# Investigation of Alternative Fuel Pathways in Shipping following IMO guidelines

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## Introduction

International climate policies put increasing pressure on maritime shipping to align with the energy transition regulations. ~96% of bunker fuels are made of marine diesel oil, heavy fuel oil, or marine gas oil, which produce as much as 3.114 kg $CO_2$/fuel kg [1].

The aim of the research is to compare alternative and conventional fuels for cargo ships, as this serves as a crucial indicator of the maritime sector's technical readiness for energy transition. The study will also assess how adopting alternative fuels impacts key IMO energy-efficiency and carbon-intensity indicators.

## IMO energy efficiency and carbon intensity regulations

Shipping was responsible for roughly 2.89% of global $CO_2$ emissions (IMO in 2018) [2]. The IMO's decarbonization framework is based on the EEDI and the EEXI for technical efficiency (g$CO_2$/tonne-mile), and the CII for operational performance, supported by the SEEMP and the IMO DCS. IMO GHG strategies target at least a 40% reduction in carbon intensity by 2030 and net-zero emissions by 2050, while increasingly incorporating Well-to-Wake assessment and fuel standards to support the transition to low- and zero-carbon marine fuels [2] (Fig. 1).

## Technical comparison of Hydrogen, Ammonia and Methanol

Adopting alternative fuels is based on availability, fuel characteristics such as energy density, ease of transport, ease of storage, safety during handling safety, regulation, environmental footprint, technological maturity, and economic considerations. Options such as LNG, $CH_3OH$, $H_2$, and $NH_3$ require ship engine retrofits, new supply chains, upgraded bunkering and storage systems, and revised safety standards [3]. The transition extends beyond ship design to broader economic and regulatory adjustments that enable large-scale, secure deployment of these fuels and assessment of technical feasibility and sustainability [1].

| Hydrogen | |
|---|---|
| **Advantages** | **Challenges** |
| Zero carbon and sulfur emissions | High production cost |
| Can be stored as liquid or gas | Limited green $H_2$ availability |
| Compatible with fuel cells and internal combustion engines | Infrastructure and bunkering requirements |
| | Cryogenic/high-pressure storage challenges |
| | Material compatibility and explosion risks |
| **Ammonia** | |
| **Advantages** | **Challenges** |
| Carbon-free combustion potential | Low efficiency |
| Suitable for fuel cells and internal combustion engines | Large storage volume requirements |
| Existing production and transport infrastructure | Engine redesign and $NO_x$ mitigation needed |
| | Fuel cell integration and onboard thermal management |
| **Methanol** | |
| **Advantages** | **Challenges** |
| Easier fuel handling than LNG | Limited availability of renewable methanol |
| Low $NO_x$ and $SO_x$ emissions | Flammability and toxicity |
| Compatible with existing infrastructure | Low volumetric energy density |
| Works with dual-fuel engines | Fossil-based methanol may have similar life-cycle emissions to marine diesel oil |

## Data Based Comparison

***IMO Data Collection System***

LNG shows a steady increase as a transitional fuel (reaching 12.89 million tonnes in 2023), while $CH_3OH$ demonstrates rapid relative growth (93,876 tns in 2023 vs. 35,523 tns in 2022) and the lowest carbon conversion factor among reported fuels, indicating strong decarbonization potential. However, $H_2$ and $NH_3$ remain absent from reported consumption data, reflecting their early-stage deployment in global shipping [4].

***MSSO Pre-feasibility calculator***

The MSSO pre-feasibility calculator enabled the development of structured route scenarios, allowing users to input route characteristics, ship specifications, operational profiles, and fuel configurations, thereby generating detailed estimates of fuel and energy requirements for alternative fuels [5]. A viable comparison was performed among LNG, $CH_3OH$, $H_2$, and $NH_3$ regarding differences in fuel consumption (Fig.2) [5].

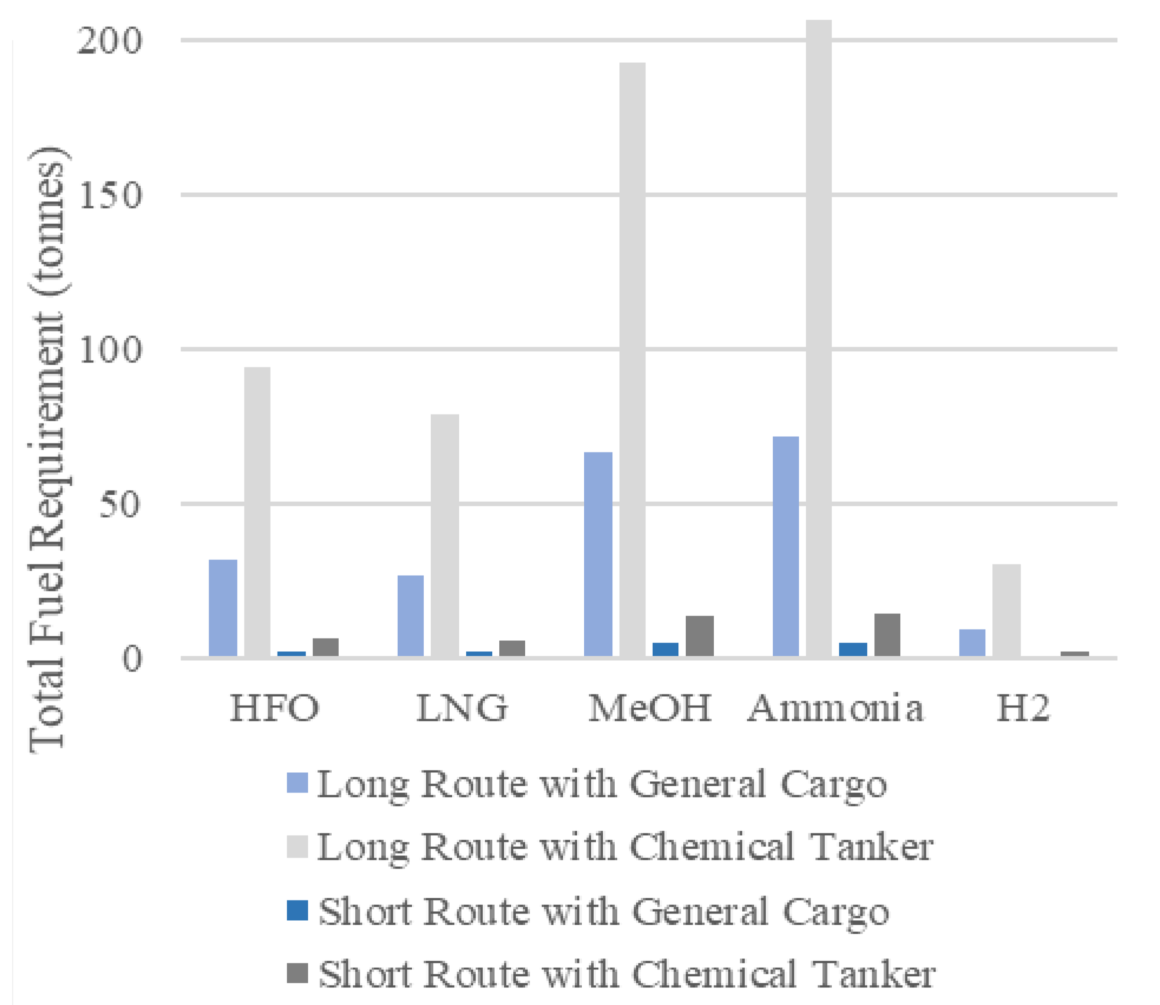


**Fig. 2** Total fuel requirements for scenarios

## Conclusions & Future Research

- The impact of alternative fuels on IMO decarbonization indices to be assessed using IMO DCS data, ship specifications, operational datasets, and real-world case studies.
- Commercial or commercial-ready vessels using $CH_3OH$, $H_2$, and $NH_3$ will be analyzed.
- The MSSO pre-feasibility calculator was used to create route scenarios based on ship characteristics, operational profiles, and fuel configurations.
- The study compares LNG, $CH_3OH$, $H_2$, and $NH_3$ in terms of fuel consumption, operational requirements, and overall maritime feasibility.

LIST OF ABBREVIATIONS

*CII – Carbon Intensity Indicator*
*EEDI – Energy Efficiency Design Index*
*EEXI – Energy Efficiency Existing Ship Index*
*GHG – Greenhouse gas*
*IMO – International Maritime Organisation*
*MSSO – Mediterranean Sustainable Shipping Observatory*
*SEEMP –Ship Energy Efficiency Management Plan*

## References

[1] Y. Wang, L. A. Wright. A comparative review of alternative fuels for the maritime sector: Economic, technology, and policy challenges for clean energy implementation. World 2(4), 456-481 (2021).

[2] International Maritime Organization. 2023 IMO strategy on reduction of GHG emissions from ships (Resolution MEPC.377(80)). London (2023).

[3] H. Lee, J. Lee, G. Roh, S. Lee, C. Choung, H. Kang. Comparative life cycle assessments and economic analyses of alternative marine fuels: Insights for practical strategies. Sustainability 16(5), 2114 (2024).

[4] International Maritime Organization. Report of fuel oil consumption data submitted to the IMO Ship Fuel Oil Consumption Database in GISIS (Reporting year: 2023), MEPC 82/6/38. London (2024).

[5] Maritime Risk Group. GreenMed Dashboard, MSSO–Maritime Safety & Security Observatory, https://msso.maritimeriskgroup.edu.gr/greenmed/dashboard/

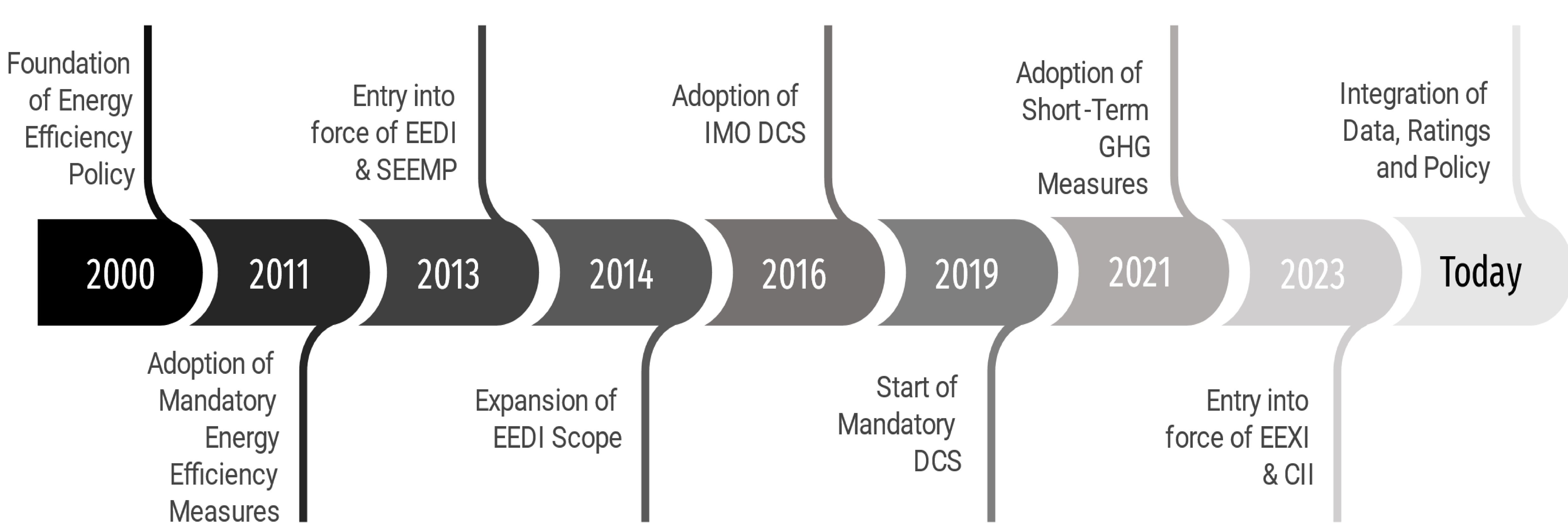


**Fig. 1.** Timeline of IMO Energy Efficiency and Carbon Intensity Regulations in International Shipping.