason, 2024).

Last but not least, promoting public-private partnerships can attract investments and share the financial burden associated with the transition to alternative fuels. Such partnerships can facilitate the development of necessary infrastructure and technological advancements (Maritime Professionals, 2023).

Regulatory and Policy Changes

To deal with regulatory challenges, shipping companies need to proactively engage and ensure they are knowledgeable about new regulatory requirements. Companies need to invest in regulatory intelligence to anticipate and prepare for upcoming changes (Hellenic Shipping News, 2023). This means that the regulators and the stakeholders should work closely together to ensure that the rules do not hamper progress, but rather encourage the use of new technology. This cooperation can help create a regulatory environment that encourages the adoption of alternative fuels while ensuring compliance and staying pragmatic (Clarksons, 2022). Furthermore, aligning international regulations can create a more predictable and stable regulatory environment, facilitating the adoption of alternative fuels. Harmonizing regulations across regions can reduce the complexity and costs associated with meeting diverse regulatory requirements, thus supporting a smoother transition (Foretich et al., 2021).

Infrastructure Development

Adding to our previous discussion on economic support, public-private partnerships can play a crucial role in financing and developing the necessary facilities. Collaboration among port authorities, fuel suppliers, and ship operators is essential to ensure the seamless integration of alternative fuel infrastructure (Clarksons, 2022). These partnerships can pool resources, share risks, and streamline processes, making the development of alternative fuel infrastructure more feasible and efficient. Government support in the form of grants and low-interest loans can further facilitate the development of this infrastructure. Such financial support can lower the barriers to entry for new technologies and accelerate the deployment of necessary facilities, enhancing the feasibility of alternative fuels.

Developing strategic infrastructure plans that include modular and scalable designs can ensure that ports are equipped to handle various alternative fuels. This can optimize investment and operational efficiency, allowing ports to adapt to evolving fuel technologies and regulatory requirements (DNV, 2023). Such plans can provide a robust foundation for the wide application of alternative fuels in the maritime sector if consideration is also given to long-term sustainability and flexibility.

Technological Innovation and Digitalization

Another key area is technological innovation, which may significantly improve the feasibility and efficiency of alternative fuels by betterment in the area of fuel production, storage technologies, and development of efficient systems of propulsion. The development of advanced technologies that enable a single type of engine to efficiently use several types of alternative fuels could provide greater flexibility and resilience in the fuel supply chain (Wang and Wright, 2021; Prussi

et al., 2021; Clarksons, 2022). Academia–industry–government collaboration could accelerate these innovations and help bring them into practice.

The integration of digital technologies and data analytics can optimize fuel use and enhance operational efficiency. Predictive maintenance, backed by digitalization, can reduce downtime and increase overall efficiency (Percic et al., 2021). Besides, digital technologies can monitor and control, in real-time, fuel consumption, emissions, and operational performance—parameters very useful for making more informed decisions and strategic planning.

Lastly, integrating renewable energy sources such as solar and wind power on ships can help reduce fuel consumption and emissions. These technologies can complement alternative fuels and enhance the sustainability of maritime operations (Safety4Sea, 2022). As an example, hybrid arrangements combining renewable energy sources and alternative fuels are useful in planning a more sustainable and resilient solution for the supply of energy on ships.

Investing in the Human Element

The human element is critical to the successful adoption of alternative fuels. Crew readiness and comprehensive training programs are essential for handling new types of fuels safely and efficiently. Inadequate training can lead to safety risks and operational inefficiencies (Prussi et al., 2021; Kim and Lee, 2024; Turcanu et al., 2021). Shipping companies must invest in robust training programs that equip crews with the necessary knowledge and skills. This includes understanding the unique properties of each fuel, potential hazards, and specific handling and storage requirements. Continuous education and adaptation of standard operating procedures and emergency response protocols are necessary to ensure crew safety and operational efficiency (Foretich et al., 2021; Percic et al., 2021).

In addition to addressing these immediate challenges we discussed in the first part, it is important to change the perspective of training in maritime from merely a compliance exercise (tick-the-box) to a proactive approach that builds on the competencies needed for the green transition. This involves not only updating current training programs but also fostering a culture of continuous learning and adaptation. By prioritizing the development of skills and knowledge related to alternative fuels and sustainable practices, the industry can better prepare its workforce for the -hopefully greener- future.

Conclusion

Transitioning to these alternative fuels requires addressing a range of technical, economic, regulatory, and crewing issues. Technically, we need to develop and incorporate new engine technologies and fuel systems into the fleets we have now sailing the oceans. Economically, the high start-up costs of alternative fuels and the infrastructure that follows are substantial. Meanwhile, there is the matter of coping with an incredibly complicated and evolving system of international shipping emissions regulations. It is also essential to have the necessary infrastructure in place to support the introduction of sustainable fuels. Refuelling stations in ports would be a good example.

That being said, it is clear that there are challenges for these sectors to fully integrate alternative fuels today, despite some positive signs. Public-private partnerships, government incentives, and international collaboration are key to overcoming these barriers. Innovative solutions, such as hybrid propulsion systems and modular fuel storage designs, are being developed to facilitate the transition. Furthermore, digital technologies and data analytics are being leveraged to optimize fuel use and improve operational efficiency. But all this would make no sense if the people involved in the operations of vessels using alternative fuels are not competent. Ensuring that the onboard and ashore teams are well-trained and capable of handling these new technologies is crucial for the successful integration of alternative fuels into the maritime industry.

Future research should continue to explore these areas, providing further insights and solutions to support the maritime industry's decarbonization efforts.

References:

Andersson, K., Brynolf, S., Hansson, J. & Grahn, M. (2020). Criteria and Decision Support for A Sustainable Choice of Alternative Marine Fuels, *Sustainability,* 12:3623

Bourboulis, S., Krantz, R. & Mouftier, L. (2022). Retrofitting ship engines for alternative fuels, Global Maritime Forum, Available at: https://globalmaritimeforum.org/insight/alternative-fuels-retrofitting-ship-engines/

Clarksons, 2022. Alternative fuels challenge the sustainability of maritime decarbonisation. Available at: https://www.clarksons.com/home/news-and-insights/2022/alternative-fuels-challenge-the-sustainability-of-maritime-decarbonisation/.

Curran S, Onorati A, Payri R, et al (2014). The future of ship engines: Renewable fuels and enabling technologies for decarbonization. *International Journal of Engine Research,* 25(1), 85-110.

DNV (2023). Methanol as fuel heads for the mainstream in shipping. Available at: https://www.dnv.com/expert-story/maritime-impact/Methanol-as-fuel-heads-for-the-mainstream-in-shipping/

European Commission (2023). Reducing emissions from the shipping sector. Available at: https://climate.ec.europa.eu/eu-action/transport/reducing-emissions-shipping-sector_en#:~:text=2023%20IMO%20greenhouse%20gas%20strategy&text=The%20revised%202023%20strategy%20sets,in%20the%20same%20time%20horizon.

Foretich, A., Zaimes, G. G., Hawkins, T. R., & Newes, E. (2021). Challenges and opportunities for alternative fuels in the maritime sector. *Maritime Transport Research*, 2:100033.

Heine, D., Semmler, W., Mazzucato, M., Braga, J.P., Flaherty, M., Gevorkyan, A., Hayde, E & Radpour, S., (2019), Financing Low-Carbon Transitions through Carbon Pricing and Green Bonds, *Policy Research Working Paper*, 8991, World Bank Group

Hellenic Shipping News, 2023. New fuels, new challenges. Available at: https://www.hellenicshippingnews.com/new-fuels-new-challenges/.

Hoffmann, J., Asariotis, R., Assaf, M. & Benamara, H. (2018) *UNCTAD review of maritime transport*. UNCTAD

Hyungju K., Kwi Y. K. & Tae-Hwan J. (2020) A study on the necessity of integrated evaluation of alternative marine fuels, *Journal of International Maritime Safety, Environmental Affairs, and Shipping*, 4(2), 26-31

Karvounis, P., Tsoumpris, C., Boulougouris, E. & Theotokatos, G. (2022). Recent advances in sustainable and safe marine engine operation with alternative fuels. *Frontiers in Mechanical Engineering*, 8:994942.

Lewis, I. & Eason, C. (2024), Shipping facing $1.46bn in penalties from next European carbon emission crackdown, Available at: https://www.tradewindsnews.com/containers/shipping-facing-1-46bn-in-penalties-from-next-european-carbon-emission-crackdown/2-1-1674865

Lloyd's Register (2023). The Future of Maritime Fuels. Available at: https://www.lr.org/en/knowledge/research-reports/the-future-of-maritime-fuels/

Lloyd's Register, (2023). EU carbon pricing brings new pressures and new plays to maritime. Available at: https://www.lr.org/en/knowledge/technical-articles/eu-carbon-pricing-brings-new-pressures-and-new-plays-to-maritime/

Makitie, et al. (2022). Norwegian ship-owners' adoption of alternative fuels. *Energy Policy*, 163: 112869.

Marine Log, 2023. Marine engine design and the future fuels challenge. Available at: https://www.marinelog.com/shipbuilding/engines-fuel/marine-engine-design-and-the-future-fuels-challenge/

Maritime Professionals, 2023. The potential of alternative fuels in the shipping industry. Available at: https://maritime-professionals.com/the-potential-of-alternative-fuels-in-the-shipping-industry/.

Percic, M., Vladimir, N. & Fan, A. (2021). Techno-economic assessment of alternative marine fuels for inland shipping in Croatia. Renewable and Sustainable Energy Reviews, 148: 111363

Prussi, M., Scarlat, N., Acciaro, M., & Kosmas, V. (2021). Potential and limiting factors in the use of alternative fuels in the European maritime sector. *Journal of Cleaner Production*, 291: 125849

Safety4Sea (2022). 10 things to know about alternative fuels in shipping, Available at: https://safety4sea.com/10-things-to-know-about-alternative-fuels-in-shipping/

SeaTrade Maritime (2023). Maersk methanol orderbook hits 25 vessels. Available at: https://www.seatrade-maritime.com/containers/maersk-methanol-orderbook-hits-25-vessels

Together in Safety (2022), *Future Fuels Risk Assessment,* Available at: https://togetherinsafety.info/wp-content/uploads/2022/06/Future-Fuels-Report.pdf

Turcanu, A.L., Gasparotti, C. & Rusu, E. (2021). Green fuels—A new challenge for marine industry, *Energy Reports*, 5, 127-132

Wang, Y., & Wright, L. A. (2021). A Comparative Review of Alternative Fuels for the Maritime Sector: Economic, Technology, and Policy Challenges for Clean Energy Implementation. *World*, 2(4), 456-481.

Wartsila (2024). LNG as fuel for ships: expert answers to 17 important questions. Available at: https://www.wartsila.com/insights/article/lng-fuel-for-thought-in-our-deep-dive-q-a

Wong, A. Selin, N., Eastham, S., et al., (2024). Climate and air quality impact of using ammonia as an alternative shipping fuel, *Environmental Research Letters,* 19:084002