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ALTERNATIVE FUELS – THE COMLEX PATH TO SUSTAINABLE SHIPPING [3]

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Abstract: The maritime industry is the backbone of global trade, transporting around 90% of world cargo, but at same time it also contributes approximately 3% of global greenhouse gas emissions, mainly due to its reliance on fossil-based marine fuels. With growing international pressure to reduce emissions and slow the effects of global warming and climate change, the maritime industry is stepping up its decarbonization efforts. One of the main areas of work is the replacement of conventional fuels with more environmentally friendly alternatives. This study examines the potential reducing emissions and improved sustainability which the transition toward alternative fuels can lead, as well as the difficulties and challenges along the way.

Keywords: Shipping future, sustainability, environment protection, alternative fuels.

INTRODUCTION

In UNSTAD review of maritime transport 2025 was confirmed that the growth of trade volumes, transported by sea continued through 2024 exceeding the 2013-2023 average with 2,2%. A same time it is found that the global fleet continues to age despite new ship deliveries and orders. Weighted by gross tonnage, the global fleet was, on average, 12.6 years old in 2024, a 3.2 % increase over 2023. By vessel count, the fleet was 22.2 years old or 1.8 % older than a year earlier. These two facts contributed carbon emissions from shipping to increase by an estimated 5 per cent in 2024 over 2023, additionally driven by continued ship rerouting and increased speeds. In the first half of 2025, a reduction in emissions was observed, probably reflecting slower sailing speeds, some operational improvements and the deployment of new ships. (UNCTAD, 2025).

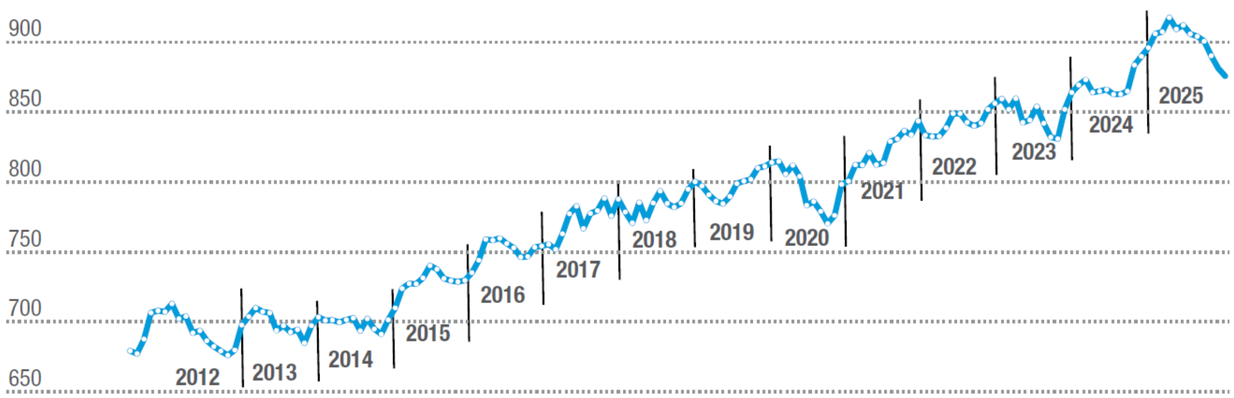

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Fig. 1. Monthly annualized carbon dioxide emissions (millions of tons). *Source:* UNCTAD calculations, based on AIS data from Marine Benchmark, 2025.

At the same time, the regulatory push for decarbonizing shipping continues. Although shipping's quest for decarbonization is expected to be long and difficult, goals have been set, and the journey has begun. At Marine Environment Protection Committee (MEPC) 80th session in June 2023, the International Maritime Organization (IMO) agreed on a set of ambitious targets, including full decarbonization around 2050. Delegates also agreed to stepped targets along the way: a 20% reduction in emissions by 2030, and a 70% reduction by 2040, compared in each case with emissions in 2008. At its 83rd session in April 2025 the MEPC approved new midterm greenhouse gas reduction measures, including Net-Zero Framework (NZF) which will be included as a new Chapter 5 in Annex VI to the International Convention for the Prevention of Pollution from Ships (MARPOL Convention). The measures combine mandatory fuel intensity limits and a greenhouse gas pricing mechanism. The agreed plan centers on a fee of $380 per tonne of CO2 for exceeding a maximum level of emissions intensity, plus another $100 per tonne for exceeding a baseline level; this marginal tax structure is expected to raise the cost of operations and incentivize uptake of green ships. These measures will be considered for adoption at an extraordinary session of the Committee in the end of October 2025 before entering into force in March 2027, with a 1 January 2028 date of implementation. While it is too early to assess the outcomes, the new measures would likely help to increase the supply of alternative fuels and lower their prices, both of which remain key hurdles to uptake. Revenues to be collected would provide rewards to ships for greenhouse gas emissions avoided by using zero- or near-zero emissions energy sources.

In the EU, apart from the targets, the impact of non-compliance has also been defined. In 2024, the EU's Emissions Trading Scheme (ETS) was extended to shipping, putting a price on carbon emissions. In 2025, this has been followed by the EU's FuelEU Maritime regulation, which will set well-to-wake greenhouse gas (GHG) emission intensity requirements on energy used on board vessels over 5,000 GT trading in the EU, with financial penalties for non-compliance.

EXPOSITION

Alternative Fuels Basics

Energy-efficiency measures are the backbone of shipping's decarbonization journey. And essential part of this journey is using alternative fuels, instead of fossil ones (Atanasov, Dimitrakieva, 2019). Despite that waterborne transport (including inland waterways) is generally considered energy efficient, when compared to road transport and aviation and when GHG emissions are used as metric, the use of Heavy Fuel Oil (HFO) (which is considered as a low-quality grade fuel) resulted in high pollutant emissions (e.g., CO2, SOx, NOx), and consequently high environmental impacts (M. Prussi et al., 2021; Dimitrakiev, Dachev, Milev, 2020)

With a few exceptions, the shipping sector currently relies on internal combustion engines (ICE), supplied with petroleum-derived fuels. If this propulsion technology continues to dominate the sector, different alternative fuel types could be used as a tool towards decarbonisation because the liquid fuels are expected to be the main source of energy in the global maritime transport in the nearest future. Together with energy efficiency improvements, operational and technical optimisation (hull design, vessel size, engines and routing optimisation), alternative fuels can play a crucial role in decarbonization of the shipping sector (Velinov, 2024). Using alternative fuel for marine diesel engines is one of the new and prospective methods to reduce shipboard emissions (Bakalova, 2023). And while the inland and short-sea maritime transport could rely on battery-powered electric propulsion or hydrogen because of better opportunity for charging, the long-distance ocean ships' option of green operation are only alternative fuels, such as ammonia or methanol.

The Spectrum of Alternative Fuels

A variety of alternative fuels are currently under development and practically testing, each with distinct advantages and significant challenges:

Liquefied Natural Gas (LNG). LNG is the most established alternative fuel in the market today. It emits significantly fewer particulates, NOx, and SOx than HFO and offers modest GHG reductions.

However, LNG is still a fossil fuel, and concerns about methane slip (unburned methane released into the atmosphere) can reduce its climate benefits and potent greenhouse gas cast doubt on its long-term sustainability.

Methanol and Bio-Methanol. Methanol can be produced from natural gas (grey methanol), biomass (bio-methanol), or captured CO_2 and green hydrogen (e-methanol). It is easy to store and handle, and some ships are already running on methanol blends. However, widespread use of green or bio-methanol requires scalable production, which is currently limited.

Ammonia. Ammonia is gaining attention as a zero-carbon fuel when produced using green hydrogen. It contains no carbon, so it doesn't emit CO_2 during combustion. Yet it is highly toxic and challenging to handle. Moreover, its production is energy-intensive and depends heavily on renewable electricity to be truly sustainable.

Hydrogen. Green hydrogen, derived from electrolysis powered by renewables, is the cleanest option on paper. However, storing and handling hydrogen is technically complex due to its low energy density and flammability. Current hydrogen-powered ship designs remain largely experimental, and the infrastructure needed to support them is virtually non-existent at a global scale.

Biofuels. Derived from organic materials, biofuels are compatible with existing engines, making them a drop-in solution. But questions remain about their sustainability, especially when feedstock competes with food production or leads to deforestation.

Challenges

The main challenge to the mass introduction of alternative fuels in the maritime industry is the low levels of their production and, accordingly, their shortage. According to a study by DNV study, in 2023, the total global energy consumption was approximately 10,600 Mtoe (Million Tonnes of Oil Equivalent) where transport and industry accounted for about 65% of this demand.

With the maritime industry accelerating its transition towards decarbonization, the competition for low-GHG fuels is intensifying across multiple industries. Achieving net-zero emissions will require substantial access to renewable electricity (for fossil with CCS), but maritime is not the only industry vying for these resources. Maritime transport accounts for roughly 11% of total transport energy demand or about 3% of total global energy demand (Koritarov, Dimitrakiev, 2024).

The total estimated global production of low-GHG fuels, including an estimate of each main fuel type up to 2032, is shown in Figure 2.

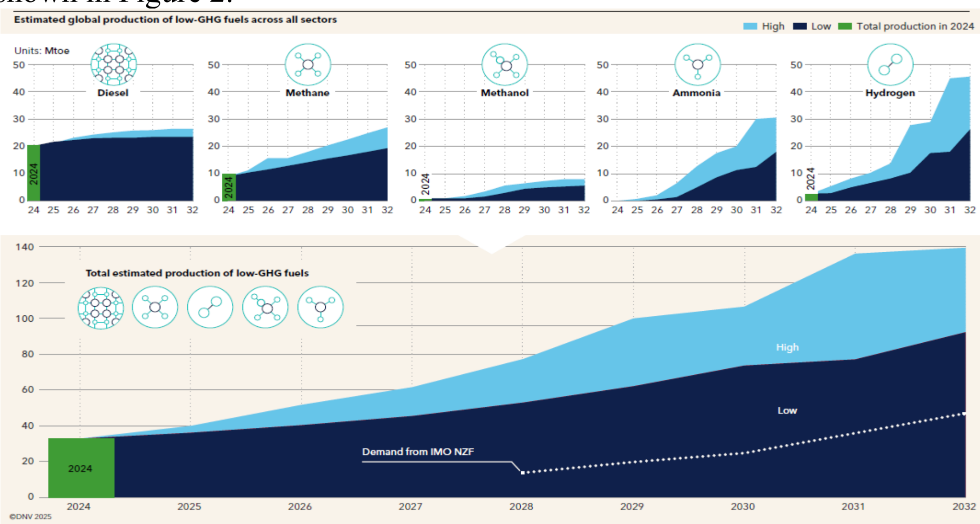

Fig. 2. Estimated global production of low-GHG fuels across all sectors

These high and low estimates are based on the current production capacity including a probability adjusted estimated production capacity, based on the status of all projects in the project pipeline meeting the sustainability criteria set by the EU in the second Renewable Energy Directive RED II. Estimated demand for low-GHG fuels from shipping due to the IMO's Net-Zero Framework is also included. (DNV, 2025). The global availability (which means usage popularity worldwide) is a serious challenge to widespread using of alternative fuels. Due to bunker capability and more space is required than HFO or MDO for storage of methanol or ethanol, only there are few ferry companies which modified their ships engine for methanol fuel. On the other hand, methanol and ethanol usage in diesel engines is a new technology, and this also affects its use on ships. LNG as well requires two times more storage area than HFO, but it is trend nowadays, and bunkering areas are increasing. The availability affects the bunker capabilities as well, because they are related. If more ships demand to use a certain fuel type, bunker capability for that fuel type will be high. Use of methanol and ethanol in ships are limited, and this affects the bunker capability. On the other side, LNG use is rising, and it affects bunkering of LNG. Although LNG bunker capability develops, it is not enough for global supply network. (Deniz C., Zincir B. 2015).

Another challenge is the differences between NZF and FuelEU Maritime. In addition to the NZF requirements, ships that also fall under the scope of the EU ETS and FuelEU Maritime will have to continue to adhere to these regulations before a potential alignment with the NZF. These ships will then have to both surrender emission allowances for the EU ETS and will have to potentially pay a penalty under FuelEU Maritime in case of undercompliance. FuelEU Maritime applies a similar metric and mechanism to the NZF. However, an important aspect to note is that the default emission factors and reference values are not the same in the NZF and FuelEU Maritime, meaning that it is difficult to compare the trajectories based on the reduction factors only. In Figure 3 there is a comparison of the stringency by showing the share of low-GHG fuels, as a percentage of total energy used, needed to meet the IMO NZF Base target and FuelEU Maritime requirements, shown in 2030 and 2035 for a conventional MGO-fuelled vessel, and an LNG-fuelled vessel with a low methane slip – having a default factor of 0.2% under FuelEU and 0.15% under NZF – and using 5% MGO as pilot fuel. (DNV, 2025).

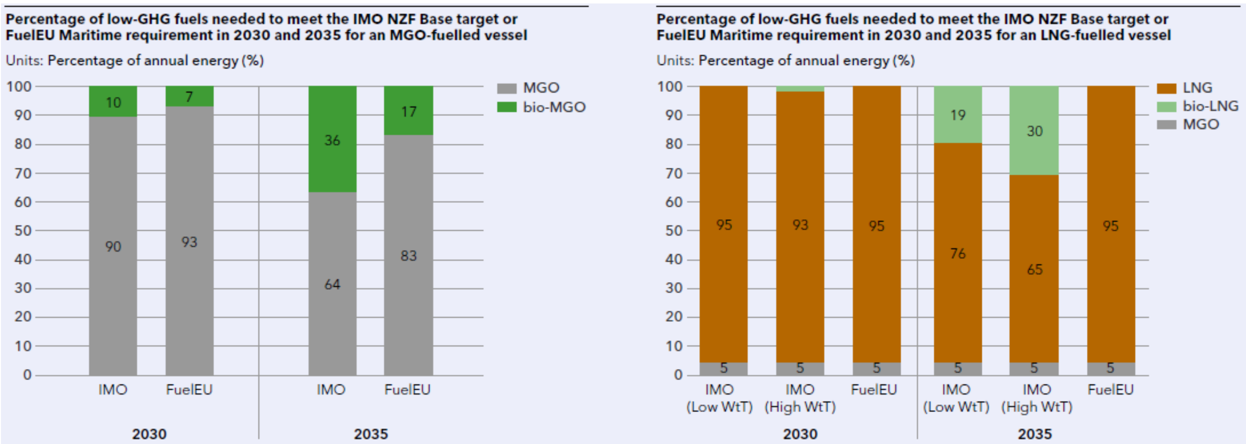

Fig. 3. Comparison of the NZF requirements with FuelEU Maritime

Adaptability of alternative fuel systems to new building ships is more feasible, however it is difficult to apply new systems to existing ships, due to inadequate space, and required modifications on main engine. Methanol and ethanol fuel systems need additional fuel tanks, or conversion of existing ballast tanks onboard to fuel tanks. Space is required for separate rooms of transfer pumps, and high-pressure pumps. LNG fueled ships need special designed LNG tanks as well as tank connection space for conditioning LNG in the tank, and provide the delivery of LNG to the main engine. Also, they need gas ventilation space, double wall gas piping, specially protected bunker stations, separation of main engine from engine room by walls and gas safe machinery space. Such adaptation to existing ships leads to significant investment, which certainly is a great challenge too.

It is important to evaluate the effect of alternative fuels on engine combustion chamber components, because repair and maintenance intervals are shortened, and spare part expenses are increased with the negative effect. Fuel effect on engine components is related with calorific value and elementary composition of the fuels. Methanol and ethanol have nearly half of the net heating value of diesel fuel, however methanol deteriorates lubricating oil structure and increase viscosity. Ethanol has close structure with methanol, and also it has negative effect on lubricating oil. Their use on a diesel engine reduce life time of exhaust valves and seats, piston ring, and liner wear may occur due to inadequate lubrication. LNG has close net heating value to diesel fuel, composes around same level of heat release, so it does not affect engine combustion chamber components negatively. Hydrogen has three times bigger net heating value than diesel fuel, and has high flame speed. These properties of hydrogen provide quick heat release rate in combustion chamber, and shorten the life time of the combustion chamber components. There has not been any comparative research about these fuels effect on engine combustion chamber components, so it is impossible to estimate and evaluate it. (Deniz C., Zincir B. 2015).

The last, but not the least, as the maritime industry shifts towards low-GHG fuels, ensuring safety during this transition is paramount. With the IMO targeting net-zero greenhouse gas emissions by 2050, both LNG and methanol derived from fossil sources are expected to serve primarily as transitional fuels, requiring a further shift to low or zero GHG alternatives. To support this transition, it is essential that considerations for future fuel flexibility are embedded from the design and newbuilding phase. Risk mitigation measures for liquefied gases such as hydrogen and ammonia typically include physical barriers between fuel storage, processing, and pumping equipment, and, to the extent possible, maintaining a distance from crew accommodation and workspaces. Detection systems for hazards such as gas leakages and fire are crucial safeguards to implement in relevant locations, enabling early warnings and the initiation of mitigating measures in case of occurrence. From a safety and design perspective, enabling a future switch from conventional fossil fuels to biofuel involves practical and operational risks that need to be addressed to ensure compatibility of fuel systems with varying purity levels or slight differences in properties resulting from various production processes (for some biofuels there may be a need for additional training of crew with regard to handling). As the industry looks towards fuels such as ammonia, hydrogen, and green methanol, safety must remain a top priority due to their unique risk profiles - ammonia's toxicity, hydrogen's flammability and dispersion behaviour as well as its properties in both liquefied and compressed state, and methanol's low flash point and near-invisible flame. Hydrogen is prone to leakage and can cause severe explosions when escaping. When stored in liquid form at ultra-low temperature of -253°C, it requires sophisticated vacuum-insulated pressure tanks that must meet even stricter requirements than LNG tanks. Interaction of liquefied hydrogen with air or other gases harbours additional safety risks that must be considered in the design of storage and processing systems. (DNV, 2025)

CONCLUSION

The compromise carbon agreement, agreed at MEPC's 83rd meeting, to tax excess greenhouse gas emissions lately was opposed by USA. The Trump administration has pledged to fight the proposal and retaliate against any nations that vote for it. In an updated position statement, the U.S. State Department noted that MEPC's framework is a "global carbon tax," and made it clear that the administration will not accept it. On another side, a group of shipping companies, representing more than 1,200 vessels, warned that the IMO's planned net zero rules risk imposing significant costs on the industry (Koritarov, Dimitrakieva, 2024). They claimed that the sector faces paying about \$20 billion to \$30 billion a year by 2030, shippers representing more than 1,200 vessels said in a statement dated Thursday. The amount could accumulate to more than \$300 billion by 2035 if the global fleet misses targets by as little as 10%. This view is also supported by ABS Chairman and CEO Christopher J. Wiernicki who has called for the IMO to pause and reconsider its Net Zero Framework, highlighting significant concerns about implementation feasibility. (https://gcaptain.com)

The concerns of the shipping sector regarding the successful implementation of also reflect on the construction of new ships. Uncertainties around the IMO's Net-Zero Framework, including lifecycle assessment factors for certain fuels, are prompting many owners to adopt a 'wait and see' approach to new orders. It is, therefore, essential that the industry receives greater regulatory clarity in the coming months. According to data from DNV's Alternative Fuels Insight (AFI) platform September 2025 saw just 14 orders for alternative-fuelled vessels. Of these, 12 were LNG-fuelled vessels, primarily from the container segment (6), with additional orders from bulk carrier (4) and cruise (2) segments. The remaining two orders were for LPG carriers. The first nine months of 2025 have recorded 192 new orders for alternative-fuelled vessels, marking a significant 48% decline compared to the same period in 2024. LNG remains the dominant alternative fuel choice with 121 orders, followed by methanol (43), LPG carriers (19), ammonia (5), and hydrogen (4). (https://www.dnv.com)

Although there are already serious developments and experimental use of renewable energy sources as alternative fuels, in practice fossil fuels are still in a dominant position in shipping. Given the diversity of maritime routes, the different types of ships with different propulsion systems, and the different profiles and capabilities of ship-owning and operating companies, it is unlikely that there will be a universal solution for the fuels used (Dimitrakiev, Koritarov, Velinov, 2025). The future of shipping may be mixed fuels, with different fuel systems serving different niches in the maritime industry.

REFERENCES

Atanasov R., Dimitrakieva Sv. (2019). CRITERIA AND ALGORITHM FOR THE IMPLEMENTATION OF THE SHIP ENERGY EFFICIENCY PLAN (SEEMP). Proceedings of the Maritime Scientific Conference, October 2019, ISBN 978-619-7428-46-9 (print), ISBN 978-619-7428-47-6 (online), p. 7-18 *(Оригинално заглавие: Росен Т. Атанасов, Светлана Р. Димитракиева, „Критерии и алгоритъм за реализация на плана за енергийната ефективност на кораба (SEEMP)", Сборник с доклади от Морска научна конференция, ISBN 978-619-7428-46-9, 2019, p. 7 – 18)*

Bakalova, R., *METHOD FOR EVALUATION THE ECONOMIC EFFICIENCY DUE TO THE USE OF COMPOUND MARINE DIESEL FUELS, NAŠE MORE 2023*, 3rd International Conference of Maritime Science & Technology, Dubrovnik, Croatia, 14 – 16 September 2023, p. 10-17, ISBN 978-953-7153-71-7

Bakalova, R., Feasibility and economic effectiveness in experimental-statistical research of marine diesel fuels, *Steno Publishing House*, Year of issue: 2023, ISBN: 978-619-241-286-9

Dimitrakiev D., Dachev Y., Milev D., Impact Of The Dispersants On The Marine Environment, *INTERNATIONAL JOURNAL OF SCIENTIFIC & TECHNOLOGY RESEARCH VOLUME 9, ISSUE 02, FEBRUARY, 2020, ISSN 2277-8616*

Dimitrakiev, D., Koritarov T., Velinov S.. Liability of maritime and inland waterway carriers and carrier identification in different contractual relations. *German International Journal of Modern Science, 2025*, issue 101, pages 46–52, ISSN 2701-8369 (Print), ISSN 2701-8377 (Online). Available from: https://doi.org/10.5281/zenodo.15119331

Deniz C., Zincir B. (2015). Environmental and economical assessment of alternative marine fuels. *Journal of Cleaner Production* 113 (2016) 438e449.

Det Norske Veritas (DNV). (2025). *Switching safely to low-carbon fuels and technologies*. Available at https://www.dnv.com/expert-story/maritime-impact/switching-safely-to-low-ghg-fuels-and-technologies/

Det Norske Veritas (DNV). (2025) *Maritime Forecast to 2050*. Available at https://www.dnv.com/maritime/maritime-forecast/

DNV (2025). *Alternative Fuels Insight (AFI).* Available at: https://www.dnv.com/services/alternative-fuels-insights/ (Accessed on 01.10.2025).

Koritarov T., Dimitrakiev D. (2024). THE IMPACT OF DIGITALIZATION ON SMART PORTS: ENHANCING EFFICIENCY, SUSTAINABILITY, AND COMPETITIVENESS IN THE MARITIME INDUSTRY. *The scientific heritage*, Issue 152, pages 28–33, ISSN 9215-0365,

DOI: https://doi.org/10.5281/zenodo.14603507

Koritarov T., Dimitrakieva S. (2024). NAVIGATING COMPLEXITY: STAKEHOLDERS ANALYSIS AND COMMUNICATION STRATEGIES IN THE MARITIME INDUSTRY. *Deutsche Internationale Zeitschrift Für Zeitgenössische Wissenschaft / German International Journal of Modern Science*, Issue 95, pages 73-78, ISSN (Print) 2701-8369, ISSN (Online) 2701-8377, DOI: https://doi.org/10.5281/zenodo.14609717

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

Schuler M. (2025). *Safety Must Lead Shipping's Transition*. gCaptain. Available at: https://gcaptain.com (Accessed on 15.09.2025).

UNCTAD (2025). *Review of Maritime Transport 2025*. United Nations Publications, New York. eISBN: 978-92-1-159177-4.

Velinov, S. (2024). Decarbonization of maritime industry. *Морско право и индустрия, ВСУ "Черноризец Храбър"*, брой 2, с. 183-191. ISSN: 2815-5130