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REDUCTION OF GHG EMISSIONS FROM SHIPS

Cost-effective pathways to reach net zero by 2050 for the international shipping sector: fuel transition outlook and policy implications

Submitted by Pacific Environment

SUMMARY

Executive summary: This document outlines key recommendations for fuel transitions in achieving net-zero greenhouse gas (GHG) emissions in the international shipping sector by 2050, emphasizing cost-effective strategies and evidence-based policymaking. The recommendations include: 1) implementing financial support measures to incentivize early consumption of e-fuels, 2) internalizing the price of carbon within the fuel price of conventional fuels and 3) setting higher interim targets to ensure the international shipping sector remains on track to reach net-zero emissions by 2050. To support these recommendations, a cost optimization model was employed to analyse the maritime fuel consumption, fuel costs and the shadow price of carbon in multiple scenarios. Comparative analysis of the results offers actionable insights to guide policy formulation and investment strategies critical to meeting the sector's decarbonization goals.

Strategic direction, if applicable: 3

Output: 3.2

Action to be taken: Paragraph 15

Related document: MEPC 82/17

Introduction

1 The International Maritime Organization has established a target to achieve net zero by 2050, with interim targets of a 20% to 30% reduction by 2030 and 70% to 80% reduction by 2040, and net-zero GHG emissions by or around, i.e. close to, 2050. These ambitious goals require comprehensive and cost-effective strategies across various sectors of the industry, including fuel transition, operational measures and policy support.

2 Identifying cost-effective multi-fuel transition pathways and optimal carbon pricing is necessary to achieve net-zero GHG emissions by 2050 in the international shipping sector. A dynamic optimization model was developed to evaluate abatement costs, defined as the average cost of reducing a ton of CO₂ under a binding emission constraint, for various decarbonization pathways to achieve the IMO's net-zero target. Based on the modelling results, this document offers insights into the fuel transition pathway and implications for climate policy to inform policymakers and investors.

3 Under a set of constraints, the model provides fuel transition pathways, associated costs and shadow price of carbon for various scenarios (the shadow price of carbon represents the abatement cost of reducing one additional unit of CO₂ emissions under a binding emissions constraint), including baseline scenario (BASE) that assumes the use of all fossil fuels and alternatives:

- .1 reference scenario (REF) prioritizes electrified fuels such as e-hydrogen and e-ammonia;
- .2 low-cost e-fuel scenario (Lo-E) assumes a deeper reduction in e-fuel costs;
- .3 high fossil fuel cost scenario (Hi-FF) assumes higher fossil fuel costs;
- .4 deeper emission reduction target scenario (DEEP) assumes a more ambitious reduction target;
- .5 early adaptation scenario (EARL) assumes the earlier introduction of e-methanol; and
- .6 efficiency improvement scenario (EI) is a scenario where efficiency regulations are in place without any other intervention.

4 The primary source of input data is the IMO's Global Integrated Shipping Information System (GISIS) database. The data covers fuel consumption of vessels above 5,000 gross tonnage (93% of reported tonnage under MARPOL Annex VI) from 2019 to 2021. Historical fossil fuel price data and alternative fuel cost projections were adopted from Longva et al. (2024) and converted to USD/tonne.

Results

5 A comparative scenario analysis of abatement cost optimization consistently highlights two key trends across all scenarios (table 1). First, fuel costs exhibit an overall upward trajectory throughout the transition, driven by the adoption of advanced alternative fuels and increasing regulatory measures. However, the extent of this increase varies by scenario, with pathways incorporating subsidies (Lo-E) and efficiency measures (EI) showing a slower rise compared to others. Second, abatement costs per ton of CO₂ follow a contrasting trend, starting relatively high in the early stages but decreasing significantly over time. This reduction is primarily due to advancements in alternative technologies, improved market maturity of e-fuels, and the achievement of economies of scale. By 2035, all scenarios (excluding BASE) show abatement costs declining by more than 50% from their initial levels. In scenarios like Lo-E and DEEP, abatement costs even turn negative in later stages, reflecting the combined effect of cost moderation and significant emission reductions as the market evolves.

6 Reducing costs of e-fuels (Lo-E) through subsidies has demonstrated significantly greater effectiveness in facilitating decarbonization compared to imposing penalties on fossil fuel consumption (Hi-FF). Both scenarios achieve lower abatement costs than the REF scenario. The Lo-E scenario shows a steady decrease in abatement costs from 294 USD/tCO₂ in 2030 to -26 USD/tCO₂ by 2050. In contrast, the Hi-FF scenario maintains higher abatement costs, starting at 495 USD/tCO₂ in 2030 and reducing to -204 USD/tCO₂ by 2050. The Lo-E and EI scenarios demonstrate superior cost containment, limiting abatement costs compared to other scenarios, which experience slower cost reductions. Note that a negative abatement cost indicates that the total cost peaks before 2050.

Table 1: 5-year average abatement cost (Δ Emissions / Δ Total Cost) curve by scenarios (USD/tCO₂)

Year	BASE	REF	Lo-E	Hi-FF	DEEP	EARL	EI
2030	224	349	294	495	421	385	120
2035	223	343	246	402	320	305	318
2040	254	277	139	258	257	219	235
2045	302	250	70	103	111	339	202
2050	384	120	-26	-204	-12	136	81

7 Adopting deeper emission reduction targets (DEEP) can lead to a cost benefit in the later stage (after 2040) compared to the Hi-FF scenario. Setting a deeper reduction target (DEEP) can reduce the peak fuel cost compared to the Hi-FF scenario, while reducing about 15% additional greenhouse gas emissions between 2025 and 2050.

8 Due to the technical challenges and slower market acceptance of hydrogen-based fuels such as liquefied hydrogen and ammonia, the EARL scenario adopts e-methanol as a transition fuel to bridge the gap between fossil fuels and hydrogen-based alternatives. E-methanol offers notable benefits, including easier handling, compatibility with existing global infrastructure and lower storage and transport costs, making it a practical and cost-effective interim solution. This scenario results in a modest 3.8% increase in total fuel costs compared to the REF scenario between 2025 and 2050.

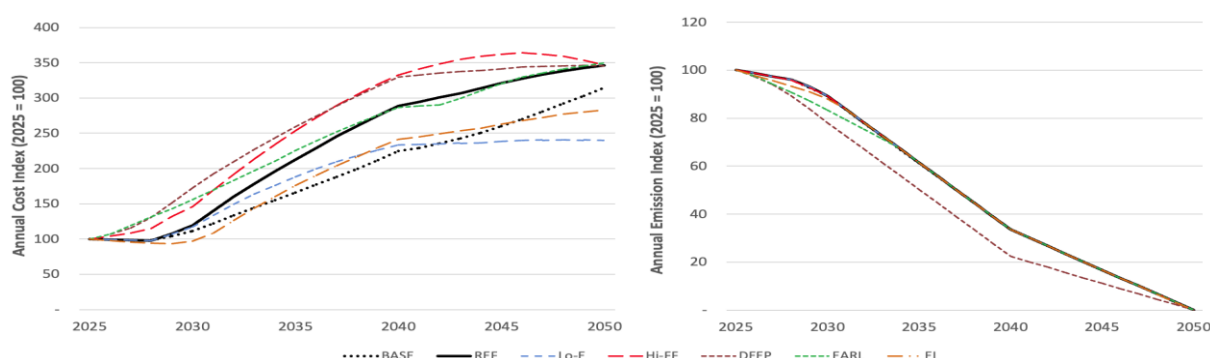


Figure 1: annual fuel cost index (left) and annual emission index (right) (2025 = 100)¹

¹ Source: SFOC. Note that fuels contributing less than 0.01% of the total energy have been excluded from the research.

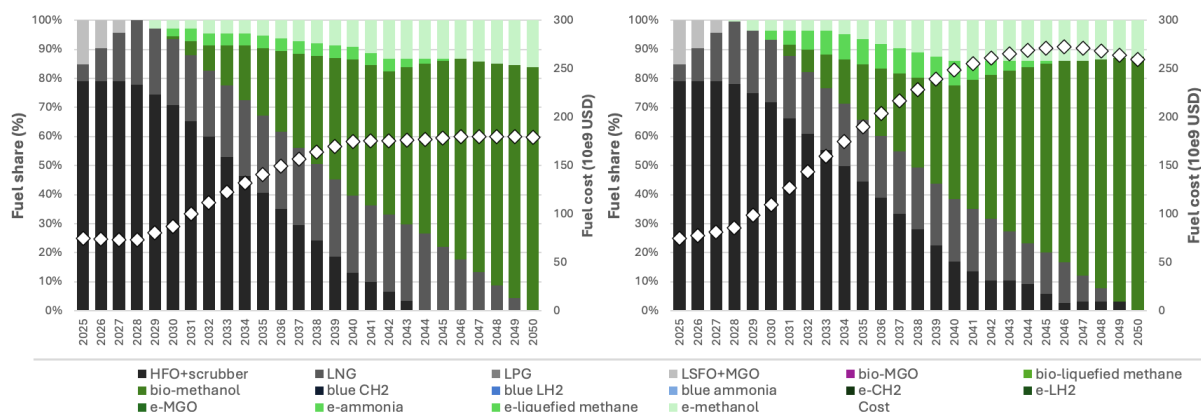


Figure 2: Lo-E scenario (left) vs Hi-FF scenario (right)²

9 Two key e-fuels—liquefied hydrogen fuel (e-LH₂) and e-methanol—are crucial to the decarbonization of global shipping, underscoring their importance and the need for investment to speed up this transition. E-LH₂ is projected to contribute between 20.25% (EARL scenario) and 44.55% (DEEP scenario) to total energy consumption from 2025 to 2050. In parallel, e-methanol is expected to account for 5.31% (DEEP scenario) to 24.87% (EARL scenario), highlighting its vital role as a transitional fuel in shifting from LNG to hydrogen-based alternatives. Notably, in the DEEP scenario, the reliance on fossil fuels drops significantly to 45.04%, compared to 54.94% in the REF scenario. This highlights the crucial role of ambitious emission reduction targets in accelerating the transition away from conventional fuels.

Table 2: Cumulative share of fuel in total energy consumption (%) between 2025 and 2050

Group	Fuels	BASE	REF	Lo-E	Hi-FF	DEEP	EARL	EI
Fossil Fuels	Total	54.15	54.94	54.76	53.73	45.04	51.68	60.56
	HFO+scrubber	34.78	32.78	33.32	36.22	32.63	37.51	36.31
	LNG	18.26	21.05	20.32	16.40	10.93	12.69	23.07
	LPG	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	LSFO+MGO	1.11	1.11	1.11	1.11	1.48	1.47	1.17
Bio & Blue Fuels	Total	45.85	-	-	-	-	-	-
	bio-liquefied methane	41.14	-	-	-	-	-	-
	bio-methanol	4.51	-	-	-	-	-	-
	blue LH ₂	0.19	-	-	-	-	-	-
E-Fuels	Total	-	45.06	45.24	46.27	54.96	48.32	39.44
	e-CH ₂	-	0.00	-	-	-	-	-
	e-LH ₂	-	37.67	35.12	33.87	44.55	20.25	31.25
	e-MGO	-	0.00	-	-	0.00	0.00	-
	e-ammonia	-	1.88	2.28	3.87	5.10	3.20	1.87
	e-methanol	-	5.51	7.85	8.53	5.31	24.87	6.32

² Source: SFOC. The total system fuel cost showcases that higher subsidy for e-fuels is cost-effective compared to solely a fossil fuel penalty.

Conclusion and policy recommendations

10 The transition to a decarbonized maritime sector necessitates targeted, timely and coordinated policy actions to tackle the sector's pressing challenges. The findings highlight the need to implement early financial mechanisms, accelerate emission reduction targets and invest in research and infrastructure development to achieve these objectives.

11 Early-stage financial support for e-fuels is critical to enabling their widespread adoption and achieving economies of scale. Subsidies or incentives for the production and consumption of e-methanol, e-ammonia and e-hydrogen should be introduced during the initial phases of the transition, ideally before 2035. Such measures will rapidly reduce production costs and ensure sufficient production capacity to meet the maritime sector's growing demand for e-fuels.

12 Internalizing the price of carbon within the fuel costs of conventional fuels is essential. The implementation or enhancement of carbon pricing mechanisms, including surcharges or levies on HFO, LNG and other fossil fuels, will account for their environmental externalities. However, these mechanisms should be complemented by targeted financial support for e-fuels and investments in operational efficiency improvements to maximize their impact and ensure a balanced transition.

13 Accelerating interim emission reduction targets for 2030 and 2040 is necessary to drive earlier adoption of advanced e-fuels and efficiency measures. Higher interim targets create strong incentives for early investments, also enabling the maritime sector to leverage economies of scale and reduce abatement costs more effectively over time. By setting more ambitious short- and medium-term goals, the industry can better align with long-term decarbonization objectives.

14 Expanding research and development funding is crucial to enable the large-scale adoption of advanced e-fuels. This includes supporting diverse fuel transition pathways, such as e-methanol, while simultaneously developing the necessary infrastructure for long-term hydrogen-based solutions, such as e-LH₂ and e-ammonia. Investments in retrofitting existing infrastructure and developing new technologies will ensure a sound transition and broaden the availability of e-fuels across sectors.

Action requested of the Committee

15 The Committee is invited to consider the information in this document, particularly the proposals in paragraphs 11, 12, 13 and 14, and take action as appropriate.
