Decarbonizing International Shipping at the IMO: Are Alternative Fuels The Way Forward?

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The International Maritime Organization (IMO) is the United Nations specialized agency responsible for safe, secure and efficient shipping and the prevention of ship-sourced pollution. Responding to increasing environmental pressures to tackle ship-sourced GHG emissions, IMO adopted the 2023 IMO Strategy on Reduction of GHG Emissions from Ships (2023 Strategy) which significantly accelerated ambitions to decarbonize international shipping. To meet the new targets, the shipping industry and port States have rapidly increased research into alternative shipping fuels which produce low- or zero-GHG emissions. Ammonia and methanol have emerged as two of the most promising options. This article addresses the physical characteristics of fuels, IMO's internal regulations and policy options. It examines how the move to use methanol and ammonia as alternative fuels for shipping could meet the IMO's ambitions under its 2023 GHG Strategy. Further, it argues that while the efforts to demonstrate their feasibility as marine fuels are essential, the impact of methanol and ammonia fuels on human safety and on the marine environment will have to be given greater emphasis by IMO going forward. It argues that a knowledge gap currently exists on the impact of ammonia and methanol on the marine environment and on human safety. Consequently, it argues that the IMO should develop a comprehensive strategy and offers policy recommendations which incorporate the impact of the new fuels on human safety and protection of the marine environment.

I. Introduction

1. Ship-Sourced Air Emissions: The Broader Context

The abatement of Greenhouse Gas (**GHG**) emissions is of increasing urgency in order to mitigate the rise in global average temperature and the effects of climate change. Shipping is the most efficient form of transport and it carries over 80 per cent of the world's trade [1]. However, international shipping is a significant source of GHG emissions. It accounts for some 2.89 per cent of global anthropogenic emissions and it is the sixth largest emissions source by sector [2]. In 2023, carbon emissions from international shipping were 20 per cent higher than ten years earlier [3], and

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1 United Nations Conference on Trade and Development, *Review of Maritime Transport 2023 (Overview)* (2023) <https://unctad.org/system/files/official-document/rmt2023overview_en.pdf> accessed 27 December 2023.

2 'Fourth Greenhouse Gas Study 2020' <https://www.imo.org/en/OurWork/Environment/Pages/Fourth-IMO-Greenhouse-Gas-Study-2020.aspx> accessed 27 December 2023.

3 'Review of Maritime Transport 2023' (2023) <https://unctad.org/system/files/official-document/rmt2023_en.pdf> accessed 29 March 2024.

they are expected to rise further by 40% from 2008 levels by 2050 with growth in global trade [4].

The international shipping sector is excluded from the climate change law regime [5] established under the 1992 United Nations Framework Convention on Climate Change (**UNFCCC**) [6], the 1997 Kyoto Protocol [7], and the 2015 Paris Agreement [8]. Parties to the UNFCCC had expressly requested that industrialised countries in the Kyoto Protocol "pursue limitation or reduction of emissions of [GHGs] not controlled by the Montreal Protocol from...marine bunker fuels through the International Maritime Organization" (**IMO**) [9], and international shipping is not mentioned in the Paris Agreement text. Instead, IMO is the UN specialized agency responsible for the international regulation of commercial shipping including the reduction of greenhouse gasses from international shipping [10], and it reports its latest progress and achievements in this regard regularly to the UNFCCC's Conference of Parties through the Subsidiary Body for Scientific and Technological Advice (**SBSTA**) [11].

This article examines the efforts of member States and the shipping industry to meet the IMO's ambitions for shipping under its 2023 GHG Strategy. It argues that IMO's focus is currently on the development of the best alternative fuel technologies in terms of GHG emissions reductions and commercial feasibility while bearing in mind development inequities among States. The IMO Strategy currently focusses on methanol and ammonia because they are the two leading alternative fuel pathways of choice for industry and port States to achieve long-term emissions reductions for shipping [12].

This article examines how the move to use methanol and ammonia as alternative marine fuels[13] could meet the IMO's ambitions for shipping under its 2023 GHG Strategy. In addition, it argues that while the efforts to demonstrate their feasibility as marine fuels are essential, the impact of methanol and ammonia fuels on human safety and on the marine environment will have to be given greater emphasis by IMO going forward. It argues that a knowledge gap currently exists on the impact of ammonia and methanol on the marine environment and on human safety. Consequently, it argues that the IMO should develop a comprehensive strategy and offers policy recommendations which incorporate the impact of the new fuels on human safety and protection of the marine environment.

This article hence proceeds as follows. Part 2 provides a comparative analysis of methanol and ammonia against traditional bunker fuels based on metrics of cost, human safety, and impact to the marine environment and atmosphere to identify useful considerations for the future direction of international law-making at IMO. Part 3 provides a brief summary of how the IMO regulates issues concerning use of alternative fuels in international shipping. Part 4 provides recommendations for the IMO to consider in the next stage of implementing their GHG Strategy, including Environmental Impact Assessments (**EIA**), protected areas, and ways to promote the uptake of fuels and harmonize global standards.

4 'Fourth Greenhouse Gas Study 2020' (n 2).

5 Beatriz Garcia, Anita Foerster and Jolene Lin, 'Net Zero for the International Shipping Sector? An Analysis of the Implementation and Regulatory Challenges of the IMO Strategy on Reduction of GHG Emissions' (2021) 33 Journal of Environmental Law 85, 88.

6 *1992 United Nations Framework Convention on Climate Change, 1771 UNTS 107, Adopted on 09 May 1992, Entered into Force on 21 March 1994.*

7 *1997 Kyoto Protocol to the United Nations Framework Convention on Climate Change, 2303 UNTS 148, Adopted on 11 December 1997, Entered into Force on 16 February 2005.*

8 *2015 Paris Agreement, UN Doc. FCCC/CP/2015/10/Add.1 Decision 1/CP.21, Adopted on 12 December 2015, Entered into Force on 04 November 2016.*

9 Article 2.2, *1997 Kyoto Protocol to the United Nations Framework Convention on Climate Change, 2303 UNTS 148, Adopted on 11 December 1997, Entered into Force on 16 February 2005.* (n 7); Sebastian Oberthür, 'Institutional Interaction to Address Greenhouse Gas Emissions from International Transport: ICAO, IMO and the Kyoto Protocol' (2003) 3 Climate Policy 191, 192.

10 Art 1, *1948 Convention on the International Maritime Organization, 289 UNTS 3, Adopted on 6 March 1948, Entered into Force on 17 March 1958.*

11 'IMO and UNFCCC' <https://www.imo.org/en/OurWork/Environment/Pages/IMO%20and%20UNFCCC.aspx> accessed 27 March 2024.

12 Rhyannon Bartlett-Imadegawa and Sayumi Take, 'Asia-Pacific Shippers Showcase Decarbonization Efforts at COP28' (*Nikkei Asia*, 12 December 2023) <https://asia.nikkei.com/Spotlight/Environment/Climate-Change/COP28/Asia-Pacific-shippers-showcase-decarbonization-efforts-at-COP28> accessed 27 December 2023; Lucy Hine, 'Methanol Trumps LNG as Newbuilding Fuel of Choice to Date in 2023' (*TradeWinds | Latest shipping and maritime news*, 4 December 2023) <https://www.tradewindsnews.com/gas/methanol-trumps-lng-as-newbuilding-fuel-of-choice-to-date-in-2023/2-1-1564908> accessed 27 December 2023.

13 Also known as bunker fuels, they are fuels sold to and burned by aircraft and ships in international transport.

2. Industry Developments

The International Tanker Owners Pollution Federation Limited (**ITOPF**), the world's leading experts on oil spills, stated that "the shipping industry is undergoing the largest fuel revolution since the obsolescence of steam-powered vessels in the 1950s" [14]. In January 2024, classification societies DNV and Lloyd's Register (**LR**) published reports highlighting the popularity of alternative fuel propulsion in newbuild vessels or retrofits in 2023 – an 8% increase year-on-year [15]. Particularly, methanol-fuelled vessels[16] experienced a sharp increase in orders of 138 compared to just 35 the year before, overtaking liquefied natural gas (**LNG**) as the leading alternative fuel choice for shipowners [17]. Another report by Clarksons Shipbuilding Review found that 6% of global fleet capacity is alternatively fuelled capable today[18] and projected to increase to 25% by 2030 [19]. A total of 539 ships (45% of ships on order in 2023 by gross tonnage) will be capable of running on alternative fuels –249 ammonia-ready and 247 methanol-ready vessels on order [20]. In terms of existing ship coverage, there are 444 LNG-ready ships and just 27 methanol-capable vessels currently in service [21], but ammonia engines are not commercially ready yet [22]. Methanol-fuel appears the most mature, with ammonia-fuel achieving significant breakthroughs, including the world's first ammonia ship-to-shore bunkering pilot in 2024 [23].

3. Literature Review

Existing research and studies on methanol and ammonia as alternative bunker fuels mainly focus on the following. First, extensive legal research which analyzed the IMO's regulation of air pollution and climate change from shipping primarily focused on the IMO's 2018 Initial Strategy and its energy efficiency measures – at the time the IMO's focus was not on green fuels (since technology was not mature and the 2023 Strategy has not been introduced yet) [24]. Where existing research focused on the 2023 Strategy, scholars tended to provide a general overview of the developments in IMO policies [25]. Some scholars

14 Andrew Le Masurier and Angela Pinzon, 'Is Greener Cleaner? Spill Implications from Alternative Marine Fuels' <https://www.itopf.org/fileadmin/uploads/itopf/data/Documents/Papers/Is_Greener_Cleaner_Interspill_2022_Extended_Abstract.pdf> accessed 27 March 2024.

15 'DNV: 2023 Saw Methanol "go Mainstream" and Ammonia Break Through' (*Riviera*) <https://www.rivieramm.com/news-content-hub/news-content-hub/dnv-2023-a-breakout-year-for-methanol-orders-79213> accessed 27 March 2024; 'Maritime Decarbonization Efforts Propelled as Orders for Alternative-Fueled Vessels Grow' (9 January 2024) <https://www.dnv.com/news/maritime-decarbonization-efforts-propelled-as-orders-for-alternative-fueled-vessels-grow-251921/> accessed 27 March 2024; 'LR Report Sees Surge in Methanol Engine Retrofits in 2023, Calls It a "Defining Trend" | Manifold Times' (12 January 2024) <https://www.manifoldtimes.com/news/lr-report-sees-surge-in-methanol-engine-retrofits-in-2023-calls-it-a-defining-trend/> accessed 27 March 2024.

16 Excluding methanol carriers, these are ships which would run on methanol as bunker fuel.

17 The dominating vessel-type for methanol was container ships (106), followed by bulk carriers (13) and car carriers (10): 'Maritime Decarbonization Efforts Propelled as Orders for Alternative-Fueled Vessels Grow' (n 15).

18 Up from 2.3% in 2017.

19 The Clarksons data is also cited by the IMO Plenary Presentation at MEPC 81 in March 2024: Jasmina Ovcina Mandra, 'Clarksons: 45% of Ships Ordered in 2023 Embrace Alternative Fuels, with LNG Still in the Lead' (*Offshore Energy*, 3 January 2024) <https://www.offshore-energy.biz/clarksons-45-of-ships-ordered-in-2023-embrace-alternative-fuels-with-lng-still-in-the-lead/> accessed 27 March 2024.

20 "In 2022, a record ~55% of all newbuild orders by tonnage (GT) were alternative fuel capable (basis non-LNG carriers: ~40% of tonnage). For context, in 2021 31% of newbuild tonnage ordered was for alternative fuel capable vessels, up from 27% in 2020 and 8% in 2016…Of the total orderbook, 37.4% of tonnage is set to use LNG (916 units), 8.3% to use methanol (203 units), 1.7% to use LPG (84 units) and ~3.3% due to use other alternative fuels (~379 units) including hydrogen (8)…": ibid.

21 'LR Report Sees Surge in Methanol Engine Retrofits in 2023, Calls It a "Defining Trend" | Manifold Times' (n 15).

22 The first such ammonia-fuelled engines are expected to be ready in 2027.

23 Although ammonia-readiness is not at the level of LNG yet: 'Maritime Decarbonization Efforts Propelled as Orders for Alternative-Fueled Vessels Grow' (n 15); 'World's First Use of Ammonia as a Marine Fuel in a Dual-Fuelled Ammonia-Powered Vessel in the Port of Singapore | Maritime and Port Authority of Singapore' <https://www.mpa.gov.sg/media-centre/details/world-s-first-use-of-ammonia-as-a-marine-fuel-in-a-dual-fuelled-ammonia-powered-vessel-in-the-port-of-singapore> accessed 28 March 2024.

24 Yubing Shi and Warwick Gullett, 'International Regulation on Low-Carbon Shipping for Climate Change Mitigation: Development, Challenges, and Prospects' (2018) 49 Ocean Development & International Law 134; Aldo Chircop, 'The IMO Initial Strategy for the Reduction of GHGs from International Shipping: A Commentary' (2019) 34 The International Journal of Marine and Coastal Law 482.

25 Levent Bilgili and Aykut I Ölçer, 'IMO 2023 Strategy-Where Are We and What's next?' (2024) 160 Marine Policy 105953; Pierre Cariou and Laingo M Randrianarisoa, 'Stakeholders' Participation at the IMO Marine Environmental Protection Committee' (2023) 149 Marine Policy 105506; Qiuwen Wang and others, 'The Use of Alternative Fuels for Maritime Decarbonization: Special Marine Environmental Risks and Solutions from an International Law Perspective' (2023) 9 Frontiers in Marine Science <https://www.frontiersin.org/articles/10.3389/fmars.2022.1082453> accessed 28 March 2024; Tae-Hwan Joung and others, 'The IMO Initial Strategy for Reducing Greenhouse Gas(GHG) Emissions, and Its Follow-up Actions towards 2050' (2020) 4 Journal of International Maritime Safety, Environmental Affairs, and Shipping 1.

tended to focus on the regime interaction between climate change or international environmental law, the IMO, and International Civil Aviation Organization for international bunker fuels [26], the history behind climate change as an agenda at the IMO [27], and issues with the IMO's slow progress from an environmentalist perspective[28]. Few existing studies incorporate the physical characteristics of the fuels and legal issues which may arise on balance. They focus on the specificities of new fuels from technical, engineering, or scientific disciplines, or examine the legal aspects at a regime or sectoral level more broadly.

Second, past research has focused most extensively on LNG as an alternative fuel[29] or on methanol and ammonia carried as cargo onboard ships (but not as bunker fuel)[30], or on energy efficiency measures of the IMO (including the Energy Efficiency Design Index (**EEDI**), Energy Efficiency Existing Ship Index (**EEXI**), Carbon Intensity Indicator (**CII**), and Ship Energy Efficiency Management Plan (**SEEMP**)) to reduce emissions for shipping [31]. This is understandable since historically, the IMO has primarily focused on improving energy efficiency to achieve lower consumption of fuel, and therefore reduce the carbon footprint of ships. The rise in popularity of methanol, and more recently, ammonia, as bunker fuels have only taken place in the latter half of 2023, whereas they were conventionally transported as cargo as widely used commodities for industrial uses (IMO has well-developed regulations on this).

Third, existing research have made extensive comparisons of alternative fuels from a scientific and technical perspective [32]. They focus primarily on the benefits of new fuels and on ways to accelerate the uptake of new fuels through reducing transition costs [33]. They also analyze the inherent dangers of new fuels in terms of safety risks [34], and to a lesser extent, their environmental impact [35], but it is argued that there are few studies closely examining the legal implications in this regard, save for one by ITOPF which briefly highlights the liability gap issues concerning these new bunker fuels and provides a concise summary of their pollution and safety risks [36]. One recent paper conducted an empirical study of the

26 Beatriz Martinez Romera, 'The Paris Agreement and the Regulation of International Bunker Fuels' (2016) 25 Review of European, Comparative & International Environmental Law 215; Kulovesi Kati and Dafoe Joanna, 'Chapter I.23: ICAO and IMO: International Sectoral Approaches to Greenhouse Gas Reductions in Transport' (2016) <https://www.elgaronline.com/view/nlm-book/9781786436986/b-9781783477616-I_23.xml> accessed 29 March 2024; Md Saiful Karim and Shawkat Alam, 'Climate Change and Reduction of Emissions of Greenhouse Gases from Ships: An Appraisal' (2011) 1 Asian Journal of International Law 131; Kati Kulovesi, 'Addressing Sectoral Emissions Outside the U Nited N Ations F Ramework C Onvention on C Limate C Hange: What Roles for Multilateralism, Minilateralism and Unilateralism?' (2012) 21 Review of European Community & International Environmental Law 193; Louise de La Fayette, 'The Marine Environment Protection Committee: The Conjulnction of the Law of the Sea and International Environmental Law' (2001) 16 International Journal of Marine and Coastal Law 155; Oberthür (n 9); Simon Bullock, James Mason and Alice Larkin, 'Are the IMO's New Targets for International Shipping Compatible with the Paris Climate Agreement?' [2023] Climate Policy 1.

27 Martinez Romera (n 26); Oberthür (n 9); 'Shipping and Climate Change: International Law and Policy Considerations' (*Centre for International Governance Innovation*, 6 September 2018) <https://www.cigionline.org/publications/shipping-and-climate-change-international-law-and-policy-considerations/> accessed 19 February 2024.

28 Kevin Anderson and Alice Bows, 'Executing a Scharnow Turn: Reconciling Shipping Emissions with International Commitments on Climate Change' (2012) 3 Carbon Management 615; Hanna Bach and Teis Hansen, 'IMO off Course for Decarbonisation of Shipping? Three Challenges for Stricter Policy' (2023) 147 Marine Policy 105379; Simon Bullock, James Mason and Alice Larkin, 'The Urgent Case for Stronger Climate Targets for International Shipping' (2022) 22 Climate Policy 301; Alice Bows-Larkin, 'All Adrift: Aviation, Shipping, and Climate Change Policy' (2015) 15 Climate Policy 681; Kulovesi (n 26).

29 Wang and others (n 25) 3; Jingjing Xu, David Testa and Proshanto K Mukherjee, 'The Use of LNG as a Marine Fuel: Civil Liability Considerations from an International Perspective' (2017) 29 Journal of Environmental Law 129.

30 Maritime Safety Forum and Oil Companies International Marine Forum, 'The Carriage of Methanol in Bulk Onboard Offshore Vessels' <https://www.marinesafetyforum.org/wp-content/uploads/2020/08/Carriage-of-Methanol-final-15.06.20-in-bulk-onboard-offshore-vessels.pdf> accessed 29 March 2024.

31 Sang-Su Lee, 'Analysis of the Effects of EEDI and EEXI Implementation on CO2 Emissions Reduction in Ships' (2024) 295 Ocean Engineering 116877; 'The Role of Energy Efficiency Regulations | Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping' <https://www.zerocarbonshipping.com/publications/the-role-of-energy-efficiency-regulations/> accessed 28 March 2024.

32 Youngkyun Seo and others, 'Technical–Economic Analysis for Ammonia Ocean Transportation Using an Ammonia-Fueled Carrier' (2024) 16 Sustainability 827.

33 K Machaj and others, 'Ammonia as a Potential Marine Fuel: A Review' (2022) 44 Energy Strategy Reviews 100926; Mohamad Issa, Adrian Ilinca and Fahed Martini, 'Ship Energy Efficiency and Maritime Sector Initiatives to Reduce Carbon Emissions' (2022) 15 Energies 7910.

34 Le Masurier and Pinzon (n 14); Hans Kristian Haram and others, 'Ammonia as a Marine Fuel Safety Handbook' <https://grontskipsfartsprogram.no/wp-content/uploads/2022/03/Ammonia-as-Marine-Fuel-Safety-Handbook-Rev-01.pdf>; Phan Anh Duong and others, 'Safety Assessment of the Ammonia Bunkering Process in the Maritime Sector: A Review' (2023) 16 Energies 4019; Hayoung Jang and others, 'Regulatory Gap Analysis for Risk Assessment of Ammonia-Fuelled Ships' (2023) 287 Ocean Engineering 115751.

35 Lloyd's Register, 'Methanol - Compare Zero Carbon Fuels | Lloyds Register | LR' <https://www.lr.org/en/expertise/maritime-energy-transition/maritime-decarbonisation-hub/zcfm/Methanol/> accessed 27 December 2023; 'Fuel for Thought: Introduction to Ammonia | LR' <https://www.lr.org/en/knowledge/webinars/introduction-to-ammonia-as-a-fuel-for-shipping/> accessed 28 March 2024.

36 Le Masurier and Pinzon (n 14).

change in actors and power within the Marine Environment Protection Committee (**MEPC**) [37]. Besides scholarly work on IMO regulations and lifecycle emissions [38], classification societies such as American Bureau of Shipping [39], LR [40] and DNV [41], as well as public-private partnership-formed research centers of excellence such as the Maersk-Mckinney Moller Center for Zero Carbon Shipping have published extensively on the empirical, economic, and technical analysis of new fuels [42]. The International Monetary Fund published a working paper analyzing carbon taxation for international maritime fuels [43]. In summary, literature from industry have been drivers for standard-setting and rules of reference by regulators and industry, with frequent and comprehensive publications providing guidance on issues including fuel options [44], industry strategies [45], and regulatory implications of their uptake[46].

II. Comparative Analysis of Methanol and Ammonia Against Traditional Marine Fuels

This section will briefly provide an overview of the characteristics of ammonia and methanol to explain why industry and IMO considers them to be leading alternative fuels for research [47]. It will compare the impact that ammonia and methanol have vis-à-vis traditional bunker fuels in terms of cost, safety, and the environment (not just to the atmosphere, but also to the marine environment) to demonstrate how the former may have serious impacts for human safety and the marine environment which the IMO must now consider when adopting them as leading future fuels for their GHG-reduction benefits. Further, IMO should note that they are more costly and less energy-efficient than traditional fuels, and may have other impact with regard to air pollution.

1. Overall Architecture of Alternative Fuel Candidates

From a lifecycle perspective, the five main aims of research into alternative fuels are i) to maximise energy-efficiency (and hence reduce costs[48]) while ii) minimising space required onboard vessels for fuel; iii) ensuring minimal GHG leakage into the atmosphere (to meet emissions reduction targets) during its entire lifecycle from a “well-to-wake” perspective (i.e., fuel production, containment and transporta-

37 Jennifer Baumann, ‘Shifting to Sustainable Shipping: Actors and Power Shifts in Shipping Emissions in the IMO’ (2023) 15 Sustainability 12742.

38 Levent Bilgili, ‘A Systematic Review on the Acceptance of Alternative Marine Fuels’ (2023) 182 Renewable and Sustainable Energy Reviews 113367; Bilgili and Ölçer (n 25) 4; Levent BiLgiLi, ‘A Discussion on Alternative Fuel Criteria for Maritime Transport’ (2022) 11 Marine Science and Technology Bulletin 352; Levent Bilgili, ‘LCA Studies on Marine Alternative Fuels’ in Burak Zincir, Pravesh Chandra Shukla and Avinash Kumar Agarwal (eds), *Decarbonization of Maritime Transport* (Springer Nature Singapore 2023) <https://link.springer.com/10.1007/978-981-99-1677-1_2> accessed 28 March 2024; Andrea Mio, Maurizio Fermeglia and Claudio Favi, ‘A Critical Review and Normalization of the Life Cycle Assessment Outcomes in the Naval Sector. Bibliometric Analysis and Characteristics of the Studies’ (2022) 371 Journal of Cleaner Production 133268.

39 ABS, ‘Sustainability Whitepaper: Ammonia as Marine Fuel’ (2020) <https://safety4sea.com/wp-content/uploads/2021/01/Ammonia_as_Marine_Fuel_Whitepaper_20188.pdf> accessed 27 December 2023; American Bureau of Shipping (ABS), ‘An Approach to Green Shipping Corridor: Modeling and Optimization’ (2023) <https://ww2.eagle.org/content/dam/eagle/publications/whitepapers/outlook-green-shipping-corridors.pdf> accessed 28 March 2024.

40 ‘Knowledge Hub: Research Reports, Class News & Insights | LR’ <https://www.lr.org/en/knowledge/> accessed 28 March 2024.

41 ‘Resources’ <https://www.dnv.com/maritime/hub/decarbonize-shipping/resources/> accessed 28 March 2024.

42 Maersk-Mckinney Moller Center for Zero Carbon Shipping, ‘Our Publications’ <https://www.zerocarbonshipping.com/publications/> accessed 28 March 2024.

43 Ian Parry and others, ‘Carbon Taxation for International Maritime Fuels: Assessing the Options’ (1 September 2018) <https://papers.ssrn.com/abstract=3267230> accessed 29 March 2024.

44 ‘Fuel Options Position Paper’ <https://www.zerocarbonshipping.com/publications/fuel-options-position-paper/> accessed 28 March 2024.

45 ‘Industry Transition Strategy’ <https://www.zerocarbonshipping.com/publications/industry-transition-strategy/> accessed 28 March 2024; Transition Modeling & Analytics Mærsk Mc-Kinney Møller center for Zero carbon shipping, ‘NavigaTE to Zero: Modelling of the Maritime Decarbonization’ (1 November 2021) <https://cms.zerocarbonshipping.com/media/uploads/documents/NavigaTE_Whitepaper_final.pdf> accessed 28 March 2024.

46 Lloyd’s Register, ‘Future IMO and ILO Legislation Autumn 2023 | LR’ (1 December 2023) <https://www.lr.org/en/knowledge/regulatory-updates/imo-meetings-and-future-legislation/fil-autumn-2023/> accessed 27 December 2023; ‘Classification of Ships Using Gases or Other Low-Flashpoint Fuels | LR’ <https://www.lr.org/en/knowledge/lloyds-register-rules/rules-and-regulations-for-ships-using-gases-or-low-flashpoint-fuels/> accessed 28 March 2024.

47 DNV, ‘What Are the Key Success Factors in Singapore’s Decarbonization Journey? - DNV’ (*DNV GL*, 18 December 2023) <https://www.dnv.com/expert-story/DigitalMagazineDefault> accessed 27 December 2023; *Podcast: The Journey from LNG as a Fuel to Hydrogen* (Directed by Seatrade Maritime News, 2023) <https://www.youtube.com/watch?v=64bl8TBJZ_o> accessed 27 December 2023.

48 Operational costs of transportation, storage and production etc.

tion, and eventual use); iv) ensuring safety when using such fuels onboard vessels; and v) protecting the marine environment. From Figure 1 (Appendix), the potential fuel candidates can be broadly categorised as e-fuels (synthetic fuels), blue fuels (low-carbon fuels), and bio-fuels (produced from organic sources).

From the shipping end-user's perspective (ie, ship owners and operators), the purpose of using e- or blue bunker fuels such as ammonia and methanol are to serve as safer and more efficient carriers of hydrogen, where the hydrogen contained within such fuels are consumed for energy (just like hydrocarbons – except that with fossil fuels, carbon dioxide is emitted as a waste by-product) [49]. Broadly speaking, while hydrogen is an energy source which can be used to provide propulsion, directly powering large ocean-going vessels with hydrogen is viewed as the most technically challenging (although recent developments suggest some potential with 14 hydrogen-ready vessels on order and new engines tested[50]), dangerous, and energy consuming among the alternative fuel candidates due to potential leakages and limitations in transportation and storage [51], making it potentially a more costly pathway [52] or even more pollutive than diesel power [53]. Hence, industry primarily looks toward research into carriers of hydrogen such as ammonia and methanol which "enables hydrogen to be stored and transported in safer and more efficient conditions" [54], before hydrogen is separated and burnt to power a vessel's engines. That said, engines are envisaged to be dual-fuelled because methanol and ammonia have poor autoignition properties and require a small pilot fuel injection (fuel oil) to ignite [55].

From a State's perspective, methanol and ammonia has two potential use cases[56]: (1) either combusted directly for energy production (in ship engines or fuel cells), or (2) as a carrier of hydrogen for electricity generation in a power plant (to reduce emissions and meet its Nationally Determined Contributions (**NDCs**) under the Paris Agreement[57]). In the latter case, ammonia is favoured over methanol given its

49 "Ammonia is formed when hydrogen combines with nitrogen from ambient air. As a hydrogen carrier, it can be stored at room temperature and is easy to transport. Hydrogen is seen as a clean fuel as it does not produce any planet-warming carbon dioxide when burned.": Cheryl Tan, 'Singapore a Step Closer to Using Low-Carbon Ammonia for Bunkering, Power Generation' *The Straits Times* (Singapore, 23 October 2023) <https://www.straitstimes.com/singapore/s-pore-a-step-closer-to-using-low-carbon-ammonia-for-bunkering-power-generation> accessed 27 December 2023.

50 Envisaged as a longer term solution after methanol and ammonia. Mandra (n 19); Adis Ajdin, 'CMB and Boeckmans Team up for Hydrogen-Powered Newbuilds' (*Splash247*, 30 November 2023) <https://splash247.com/cmb-and-boeckmans-team-up-for-hydrogen-powered-newbuilds/> accessed 27 December 2023; Lloyd's Register, 'LR Awards Type Approval to BeHydro for Its Hydrogen Dual-Fuel Engine | LR' (10 November 2023) <https://www.lr.org/en/about-us/press-listing/press-release/lr-awards-type-approval-to-behydro-for-its-hydrogen-dual-fuel-engine/> accessed 27 December 2023; Gary Howard, 'World-First Hydrogen Test Success for Mitsui Using MAN Engine' (*Seatrade Maritime*, 7 March 2024) <https://www.seatrade-maritime.com/sustainability-green-technology/world-first-hydrogen-test-success-mitsui-using-man-engine> accessed 27 March 2024.

51 Operational restraints in terms of storage space, duration etc.: CMA CGM Group, 'From LNG to E-Methane, an Effective Solution Now to Prepare for the Future' (*Better way story*, 5 November 2021) <https://www.cmacgm-group.com/en/betterways-story/from-lng-to-emethane-an-effective-solution-to-prepare-the-future> accessed 15 December 2023; Cf. Note early-mover innovations such as Hyundai's dual LNG-hydrogen engine which met the top-level Tier 3 of nitrogen oxide regulations set by IMO: KED Global, 'Hyundai Heavy Industries Group Develops Dual LNG-Hydrogen Engine' (*KED Global*, 23 December 2022) <https://www.kedglobal.com/energy/newsView/ked202212230005> accessed 27 December 2023.

52 Anastasia Christodoulou and others, 'A Cost-Benefit Analysis of the Use of Ammonia and Hydrogen as Marine Fuels' (2023) <https://www.researchgate.net/publication/369272930_A_cost-benefit_analysis_of_the_use_of_ammonia_and_hydrogen_as_marine_fuels>; "…using hydrogen directly in a vessel requires a huge amount of space on board relative to the goods, which makes its use complicated for long-distance container transportation. Another operating restraint is the maximum period for which this energy can be stored, which is 16 days, while an LNG vessel can run for more than 90 days on a full tank of LNG. Lastly, more than 90% of the world's hydrogen is currently carbonized as it is produced from gas and oil. Running a vessel on hydrogen today would result in emissions three times higher than with a diesel vessel.": CMA CGM Group (n 51).

53 Running a vessel on hydrogen today would result in emissions three times higher than with a diesel vessel: CMA CGM Group (n 51).

54 Zuza Nazaruk, '"Low-Carbon Product" Promoted by COP28 President 3 Times More Damaging than "Regular" Fuels' (*euronews*, 3 December 2023) <https://www.euronews.com/green/2023/12/02/low-carbon-product-promoted-by-cop28-president-is-3-times-more-harmful-to-climate-than-reg> accessed 27 December 2023.

55 Methanol has a low cetane number. A small pilot fuel injection (typically less than 5% of the total energy consumed for methanol, but for ammonia it depends on factors such as the combustion technology chosen and engine loads) is needed to ignite the fuel: 'Alternative Fuels for Containerships: Methanol and Ammonia' 57, 92 <https://www.dnv.com/maritime/publications/alternative-fuels-for-containerships-methanol-and-ammonia-download/> accessed 31 March 2024.

56 ibid 49, 92.

57 Each country's pledge to reduce national emissions and adapt to the impacts of climate change. The Paris Agreement (Article 4, paragraph 2) requires each Party to prepare, communicate and maintain successive nationally determined contributions (NDCs) that it intends to achieve. Parties shall pursue domestic mitigation measures, with the aim of achieving the objectives of such contributions: *2015 Paris Agreement, UN Doc. FCCC/CP/2015/10/Add.1 Decision 1/CP.21, Adopted on 12 December 2015, Entered into Force on 04 November 2016.* (n 8).

Table 1: Comparison of Technical Characteristics of Traditional Marine Fuels against Ammonia and Methanol.

Marine Fuel Type	Space Required [in Units of MGO, rounded-off]	Energy Produced [in Units of MGO, rounded-off]	Storage Pressure [bar]	Storage Temperature [°C]
Marine Gas Oil (MGO)	1x	1x	1	20
Methanol	2.4x	0.5x	1	20
Ammonia (Liquid)	2.9x	0.4x	1 or 10	-34 or 20
Liquefied Natural Gas (LNG)	1.6x	1.2x	1	-162

lack of carbon produced when hydrogen is extracted.

2. Comparing Ammonia and Methanol as Alternatives to Conventional Marine Fuels

a. Comparative Efficiency and Cost

Ammonia is produced from hydrogen and nitrogen, and does not produce carbon when burnt in a ship's tank directly [58]. Methanol is more energy efficient and "has the lowest carbon and…highest hydrogen content of any liquid fuel" but nevertheless produces carbon when burnt [59]. It is made from hydrogen and carbon dioxide (CO2) which provides a business case for re-using carbon dioxide which would otherwise have been a waste product [60]. CO2 emissions from energy combustion or industrial sources reached an all-time high in 2021, so producing methanol using CO2 captured from such sources could produce "net carbon-neutral" methanol which does not add new CO2 into the atmosphere and forms a "virtuous loop" [61]. However, such methanol needs to be produced using hydrogen produced in a decarbonized way (i.e., using renewable electricity) (see Figure 2 (Appendix) for further details).[62].

In terms of space required on board vessels, both methanol and ammonia require more space compared to traditional bunker fuels (or even LNG), making them more commercially costly. On a methanol-powered ship, storage and fuel tanks take about 2.4 times more space than on ships that run on Marine Gas Oil (MGO); while ammonia-powered ship would require about 2.9 times more space than on MGO-fuelled ships, which "reduces available cargo space unless more frequent bunkering is acceptable" [63]. However, unlike LNG or ammonia, methanol can be stored at ambient temperature at normal pressure in conventional fuel storage tanks and even ballast tanks on-board a vessel without requiring cryogenic storage[64] (which can have a greater impact on loss of cargo space and hence more costly) [65]. To put things into perspective, for ammonia to be stored at the same temperature as methanol and MGO at 20°C, theoretically it needs to be pressurized at 10 times the nor-

58 Note, ammonia has a high capacity for hydrogen storage, 17.6 wt.%, so it is widely considered as a suitable carrier of hydrogen for other use-cases besides powering ships such as power generation on land, in which power stations will be supported by the import of ammonia on ammonia carriers which are ammonia-fuelled.: US Department of Energy, 'Potential Roles of Ammonia in a Hydrogen Economy: A Study of Issues Related to the Use Ammonia for On-Board Vehicular Hydrogen Storage'.

59 'Alternative Fuels for Containerships: Methanol and Ammonia' (n 55) 49.

60 CMA CGM Group (n 51).

61 ibid; Methanol Institute, 'Marine Methanol Future-Proof Shipping Fuel' (2023) 35 <https://www.methanol.org/wp-content/uploads/2023/05/Marine_Methanol_Report_Methanol_Institute_May_2023.pdf> accessed 27 December 2023.

62 The same applies to ammonia.

63 'Alternative Fuels for Containerships: Methanol and Ammonia' (n 55) 80.

64 Storage at extremely low temperatures.

65 Methanol Institute (n 61) 26.

mal pressure, consuming significantly more energy [66].

In terms of energy produced, both methanol and ammonia are only about half as efficient as MGO. However, methanol is slightly better than ammonia in terms of energy productivity (0.5 times of MGO compared to 0.4 times). Admittedly, LNG is the winner [67] and is even more efficient than traditional MGO (1.2 times). It is for the above reasons that a significant cost gap exists where estimates find that ammonia and methanol fuels could be about 1.5 to 2 times costlier than traditional bunker fuels [68].

In terms of investment costs of newbuild vessels, including on vessel segments, fuels, and engine configurations or possibly retrofitting existing ones, such as Capital expenditures (**CAPEX**) or operating expenses (**OPEX**), research centers have developed models of the Total Cost of Ownership (**TCO**) accounting for various scenarios for shipowners. A whitepaper found that the annual TCO for a newbuild vessel[69] running on various alternative fuels was 28% to 56% higher than a baseline vessel running low-sulfur fuel oil (**LSFO**) [70]. This was primarily due to fuel costs as alternative-fuelled vessels have very similar OPEXs to LSFO-fuelled vessels, and very similar CAPEXs (save for one exception where it was slightly more costly) [71]. Methanol retrofits tend to suit more expensive vessels, particularly those whose original value was higher than $50m since retrofit costs range between $5m to $15m, where "a full dual-fuel retrofit...for cheaper vessels would be [more] costly compared to building a new vessel with dual-fuel engines from scratch" [72]. Although there has only been one retrofitted methanol-fuelled vessel in operation since 2015, a considerable proportion of methanol orders in 2023 (more than 100) were for retrofits rather than newbuilds [73]. Contrastingly, the exact costs of newbuild vessels are usually kept undisclosed [74], although some 3,500 TEU methanol-ships reportedly cost $68m, equivalent to a 38% hike in newbuilding prices over three years assuming a 25% cost increase due to fuel costs [75]. Evergreen's 16,000 TEU ships reportedly cost between $180 million and $210 million per ship [76]. ABS estimates that an average 10,000 TEU newbuild ship would cost (as a sum of base CAPEX and capital) about $278m on bio-methanol engines and $285m on green ammonia; less costly than $295m for LNG and $251m for HFO [77]. Further, "...the total cost for retrofitting to an ammonia-fuelled ship equipped with a 10-16 MW two-stroke engine will be $10m to $13m, depending on the type and size of the vessel, original engine and especially the number of retrofits being undertaken" [78].

66 Although note that it is considered impractical to pressurize it at 10 Bars (10 times normal pressure) at room temperature because of the safety concerns of high pressure and corresponding safety designs required (e.g., thick tank walls which would be heavy and add to the weight of the vessel). Therefore, industry believes that ammonia tanks will be kept at a temperature of around -33C at normal pressure, but such low temperatures consume significant energy too: 'Alternative Fuels for Containerships: Methanol and Ammonia' (n 55) 91.

67 See further, Antonios Trakakis, Technical Director, Marine at RINA, Greece, about his long term advocacy of LNG as the optimum fuel selection for new vessels: *Podcast: The Journey from LNG as a Fuel to Hydrogen* (n 47).

68 Sam Chambers, '$200 per Container Cost Gap for Zero Emissions Shipping' (*Splash247*, 7 December 2023) <https://splash247.com/200-per-container-cost-gap-for-zero-emissions-shipping/> accessed 27 December 2023.

69 Calculated for a 25-year period over time related to CAPEX, OPEX and capital costs.

70 For more details see, Figure 3, Mærsk Mc-Kinney Møller center for Zero carbon shipping (n 45) 5.

71 DNV also found that OPEX costs are not expected to change significantly compared to a conventional vessel, with CAPEX being generally 10% higher: 'Alternative Fuels for Containerships: Methanol and Ammonia' (n 55) 71, 73.

72 It might explain why the large proportion of methanol orders in 2023 were retrofits: Sam Chambers, 'Chinese Yard Selected for Landmark Maersk Methanol Retrofit' (*Splash247*, 20 October 2023) <https://splash247.com/chinese-yard-selected-for-landmark-maersk-methanol-retrofit/> accessed 28 March 2024.

73 'Maritime Decarbonization Efforts Propelled as Orders for Alternative-Fueled Vessels Grow' (n 15).

74 COSCO placed orders for four 16,000 teu methanol-fueled ships at its affiliated yard in Yangzhou for an undisclosed price basis delivery in 2025: Methanol Institute, 'Methanol Fuelled Vessels on the Water and on the Way' (2023) <https://www.methanol.org/wp-content/uploads/2023/10/MIs-On-the-Water-On-the-Way.pdf> accessed 28 March 2024.

75 Sam Chambers, 'Maersk Picks Guangzhou Wenchong for next Series of Methanol-Fuelled Ships' (*Splash247*, 29 December 2023) <https://splash247.com/maersk-picks-guangzhou-wenchong-for-next-series-of-methanol-fuelled-ships/> accessed 28 March 2024.

76 'Evergreen Orders 24 Methanol-Fueled Ships at a Cost of Nearly $5 Billion' (*The Maritime Executive*) <https://maritime-executive.com/article/evergreen-orders-24-methanol-fueled-ships-at-a-cost-of-nearly-5-billion> accessed 28 March 2024; Although DNV reports that methanol-fuelled 5,500 TEU containerships have an average TCO across all fuel price scenarios of around 500 Mio USD: 'Alternative Fuels for Containerships: Methanol and Ammonia' (n 55) 76.

77 Table 6, American Bureau of Shipping (ABS) (n 39) 27, 30.

78 According to the European Maritime Safety Authority. However, note that such figures are only projected and expected to change since the ammonia engines are still under commercial development: Chambers, 'Chinese Yard Selected for Landmark Maersk Methanol Retrofit' (n 68).

In terms of related fuel infrastructure, fuel production costs of alternative fuels compared to LSFO are at least 2-3 times more expensive, and details can be found in Figure 10 of the whitepaper [79]. As of 2023, LR's 'Future of Marine Fuels' report and Maritime Decarbonisation Hub found that despite significant progress in fuel supply in 2023, including the first orders for ammonia bunkering barges and large-scaled green methanol supply contracts, fuel supply still needs to be scaled up considerably for many fuel candidates.[80]

Admittedly, the slow uptake of alternative fuels is still the norm in the industry as traditional bunker fuels are still the most cost-effective notwithstanding regulatory drivers which come into force from IMO and the European Union (**EU**) [81]. Infrastructure transition is immensely costly – UNCTAD estimates that decarbonizing the world's fleet by 2050 could require $8 billion to $28 billion annually; infrastructure for 100% carbon-neutral fuels could need an even heftier $28 billion to $90 billion each year [82]. Some have argued that this could be financed by the IMO's economic pricing mechanism [83], but in terms of first-movers, there have been significant investments into fuel production and bunkering facilities in Norway, the Netherlands, Singapore and Australia; and an increase in national hydrogen strategies, such as Singapore's National Hydrogen Strategy with a strong focus on ammonia [84]. States would likely support hydrogen fuels in their national interest if they can produce them easily – blue fuels would be favoured by those with significant reliance on extractive industries as alternative energy sources or to meet their NDCs; green fuels are likely preferred by states with abundant renewable energy; and bio-fuels by states with large agricultural industries, imports or populations [85].

The carbon levy regulations on fossil fuels by the EU or IMO in the mid-term would likely be the primary driver of accelerated adoption of ammonia and methanol [86]. In preparation, some shipowners such as Evergreen and Maersk, some of the largest shipowners in the world, have begun constructing a fleet of methanol ships and purchasing future supplies of green methanol [87]. Others are developing in-

79 Figure 10, Mærsk Mc-Kinney Møller center for Zero carbon shipping (n 45) 9.

80 'Technology for green and blue ammonia is available but current production volumes are very small. Producing green ammonia requires a sufficient supply of green energy while blue ammonia depends on CCS capabilities': 'Alternative Fuels for Containerships: Methanol and Ammonia' (n 55) 78; See the Zero Carbon Fuel Monitor from LR's Maritime Decarbonisation Hub: 'The Future of Maritime Fuels | LR' <https://www.lr.org/en/knowledge/research-reports/the-future-of-maritime-fuels/> accessed 27 March 2024; 'LR Report Sees Surge in Methanol Engine Retrofits in 2023, Calls It a "Defining Trend" | Manifold Times' (n 15).

81 David Glass, 'Greek Shipowners Call for Governments to Back IMO Green Transition Policies' (*Seatrade Maritime*, 21 December 2023) <https://www.seatrade-maritime.com/regulation/greek-shipowners-call-governments-back-imo-green-transition-policies> accessed 27 December 2023; Craig Eason, 'Bimco: Shipping on Track to Reach IMO 5% Clean Fuel Target by 2030' (*TradeWinds | Latest shipping and maritime news*, 21 December 2023) <https://www.tradewindsnews.com/technology/bimco-shipping-on-track-to-reach-imo-5-clean-fuel-target-by-2030/2-1-1575254> accessed 27 December 2023; 'EU Carbon Pricing Brings New Pressures and New Plays to Maritime | Lloyd's Register | LR' <https://www.lr.org/en/knowledge/technical-articles/eu-carbon-pricing-brings-new-pressures-and-new-plays-to-maritime/> accessed 28 March 2024.

82 United Nations Conference on Trade and Development (n 1) 25.

83 'ICS Submits Proposal on Zero Emission Shipping Fund to IMO | Manifold Times' (6 February 2024) <https://www.manifoldtimes.com/news/ics-submits-proposal-on-zero-emission-shipping-fund-to-imo/> accessed 28 March 2024.

84 The Strategy's maritime component includes the Maritime Singapore Decarbonisation Blueprint introduced in March 2022: 'Singapore's National Hydrogen Strategy' <https://www.mti.gov.sg/Industries/Hydrogen> accessed 28 March 2024.

85 Joel Ong Jie Hao, 'Decarbonization of International Shipping: Importance of Alternative "Green" Fuels – GNHRE' (1 April 2024) <https://gnhre.org/?p=17962> accessed 2 April 2024.

86 Para 4.5.2, '2023 IMO Strategy on Reduction of GHG Emissions from Ships' (2023) <https://wwwcdn.imo.org/localresources/en/MediaCentre/PressBriefings/Documents/Resolution%20MEPC.377(80).pdf> accessed 27 December 2023; Hayden Walmsley, 'What Does COP28 Mean for Shipping? | LR' (14 December 2023) <https://www.lr.org/en/knowledge/horizons/december-2023/what-does-cop28-mean-for-shipping/> accessed 27 December 2023; Nick Savvides, 'Zero Emission Fuels Could Reach Parity in Two Years' (*Seatrade Maritime*, 15 December 2023) <https://www.seatrade-maritime.com/sustainability-green-technology/zero-emission-fuels-could-reach-parity-two-years> accessed 27 December 2023.

87 Adis Ajdin, 'Maersk Tankers Orders up to 10 Ammonia Carriers in South Korea' (*Splash247*, 1 December 2023) <https://splash247.com/maersk-tankers-orders-up-to-10-ammonia-carriers-in-south-korea/> accessed 27 December 2023; Craig Eason, 'Maersk's Morten Bo Christiansen Says Green Methanol Supply from China Is the "Real Deal"' (*TradeWinds | Latest shipping and maritime news*, 22 November 2023) <https://www.tradewindsnews.com/technology/maersk-s-morten-bo-christiansen-says-green-methanol-supply-from-china-is-the-real-deal-/2-1-1558989> accessed 27 December 2023; Katherine Si, 'SIPG and Evergreen Ink Green Methanol Supply Agreement' (*Seatrade Maritime*, 18 December 2023) <https://www.seatrade-maritime.com/ports/sipg-and-evergreen-ink-green-methanol-supply-agreement> accessed 27 December 2023; REUTERS and Jacob Gronholt-Pedersen, 'Maersk Enters Deal for Half a Million Tonnes of Green Methanol Annually' (*CNA*, 14 September 2023) <https://www.channelnewsasia.com/business/maersk-enters-deal-half-million-tonnes-green-methanol-annually-3938916> accessed 27 December 2023; Mike Schuler, 'Maersk Signs Largest Green Methanol Offtake Agreement for Low Carbon Shipping' (*gCaptain*, 22 November 2023) <https://gcaptain.com/maersk-signs-largest-green-methanol-offtake-agreement/> accessed 27 December 2023.

novations [88] on ammonia-powered ships [89] and supply and port-side infrastructure to support production and bunkering of ammonia and methanol [90].

b. Human Safety

The threats to human safety of ammonia and methanol will now be examined to show that this is an aspect which the IMO will have to give a higher priority to if the two fuels are considered to be the best options for reduction of GHG emissions.

i. IMO Regulation

The use of fuels is regulated under IMO through the *International Convention for the Safety of Life at Sea* (SOLAS) [91]. Although using fuels with a flashpoint below 60°C (**low-flashpoint fuels**) have generally been prohibited to prevent tank explosions and fires, SOLAS was amended in 2015 to allow for low-flashpoint fuels to be used on ships which comply with the IGF Code [92]. IGF Code sets the standard for the safety of all ships using low-flashpoint fuels except gas carriers.

Specific design requirements for low-flashpoint fuels only pertain to LNG at the moment, but other amendments to IGF Code will be included as and when they are developed by IMO [93]. Until amendments to IGF Code take effect, approval of ships running on fuels other than LNG (e.g., ammonia) will be based on the "alternative design" approach – first-principle analysis demonstrating that the design complies with basic functional requirements of IGF Code and an equivalent level of safety is demonstrated. It requires "an equivalent level of integrity in terms of safety, reliability and dependability as that which can be achieved with a new and comparable conventional oil fuelled main and auxiliary machinery" [94], taking into account applicable IMO interim guidelines [95].

The *International Code of the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk* (**IGC Code**) sets out the international standard for the safe carriage by sea in bulk of liquefied gases applicable to gas carriers. Presently, it does not permit the use of cargo on them as fuel, but draft amendments on incorporating use of high manganese steel for cryogenic ships carrying liquefied gases are expected [96].

Nevertheless, classification societies therefore play an important role in standard-setting and ensuring safe use of ammonia and methanol before the IMO adopts changes to its regulations [97]. When a classification society develops class rules[98] where there are no specific design requirements on such fuel in the IGF Code, a flag State may accept and apply them in lieu of the alternative design approach, and such class rules may form the basis of developing future IMO regulations [99].

88 For an overview of ongoing research by industry, see ABS (n 39) 17–9.

89 Anna Cooban, 'The World May Be Close to Getting Its First Cargo Ship That Emits Almost No Carbon Dioxide | CNN Business' (*CNN*, 1 December 2023) <https://www.cnn.com/2023/12/01/business/clean-ammonia-cargo-ship-co2-emissions/index.html> accessed 27 December 2023.

90 Polly Martin (p_martin), 'Envision to Build Gigawatt-Scale Green Hydrogen and Ammonia Project in China — with Exports to Europe, Japan and Korea in Mind' (*Hydrogen news and intelligence | Hydrogen Insight*, 12 October 2023) <https://www.hydrogeninsight.com/production/envision-to-build-gigawatt-scale-green-hydrogen-and-ammonia-project-in-china-with-exports-to-europe-japan-and-korea-in-mind/2-1-1533818> accessed 27 December 2023; Melissa Goh and Calvin Yang, 'Sarawak Targets Role as Key Producer and Exporter of Green Hydrogen' (*CNA*, 21 November 2023) <https://www.channelnewsasia.com/asia/sarawak-targets-role-key-producer-and-exporter-green-hydrogen-energy-low-carbon-economy-urban-transport-3934086> accessed 27 December 2023; MI News Network, 'World's 1st Cost-Effective Green Methanol Pilot Plant Inaugurated In Leuna Chemical Park, Germany' (*Marine Insight*, 22 November 2023) <https://www.marineinsight.com/shipping-news/worlds-1st-cost-effective-green-methanol-pilot-plant-inaugurated-in-leuna-chemical-park-germany/> accessed 27 December 2023; Project is planned on Jurong Island, "…ammonia bunkering at a capacity of at least 100,000 tonnes per annum, starting with shore-to-ship bunkering, followed by ship-to-ship bunkering": Tan (n 49).

91 For a further explanation of the regulatory framework, see ABS (n 39) 8–10.

92 Section 4, Hans Kristian Haram and others (n 34); 'International Code of Safety for Ship Using Gases or Other Low-Flashpoint Fuels (IGF Code)' <https://www.imo.org/en/ourwork/safety/pages/igf-code.aspx> accessed 27 December 2023.

93 Section 4, Hans Kristian Haram and others (n 34).

94 'International Code of Safety for Ship Using Gases or Other Low-Flashpoint Fuels (IGF Code)' (n 92).

95 For example, Interim Guidelines for the Safety of Ships Using Methyl/ Ethyl Alcohol as Fuel (MSC.1/Circ.1621): 'Alternative Fuels for Containerships: Methanol and Ammonia' (n 55) 95.

96 Hans Kristian Haram and others (n 34) 11–2; Lloyd's Register, 'Future IMO and ILO Legislation Autumn 2023 | LR' (n 46) 4.

97 See, for example, Mike Schuler, 'Bureau Veritas Launches Classification Rules for Hydrogen-Fuelled Ships' (*gCaptain*, 30 November 2023) <https://gcaptain.com/bureau-veritas-launches-classification-rules-for-hydrogen-fuelled-ships/> accessed 27 December 2023.

98 For an example of DNV class rules, see: 'Alternative Fuels for Containerships: Methanol and Ammonia' (n 55) 96–7.

99 ABS (n 39) 11; Hans Kristian Haram and others (n 34) 12.

ii. Toxicity – Ammonia

Methanol is easier to handle in terms of transport, storage, and bunkering compared to ammonia as it is kept at ambient pressure [100] while ammonia may be pressurized. This means that in event of an accident or leak, a methanol tank would at most cause a spill, while an ammonia tank may potentially result in an explosion.

The key dangers posed by ammonia are its corrosive and toxic properties [101], which are different from methanol or traditional fuels [102]. While ammonia is commonly used in fertilizer for agricultural purposes, and transported as cargo, its use case as a fuel is unprecedented. Industry experts have cautioned that ammonia "presents very significant risks in terms of safety" [103]. It "is a lethal toxin at low concentrations" [104] "without requiring a long exposure time"[105], causing severe consequences such as lung damage [106]. While exposure safety limits are defined by national legislations and varies across jurisdictions, an internationally recognised best practice is following the US Environmental Protection Agency (EPA)'s Acute Exposure Guideline Levels (**AEGL**) for airborne chemicals [107]. Pure ammonia seeks water from the nearest source (including the human body), placing the eyes, lungs, and skin at greatest risk of blindness or burns similar to but more severe than dry ice [108]. A direct blast to a seafarer's face could result in death through suffocation,[109] and during an initial leak, liquid ammonia can rapidly expand into huge volumes of lethal gas. [110]

The major concern in an accidental leakage is the creation of a hazardous plume cloud that could travel to neighbouring regions. IMO Member States such as Singapore have carried out first-steps in developing technical references and pilot trials of ammonia bunkering, using extensive modelling with research institutes to predict and assess potential impact [111]. That said, liability issues from transboundary movement of plume clouds should be expeditiously examined by IMO before the impact of spills of ammonia occur and affected parties are left to clean up an incident without financial recourse [112].

A 2023 study which reviewed 118 research papers and 50 regulations and guidelines on ammonia bunkering found that "existing ammonia bunkering safety guidelines are insufficient" and there is a "lack of clarity about the consequences of toxic gas dispersion and fire" so a "comprehensive risk evaluation" is necessary to enhance safety [113]. Past widespread applications of ammonia in the industrial sector have led to significant consequences for safety and the environment, with a high tendency of serious incidents caused by ammonia leaks [114]. A recent accident involving the release of pure ammonia from a tanker on land reportedly formed a large plume cloud; killing five, injuring seven, and causing an evacua-

100 Section 1.1, Sustainable Ships, 'The State of Methanol as Marine Fuel 2023' (*Sustainable Ships*, 2023) <https://www.sustainable-ships.org/stories/2023/methanol-marine-fuel> accessed 27 December 2023.

101 Christodoulou and others (n 52); Conclusions, Duong and others (n 34); 'Alternative Fuels for Containerships: Methanol and Ammonia' (n 55) 78.

102 GCMD, 'GCMD Ammonia Bunkering Safety Study' (*GCMD*, 11 May 2023) 35 <https://www.gcformd.org/ammonia-bunkering-safety-study> accessed 27 December 2023.

103 CMA CGM Group (n 51).

104 Hans Kristian Haram and others (n 34) 14.

105 'Alternative Fuels for Containerships: Methanol and Ammonia' (n 55) 78.

106 "Ammonia is toxic. Exposure to ammonia vapours must always be avoided. The effect of ammonia exposure on the respiratory organs is usually limited to the upper respiratory tract since the gas dissolves well in water and induces strong reflexes that would immediately cause a person to hold their breath. However, the ammonia can reach deeper airways at higher concentrations with longer exposure time. The consequences, such as lung damage (pulmonary edema), are severe, resulting in possible mortality.": GCMD (n 102) 137.

107 ABS (n 39) 6; GCMD (n 102) 138–9.

108 Hans Kristian Haram and others (n 34) 10; 'Alternative Fuels for Containerships: Methanol and Ammonia' (n 55) 78.

109 Hans Kristian Haram and others (n 34) 10.

110 Ammonia expands 850-fold when evaporating, which means that 1 litre of liquid ammonia can expand into 170,000 litres of ammonia gas of lethal concentration, and 170,000 m3 of gas with a detectable smell.: 'Alternative Fuels for Containerships: Methanol and Ammonia' (n 55) 78; Hans Kristian Haram and others (n 34).

111 'World's First Use of Ammonia as a Marine Fuel in a Dual-Fuelled Ammonia-Powered Vessel in the Port of Singapore | Maritime and Port Authority of Singapore' (n 23).

112 Le Masurier and Pinzon (n 14).

113 For Jang's analysis of regulatory gaps of ammonia-fuelled ships or an example of Hazard identification study (HAZID) by GCMD, see Conclusions, Duong and others (n 34); GCMD (n 102); Jang and others (n 34).

114 "According to statistics, from 1985 to 2019, there were approximately 71 accidents involving anhydrous ammonia. The primary causes of deaths and injuries were identified as inhalation of the gas or fires. Chemical-based hazards have a high percentage of injuries, fatalities, and evacuations, which is in line with the alarming number of serious incidents caused by ammonia leaks.": Section 2.3.6, Duong and others (n 34).

tion of a 1.6km area [115]. Hence, if IMO proceeds with widespread adoption of ammonia, it must now focus more on the impact on human safety.

On its corrosive properties, ammonia will corrode "galvanised metals, cast iron, copper, brass or copper alloys" [116], so to avoid corrosion, appropriate materials must be used [117]. This is expected to be dealt with by IMO under amendments to the IGC Code on the use of cargo and toxic products as fuel [118], and circulars or guidelines [119].

An issue which the IMO will have to pay close attention to is with regard to the human element of safety, since crew have to be sufficiently trained to operate ammonia- or methanol-powered ships. A Norwegian study recognized that, during ammonia bunkering, crew would be subjected to risk of direct exposure which "cannot be eliminated by good design and proper operating procedures" [120]. Notably, IMO's theme for 2024 is "…safety first!" with a focus on developing the human factor in parallel to technological developments [121]. However, research suggests that half a million seafarers have to be trained by 2030 to be able to sail with ammonia as a fuel [122], posing a considerable challenge for IMO going forward since training programmes have to be designed around technical specifications of new ships whose designs are still under development. In addition, while Personal Protective Equipment (**PPE**) can be highly effective in mitigating the dangers of ammonia, a discussant at the MEPC's 81st meeting (**MEPC 81**) in March 2024 noted that the topic of appropriate PPE is important but has not received much attention [123]. The IMO should now focus on ensuring that crew are trained to properly protect themselves and respond to disasters, particularly, focusing on the shortfalls in safety standards from the widely acknowledged problem of fatigue [124].

iii. Toxicity – Methanol

Methanol is a "Low acute" toxin (defined to be dangerous for humans) [125] "associated with serious complications"[126] where inhalation of vapour is not toxic unless in excess amounts; but ingestion, eye and skin contact are the key risks – "ingestion of a small amount ([above 20ml] [127]) may cause death while lesser amounts are known to cause irreversible blindness" [128], kidney failure, and in high enough doses or prolonged exposure, death [129]. Although bunkering and onboard systems would be designed to avoid direct contact with crew, a spill could occur and crew may not be competent to deal with an emergency response [130]. Methanol poisoning is easy to misdiagnose due to delayed onset of symptoms (commonly

115 Approximately 15,000 L of ammonia was released during the accident, causing a large gaseous cloud to form. Emergency crews worked overnight in windy conditions to control the plume from the leak, with residents within a 1.6 km area evacuated: Kerry Hebden, 'US Ammonia Tanker Spill Kills Five, Injures Seven' (12 October 2023) <https://www.thechemicalengineer.com/news/us-ammonia-tanker-spill-kills-five-injures-seven/> accessed 27 December 2023.

116 GCMD (n 102) 137.

117 Duong and others (n 34).

118 CCC 10 (16 – 20 Sep 2024), where amongst others, guidelines for ships using hydrogen and ammonia as fuel will be finalized, and if time permits, to further develop guidelines for low flashpoint oil fuels: 'Sub-Committee on Carriage of Cargoes and Containers (CCC 9), 9th Session, 20-29 September 2023' <https://www.imo.org/en/MediaCentre/MeetingSummaries/Pages/CCC-9th-session.aspx> accessed 27 December 2023.

119 MSC 108 (15 – 24 May 2024), Approval of draft circulars/Guidelines for use of high manganese austenitic steel or alternative metallic materials for cryogenic service and ammonia cargo and/or fuel tanks containing ammonia: ibid.

120 Hans Kristian Haram and others (n 34) 16.

121 'World Maritime Theme 2024: "Navigating the Future: Safety First!"' (25 July 2023) <https://www.imo.org/en/MediaCentre/PressBriefings/pages/World-Maritime-Theme-2024.aspx> accessed 27 December 2023.

122 Ms. Estela Vázquez Esmerode, Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping, Panelist, Session 3, 'IMO-UNEP-Norway Innovation Forum 2023' (2023) <https://www.imo.org/en/About/Events/Pages/Innovation-Forum-2023.aspx> accessed 27 December 2023.

123 It was noted that there are many types of PPE, so suitability would have to be carefully considered in greater detail: Kjersti Aass and Arvind Natrajan, '"The Maritime Just Transition Workforce": IMO MEPC 81 Main Plenary Presentation' (IMO MEPC 81, 19 March 2024).

124 Arnold & Itkin, 'Lessons Not Learned: The Maritime Industry's Ongoing Failure to Put Safety First' (*gCaptain*, 27 November 2023) <https://gcaptain.com/lessons-not-learned-the-maritime-industrys-ongoing-failure-to-put-safety-first/> accessed 27 December 2023.

125 Page 137, Table 8-2, GCMD (n 102).

126 Nikhil Gupta and others, 'A Rare Presentation of Methanol Toxicity' (2013) 16 Annals of Indian Academy of Neurology 249.

127 Maritime and Port Authority of Singapore, 'International Safety@Sea Conference - Session 2 Operationalising Methanol Bunkering' (23 October 2023) <https://www.open.gov.sg/programme/session-2/> accessed 27 December 2023.

128 Note, "Methanol absorbs through the skin and other tissues directly into the bloodstream.": KHA, 'A Beginner's Guide to Methanol' (*KHA Online-SDS Management*, 28 July 2020) <https://www.kha.com/a-beginners-guide-to-methanol-uses-hazards-safety-tips/> accessed 27 December 2023.

129 "Ingesting 10 milliliters of pure methanol can cause critical damage to the optic nerve and the median lethal dose, when ingested, is approximately 100 milliliters.": Maritime and Port Authority of Singapore (n 127); Methanol Institute (n 61) 41.

130 Methanol Institute (n 61) 42.

12 to 14 hours), especially if the affected person may be unaware of their exposure or of methanol's toxicity [131]. It is also a colourless liquid and may present safety or security risks "due to its unintentional or intentional abuse" [132]. In 2 years of operations, Maersk has seen situations where crew have consumed paint thinking it was water, and participants at a conference had shared experiences of a captain attempting suicide by consuming methanol [133]. Past examples of methanol poisoning mostly concern illicit sale of badly produced alcohol ('black market alcohol')[134], leaving several hundreds dead or hospitalized [135]. Medical literature reported a case of a foreign sailor in Rotterdam who became brain dead after accidentally caused himself severe methanol intoxication from drinking illegally bought alcohol at a celebration onboard [136]. Similarly, in 2011, four of seven Russian seafarers had died drinking methyl alcohol bought from a chandler at a party onboard the ship [137]. Further, while the risks of deliberate poisoning of another crew onboard is likely overstated and could be mitigated with proper safeguards, regulators should not rule out its possibility if they encounter suspicious circumstances as such vessels become commonplace in the future[138].

Compared to acute, high-concentration exposure, relatively little is known about long-term, chronic, low-dose exposure [139]. Similar to ammonia, PPE is recommended for crew, but its effectiveness depends on proper crew training and the type of PPE. On this point, IMO Member State, Singapore, notably successfully conducted methanol bunkering trials [140] and submitted a paper to the CCC for discussion on, inter alia, the need to enhance the *International Convention on Standards of Training, Certification and Watchkeeping for Seafarers* (**STCW**) training requirements specifically for methanol and engagement with bunker craft operators [141].

iv. Flammability – Ammonia

On flammability risks, "ammonia is flammable but difficult to ignite" and would not generally be a fire hazard in open atmosphere, but in "machinery space and fuel preparation rooms, the risk of ignition will be higher, especially if oil and other combustible materials are present" such as in an engine room [142]. This would need to be addressed by IMO through a human-centric approach and proper crew training under the STCW, and best engineering design prac-

131 A short period of intoxication causes a mild depression of the central nervous system, followed by a period in which no symptoms of intoxication or toxicity are noted (commonly 12 to 14 hours). This is followed by physical symptoms of poisoning, such as headache, nausea, vomiting, loss of equilibrium, severe abdominal pain, and difficulty in breathing. These symptoms can be followed by coma and death: KHA (n 128).

132 Gupta and others (n 126).

133 Maritime and Port Authority of Singapore (n 127).

134 M Mustafa Arslan and others, 'Analysis of Methanol and Its Derivatives in Illegally Produced Alcoholic Beverages' (2015) 33 Journal of Forensic and Legal Medicine 56.

135 From March to April 2018, Indonesia had experienced its worst spate of methanol poisoning incidents in West Java, Jakarta, and Papua, leaving more than 100 people dead and over 160 in hospital after drinking bootleg alcohol containing fatal amounts of methanol. According to a Centre for Indonesian Policy Studies, in Indonesia, "487 people had died from illegal alcohol poisoning between 2013 and 2016—a 226% increase over figures from 2008 to 2012", but the figures are often inaccurate because methanol poisoning is often misdiagnosed or attributed to something else, such as bleeding in the brain. In Iran 76 people died, 460 were hospitalized and 768 were made ill from a methanol-poisoning incident in 2018: 'Bootleg Alcohol Kills 82 People in Indonesia, 100 Others in Critical Condition - ABC News' <https://www.abc.net.au/news/2018-04-10/indonesia-bootleg-alcohol-kills-82-people/9639332> accessed 29 March 2024; Renaldo Gabriel, 'Indonesia Banned Beer in Mini Markets to Protect The Youth. It's Having The Opposite Effect' (*Vice*, 13 February 2017) <https://www.vice.com/en/article/aeyznp/indonesia-banned-beer-in-mini-markets-to-protect-the-youth-its-having-the-opposite-effect> accessed 29 March 2024; Box 4.1, OECD, *Illicit Trade in High-Risk Sectors: Implications of Illicit Alcohol for Public Health and Criminal Networks* (OECD 2022) 40 <https://www.oecd-ilibrary.org/governance/illicit-trade-in-high-risk-sectors_1334c634-en> accessed 29 March 2024; Table 1, Louise Manning and Aleksandra Kowalska, 'Illicit Alcohol: Public Health Risk of Methanol Poisoning and Policy Mitigation Strategies' (2021) 10 Foods 1625, 3–5.

136 He was found unconscious in his cabin by the ship's captain after not appearing on deck for his shift, and one crew confessed they had been celebrating together about 8-12 hours ago, with alcohol bought illegally from a small harbour store the previous day: Jelle L Epker and Jan Bakker, 'Accidental Methanol Ingestion: Case Report' (2010) 10 BMC Emergency Medicine 3.

137 It was reported that "all 7 felt bad immediately after [the] party, 1 died in his cabin, 6 others were evacuated to hospital [—] 3 died (…on the way to hospital) and 3 were put in intensive therapy ward": SAFETY4SEA Team, '4 Russian Seafarers Dead Drinking Methyl Alcohol' (*SAFETY4SEA*, 24 June 2011) <https://safety4sea.com/4-russian-seafarers-dead-drinking-methyl-alcohol/> accessed 29 March 2024.

138 i.e., where methanol is no longer transported in segregated cargo tanks but readily transferred as fuel.

139 There are limited number of case reports and epidemiologic studies: KHA (n 128).

140 Maritime and Port Authority of Singapore, 'Successful First Methanol Bunkering Operation in the Port of Singapore' (*Maritime & Port Authority of Singapore (MPA)*, 27 July 2023) <http://www.mpa.gov.sg/media-centre/details/successful-first-methanol-bunkering-operation-in-the-port-of-singapore> accessed 27 December 2023.

141 Maritime and Port Authority of Singapore (n 127).

142 GCMD (n 102) 137.

tices such as redundancy, air lock solutions, separate spaces, automatic valves with a manual backup, gas detection devices, and external water screens to prevent leaking ammonia from entering adjacent spaces [143].

v. Flammability – Methanol

The dangers of methanol are that it is easily flammable and produces a fire invisible to the naked eye in daylight [144]. Further, it is slightly denser than air and tends to accumulate in confined and low-lying spaces without dissipating and if ignited, methanol vapour could flash back to its source although it may explode rather than ignite [145]. This makes it especially prone to risk of smoking – a common cause of vessel fire – by seafarers onboard [146]. Some amendments for fire protection are envisaged with regard to insulation and ventilation pipes or air inlets for hazardous enclosed spaces [147], as well as drones equipped with sensors[148] for port authorities to detect methanol fires onboard vessels in their waters.

c. Marine Environment

i. Ammonia

From a safety perspective, it is preferable to drain ammonia spills into seawater than keep it onboard. However, it is suggested that the impact of ammonia on the marine environment should be assessed further, given the considerable scientific knowledge gap [149]. From Figure 3 (Appendix), ammonia is highly toxic to marine environments – 1161 times more lethal to fish than Heavy Fuel Oil (**HFO**) [150]. Ammonia is classified as toxic to aquatic life with long lasting effects according to the UN's Globally Harmonized System of Classification and Labelling of Chemicals (GHS) [151], and scientific studies have found that it has "severe impact on aquatic life, as lethal levels are easily surpassed, causing death to most species in close proximity" [152]. As a leading fuel candidate, the impact to marine life must now be more closely examined since ammonia "has a high affinity for water" and can be dissolved easily in water [153], and is "very toxic to aquatic life upon release to the environment" [154]. An estimated 3,500 fish died in a 12km stretch of a nearby stream contaminated by the Ohio train accident [155].

Other experts believe the risks to the marine environment are low because a significant part of ammonia will evaporate without contaminating the water, and that even if it did, that the concentration of ammonia would not exceed permissible values [156]. Yet it is also acknowledged that "it can be deadly to fauna and flora in certain circumstances, and the actual effects of ammonia spillage on the water are difficult to predict" [157].

143 For a detailed discussion on the many design considerations and safety precautions necessary, see DNV's analysis: 'Alternative Fuels for Containerships: Methanol and Ammonia' (n 55) 90–3.

144 A crew could unknowingly walk into a methanol flame onboard the ship. Low flashpoint of 11-12C: Table 8-2, GCMD (n 102) 137; Flashpoint of 12 °C is the lowest temperature at which vapors emanate from methanol in sufficient quantities to form an ignitable vapor-air mixture. Additionally, methanol's flammable range in dry air is between 6 percent and 36.5 percent and can create an explosive or flammable environment.: Section 3.6, Methanol Institute (n 61).

145 KHA (n 128).

146 SAFETY4SEA (Editor), 'No Smoking Rules Vital for Life Onboard' (*SAFETY4SEA*, 17 July 2018) <https://safety4sea.com/cm-no-smoking-rules-vital-for-life-onboard/> accessed 27 December 2023.

147 Lloyd's Register, 'Future IMO and ILO Legislation Autumn 2023 | LR' (n 46).

148 For example, infrared cameras.

149 Mengli Chen and others, 'Bunkering for Change: Knowledge Preparedness on the Environmental Aspect of Ammonia as a Marine Fuel' (2024) 907 Science of The Total Environment 167677.

150 "Methanol is…toxic to aquatic organisms at concentrations above 1000 mg/l and especially 10,000 mg/l and above. It is useful, however, to put these figures into context by comparing methanol to other marine fuels. The toxicity of a chemical is often presented as Lethal Concentration 50 (LC50), which is the dose that is lethal to 50 percent of organisms in a given population. In a body of water, the LC50 of fish for methanol is 15,400 mg/l, compared to just 79 mg/l for HFO. In other words, other things being equal, you would need to spill 200 times more methanol than HFO to kill the same number of fish. By this measure of toxicity, other fuels are even more lethal to fish than HFO and all fuels are more toxic than methanol. Further, the LC 50 for ammonia is just 0.068 mg/l, which makes ammonia highly toxic to marine environments.": Methanol Institute (n 61) 42.

151 Hans Kristian Haram and others (n 34) 10; United Nations, 'Globally Harmonized System of Classification and Labelling of Chemicals (GHS)' (2011) <https://unece.org/fileadmin/DAM/trans/danger/publi/ghs/ghs_rev04/English/ST-SG-AC10-30-Rev4e.pdf> accessed 27 December 2023.

152 Section 2.3.2, Duong and others (n 34).

153 Kenneth Lyle, 'Sharing Chemistry with the Community: The Solubility and Alkalinity of Ammonia' (*Chem 13 News Magazine*, 1 September 2017) <https://uwaterloo.ca/chem13-news-magazine/november-2015/feature/sharing-chemistry-community-solubility-and-alkalinity> accessed 27 December 2023.

154 GCMD (n 102) 138.

155 Kerry Hebden (n 115).

156 Section 4.3, Machaj and others (n 33).

157 Section 4.3, ibid.

ii. Methanol

Methanol has limited impact on marine life compared to ammonia and conventional fuels. From the figure above, methanol is about 195 times less harmful to fish than heavy fuel oil, and about 226,500 times less harmful to fish than ammonia. Short-term exposure has only temporary and reversible effects on marine life; and it is fully miscible in water (ie, easily diluted to low concentrations in case of a spill at sea) and biodegradable [158]. The relatively low risk of marine environmental damage from methanol spills compared to traditional fuels makes it a suitable choice for sensitive environments such as the Arctic and other Emission Control Areas [159].

d. Air Pollution and GHG Emissions

It is important to recognize that ammonia and methanol might not reduce air pollution compared to traditional fuels [160]. Hence, proper implementation from IMO on use of these two fuels is necessary moving forward. Ammonia spills could rapidly form a plume cloud that may affect living organisms in its vicinity in manners different from oil spills [161]. Further, in terms of GHG emissions, there are associated challenges of ensuring that green ammonia or methanol produced using renewable electricity are properly certified. Yet there is no chemical difference between grey, green or blue ammonia or methanol [162], making it hard to distinguish, although research into "fingerprinting" of synthetically-made fuels is currently underway [163]. While methanol could have less than half of conventional fuels' lifecycle GHG emissions, "environmental benefits of methanol are highly dependent on the raw materials used to make it...[with little improvement] over MGO if it is made with an electricity mix that does not have a high share of renewables" [164]. Moreover, dirty-grey ammonia and methanol are significantly more pollutive than traditional MGO [165].

Ammonia-fuel could reduce SOx and CO_2 emissions significantly, but may exacerbate the GHG emissions problem, as "burning ammonia creates N_2O, a very potent greenhouse gas, which has global warming potential (GWP) of 300, compared with 30 for methane" [166], so IMO should consider standardising ammonia engines guidelines which address

158 "…other things being equal, you would need to spill 200 times more methanol than HFO to kill the same number of fish. By this measure of toxicity, other fuels are even more lethal to fish than HFO and all fuels are more toxic than methanol": Methanol Institute (n 61) 42.

159 MEPC 81 in March 2024 had approved ECAs for the Arctic which could be potential applications for methanol-fuelled vessels. ibid 10, 42.

160 Zuza Nazaruk (n 54); Meanwhile, some question the ultimate objectives of using green fuels to decarbonise shipping altogether, and that we have set our sights on the wrong goal: 'Decarbonising the World: A Dead Horse Flogging Itself? - Splash247' <https://splash247.com/decarbonising-the-world-a-dead-horse-flogging-itself/> accessed 2 April 2024.

161 "…ammonia gas cloud can pose a significant danger to creatures in its immediate vicinity, as it can expose them to deadly amounts of ammonia. This cloud remains a threat until it is completely diluted through the processes of cloud evaporation and continuous air mixing.": Section 2.3.2, Duong and others (n 34).

162 The "colour" of such fuels are part of a labelling convention to identify the production process and how much carbon is emitted in its entire lifecycle commonly categorized as 'brown', 'grey', 'blue', or 'green', ranked in decreasing amount of carbon footprint. See, Brian Perrott, Michael Buisset, and Lee Forsyth, 'NH3 News: Is Ammonia the Future of Long-Distance Hydrogen Transport?' (*HFW*) <https://www.hfw.com/NH3-News-Is-ammonia-the-future-of-long-distance-hydrogen-transport> accessed 27 December 2023; Ship & Bunker, 'LNG Bunker Supporters Criticise Maersk's Approach to First Methanol Voyage' (*Ship & Bunker*, 15 June 2023) <https://shipandbunker.com/news/world/853764-lng-bunker-supporters-criticise-maersks-approach-to-first-methanol-voyage> accessed 27 December 2023.

163 Generally, the concept of fingerprinting refers to introduction of a drop-in tracer substance into the bunker fuel (e.g., ammonia or methanol) which would react with dirty-made fuels and distinguish it from cleanly-produced ones. See, Jialu Li and others, 'Fingerprinting the Ammonia Synthesis Pathway Using Spatiotemporal Electrostatic Potential Distribution of Intermediates' (2021) 6 ACS Omega 6292; 'Marine Fuels 360: Fingerprinting to Play Key Role in Proving Biofuel Feedstock Authenticity and beyond, Says VPS | Manifold Times' (29 November 2023) <https://www.manifoldtimes.com/news/marine-fuels-360-fingerprinting-to-play-key-role-in-proving-biofuel-feedstock-authenticity-and-beyond-says-vps/> accessed 1 April 2024.

164 International Maritime Organization, 'Methanol as Marine Fuel: Environmental Benefits, Technology Readiness, and Economic Feasibility' (2016) 16 <https://greenvoyage2050.imo.org/wp-content/uploads/2021/01/METHANOL-AS-MARINE-FUEL-ENVIRONMENTAL-BENEFITS-TECHNOLOGY-READINESS-AND-ECONOMIC-FEASIBLITY.pdf> accessed 27 December 2023.

165 Methanol produced from gasification of coal has twice as high GHG emissions as from natural gas: 'Alternative Fuels for Containerships: Methanol and Ammonia' (n 55) 49, 78; Data of Argonne National Laboratory on grey ammonia's lifecycle: Bioenergy Technologies Office, 'Sustainable Marine Fuels' (*Energy.gov*) <https://www.energy.gov/eere/bioenergy/sustainable-marine-fuels> accessed 27 December 2023; Anthony Foretich and others, 'Challenges and Opportunities for Alternative Fuels in the Maritime Sector' (2021) 2 Maritime Transport Research 100033; International Maritime Organization (n 164) 17 Figure 4–9.

166 CMA CGM Group (n 51); 'Brown/grey ammonia is a major contributor to current global CO_2 emissions. Using brown or grey ammonia as ship fuel therefore increases the well- to-wake CO_2 emissions compared to simply burning fuel oil': 'Alternative Fuels for Containerships: Methanol and Ammonia' (n 55) 78.

by-product gases (e.g., use of scrubbers) if they proceed with widespread adoption in the future to avoid liability issues [167]. Second, the formation of nitrogen oxides (NOx) from burning ammonia is still not well understood and currently the core focus of various research groups [168], but it is recognised to worsen existing illnesses and cause premature deaths [169]. Other experts warned of potential methane slips and energy inefficiencies which could cause blue ammonia to emit 2.5 to 3 times more GHG than regular fuels [170].

Methanol has the potential for air emissions reductions of NOx, SOx, particulate matter, or black carbon by 95%. [171]

III. Regulation of Alternative Marine Fuels at IMO

The IMO organs responsible for regulating issues regarding alternative fuels are the MEPC and the Maritime Safety Committee (**MSC**). MEPC deals with "the prevention and control of marine pollution from ships" and implements its GHG Strategy through amendments to Annex VI of *International Convention for the Prevention of Pollution from Ships* (**MARPOL Annex VI**) [172]. MSC regulates matters directly affecting maritime safety, such as, in*ter alia*, "...construction and equipment of vessels, manning from a safety standpoint, rules for the prevention of collisions, handling of dangerous cargoes, maritime safety procedures and requirements" [173].

The Working Group on Air Pollution and Energy Efficiency, Intersessional Working Group on Reduction of GHG Emissions from Ships (**ISWG-GHG**), and Correspondence Group on the Future Development of the Lifecycle Assessment Framework (**CG**) were established to continue work on specific items or maintain coordination between committee meetings [174]. The Sub-Committee on Carriage of Cargoes and Containers (**CCC**) which deals with the safety of carriage of dangerous goods and considers revisions to the *International Code of Safety for Ships Using Gases or Low Flashpoint Fuels* (**IGF Code**), the *International Code of the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk* (**IGC Code**) and *International Maritime Dangerous Code* (**IMDG Code**); and Sub-Committee on Ship Design and Construction (**SDC**) also support the technical work of MSC and MEPC on alternative fuels. The IMO Website contains the latest developments on this matter, and Figure 4 (Appendix) outlines the relationship between the applicable IMO bodies. [175].

Against increased environmental pressures, MEPC adopted a resolution (collectively referred to as **GHG Strategy**) setting out its plans to tackle ship-sourced GHG emissions[176] – first, the *Initial IMO Strategy on Reduction of GHG Emissions from Ships* (**2018 Initial Strategy**) [177], subsequently revoked and replaced by the *2023 IMO Strategy on Reduction of GHG Emissions from Ships* (**2023 Strategy**) [178]. IMO outlined a timeline of short-term (2018-2023) [179], mid-term (2025-2030), and long-term (beyond 2030) measures to implement GHG emissions reduction targets

167 Hans Kristian Haram and others (n 34) 10. See LNG for instance, Bojan Lepic, 'LNG as Shipping's Alternative Fuel in Crosshairs Again with European Court Challenge' (*Splash247*, 16 January 2024) <https://splash247.com/lng-as-shippings-alternative-fuel-in-crosshairs-again-with-european-court-challenge/> accessed 29 March 2024.

168 Note that it can be addressed through the use of scrubbers as well.

169 At the core of the research agendas of various research groups: Hans Kristian Haram and others (n 34) 10.

170 Howarth estimates that the methane emissions from blue hydrogen production, compounded by losses from conversion, mean that in total, blue ammonia emits 2.5 to 3 times more greenhouse gases than 'regular' fuels such as coal, natural gas, or diesel: Zuza Nazaruk (n 54).

171 Methanol Institute (n 61) 10, 42.

172 'International Convention for the Prevention of Pollution from Ships (MARPOL)' (*IMO Website*) <https://www.imo.org/en/about/Conventions/Pages/International-Convention-for-the-Prevention-of-Pollution-from-Ships-(MARPOL).aspx> accessed 27 December 2023.

173 Art 28(a), *1948 Convention on the International Maritime Organization, 289 UNTS 3, Adopted on 6 March 1948, Entered into Force on 17 March 1958.* (n 10); Maria Pia Benosa and Robert Beckman, CIL Guide to the International Maritime Organization (NUS Centre for International Law 2022) <https://cil.nus.edu.sg/publication/cil-guide-to-the-imo/> accessed 27 December 2023.

174 Maria Pia Benosa and Robert Beckman, ibid.

175 'Mid- and Long-Term GHG Reduction Measures' (*IMO Website*) <https://www.imo.org/en/OurWork/Environment/Pages/Mid--and-long-term-GHG-reduction-measures.aspx> accessed 27 December 2023.

176 Ong (n 85).

177 'Initial IMO Strategy on Reduction Of GHG Emissions From Ships' (2018) <https://wwwcdn.imo.org/localresources/en/KnowledgeCentre/IndexofIMOResolutions/MEPCDocuments/MEPC.304(72).pdf> accessed 27 December 2023.

178 '2023 IMO Strategy on Reduction of GHG Emissions from Ships' (n 86).

179 Defined as "measures finalized and agreed by MEPC between 2018 and 2023": Appendix 1, ibid.

for shipping. However, the 2023 Strategy raised targets significantly – doubling 2050 ambitions from "50%" to "net-zero" and adding a new energy share criterion for 2030 [180] – accelerating the move for shipping to explore and adopt alternative fuel pathways to meet IMO decarbonization targets. See Figure 5 (Appendix) for details on the key changes.

The 2023 Strategy was adopted by the 80th session of MEPC and its main ambitions are, compared to 2008 [181]: i) Total annual GHG emissions reductions of at least 20% (striving for 30%) by 2030, at least 70% (striving for 80%) by 2040, and reaching net-zero "by or around, i.e. close to, 2050"[182]; ii) Reduction in carbon intensity[183] by at least 40% by 2030[184]; and iii) "uptake of zero or near-zero GHG emission technologies, fuels and/or energy sources to represent at least 5%, striving for 10%, of the energy used by international shipping by 2030" (**5% fuel uptake**).

IMO agreed to standardize carbon accounting of GHG emissions for marine fuels and calculate total lifecycle emissions – from fuel production to end-use by a ship (***well*-to-wake**) – instead of existing calculations from merely a ship's fuel tank to the exhaust (***tank*-to-wake**) [185], set out in their "Guidelines on Life Cycle GHG Intensity of Marine Fuels" (**LCA Guidelines**). That said, the LCA Guidelines do not contain any provisions for application or legal requirements, and are instead intended to support the GHG Fuel Intensity regulation under development by IMO [186].

While short-term measures such as EEXI, CII, and SEEMP frameworks were introduced under the 2018 Strategy to tackle carbon intensity [187], alternative fuels is a key mid- to long-term measure to achieve green, sustainable shipping [188].

IV. Gaps and Policy Recommendations

1. IMO GHG Strategy

The IMO is conducting five-yearly reviews of its GHG Strategy (with the first review due in 2028)[189]. The gap is that, in general, principles of safety and environmental protection have to date not been formally incorporated into the review process since the IMO's focus has been on achieving the net-zero emissions targets. Hence, if the IMO proceeds with adoption of the two new fuels for shipping, it is suggested that they need to give more focus to potential risks to human safety and the marine environment in their implementation plan moving forward. The following are some recommendations.

First, under Section 4.9 of the 2023 Strategy, the IMO is considering a regulatory assessment of safety and air pollution aspects as a "possible" future step [190], and safety and marine environment are absent from the key "guiding principles" of the 2023 Strategy [191]. It is recommended that safety and marine environment should be added as key guiding principles, and the IMO should incorporate the marine environmental aspect into this regulatory assessment.

Second, the IMO will consider, *inter alia*, the data collected under the Comprehensive Impact Assessment (**CIA**) on the impact on States[192]. However, the CIA contains no express references to safety and environmental aspects except post-facto – the "disaster response" criterion [193]. The CIA is significant as mid-term GHG measures may not be considered for adoption until impact assessments are done and disproportionately negative impacts are addressed (with regard to equity and the needs of developing countries). It is recommended that the IMO include safety and

180 Para 3.3.3, ibid.

181 For further details, see Annex 1, Page 6, '2023 IMO Strategy on Reduction of GHG Emissions from Ships' (n 86); 'Marine Environment Protection Committee (MEPC 80), 3-7 July 2023' <https://www.imo.org/en/MediaCentre/MeetingSummaries/Pages/MEPC-80.aspx> accessed 27 December 2023.

182 In 2018 Strategy, the 2050 goal was a minimum 50% reduction by 2050.

183 Emissions per transport work, as an average across international shipping.

184 On carbon intensity, the minimum 40% by 2030 target was retained from 2018 Strategy, but the phrase "pursuing efforts towards 70% by 2050" was removed.

185 Paras 3.2 and 4.7, '2023 IMO Strategy on Reduction of GHG Emissions from Ships' (n 86).

186 'DNV on IMO MEPC 81: Negotiations on New GHG Reduction Requirements Continue | Manifold Times' (25 March 2024) <https://www.manifoldtimes.com/news/dnv-on-imo-mepc-81-negotiations-on-new-ghg-reduction-requirements-continue/> accessed 28 March 2024.

187 Shipping looks on track to meeting the 40% by 2030 intensity target. The Fourth GHG Study 2020 by IMO had found that overall carbon intensity between 2012-2018, averaged across international shipping, had improved by 29% compared to 2008 levels: 'Fourth Greenhouse Gas Study 2020' (n 2).

188 Garcia, Foerster and Lin (n 5) 91.

189 At MEPC 86 (Summer 2027) and MEPC 88 (Autumn 2028).

190 Para 4.9.4 and 4.9.5, '2023 IMO Strategy on Reduction of GHG Emissions from Ships' (n 86).

191 Para 3.5, ibid.

192 MEPC 80 (July 2023) initiated the CIA of the impacts on States of its basket of candidate mid-term measures.

193 Para 4.12, '2023 IMO Strategy on Reduction of GHG Emissions from Ships' (n 86).

environment as key terms for its CIA on the impact on States, especially since mitigation measures for minimizing the potential negative impacts of ammonia and methanol depend heavily on implementation of new sophisticated technologies and on adequate crew training. The IMO should take into account the fact that States have varying capacities to implement alternative fuel technologies measures, and consequently, varying abilities to implement mitigation measures for the impact of such technologies.

Since other terms can be considered for inclusion [194], it is recommended that the IMO includes safety and marine environmental considerations such as EIAs into the CIA.

2. Environmental Impact Assessments

ITOPF has stated that "it is paramount that the consequences of using these fuel types are better understood beforehand", and that more research needs to be conducted on "how these fuels will behave when spilled, how the environment and nearby receptors will be affected and how impacted stakeholders will be compensated" [195]. Similarly, LR has stated that "crucial data on environmental impact (N2O and ammonia slippage) and operational safety (toxicity during maintenance and inspection) remain missing" [196]. The IMO would have to review and adapt their guidelines for such vessels. However, ammonia dissolves differently in different parts of the world – in warmer, more humid tropical regions, it dissolves slower than colder regions such as Europe [197]. Therefore, it is important that EIAs are conducted to provide valuable data [198]. Nevertheless, concern should focus on who will pay for these EIAs, who conducts it, and who are consulted.

Further, the potential application of Particular Sensitive Sea Areas (PSSAs) or MARPOL Special Areas[199] to ammonia-fuelled vessels which can cause grave harm to the marine environment (particularly "mass marine organism fatalities...within the immediate vicinity of an incident"[200]) should be considered by IMO [201]. Routeing measures or strict discharge requirements could be introduced for ammonia-fuelled vessels to protect sensitive areas of marine biodiversity.

Beyond reporting to SBSTA, IMO could cooperate with the UNFCCC as a non-specialized UN agency under Article 61 of the *1948 Convention on the International Maritime Organization* on the request of Member States[202] and tap on their past experience in regulating issues including lifecycle emissions accounting, transparency, and certification [203]. IMO has observer status at UNFCCC [204], but ostensibly not vice versa [205]. Admittedly, it is acknowledged that this suggestion may not be practical as both the IMO and UNFCCC are complex with varying focal points[206], and that exact areas of cooperation will be hotly debated. Nevertheless, on issues more unfamiliar to IMO such

194 "inter alia": Para 4.12, ibid.

195 Le Masurier and Pinzon (n 14).

196 'Fuel for Thought: Introduction to Ammonia | LR' (n 35).

197 As with any gas, the solubility of ammonia gas in water decreases as the temperature increases.: Flinn Scientific, Inc., 'Solubility of Ammonia: Indicator Color Show' (2016) Publication No. 10832 061616 <https://www.flinnsci.com/api/library/Download/5007f36bcfa94c899f1b1f3419dd7ec1> accessed 1 April 2024.

198 Based on the principle of "evidence-based decision-making balanced with the precautionary approach": Paragraph 3.5.1.4, '2023 IMO Strategy on Reduction of GHG Emissions from Ships' (n 86).

199 Areas where ships must comply with stricter regulations with respect to the discharge of substances that can pollute the marine environment such as oil, sewage & garbage.

200 Le Masurier and Pinzon (n 14).

201 PSSAs are areas established by the IMO where ships restrictions are imposed on the passage of such ships.

202 "Article 61. The Organization may, on matters within its scope, co-operate with other intergovernmental organizations which are not specialized agencies of the United Nations, but whose interests and activities are related to the purposes of the Organization." It is clear that climate change as it pertains to shipping is a "matter within [IMO's] scope", and the UNFCCC's "interests and activities are related" to the purposes of the IMO: *1948 Convention on the International Maritime Organization, 289 UNTS 3, Adopted on 6 March 1948, Entered into Force on 17 March 1958.* (n 10).

203 'Transparency | UNFCCC' <https://unfccc.int/Transparency> accessed 28 March 2024.

204 Article 7, paragraph 6 of the United Nations Framework Convention on Climate Change (UNFCCC) provides that the United Nations, its specialized agencies and the International Atomic Energy Agency, may be represented at sessions as observers: 'United Nations Organizations | UNFCCC' <https://unfccc.int/process-and-meetings/parties-non-party-stakeholders/non-party-stakeholders/overview/united-nations-organizations> accessed 28 March 2024; *1992 United Nations Framework Convention on Climate Change, 1771 UNTS 107, Adopted on 09 May 1992, Entered into Force on 21 March 1994.* (n 6).

205 UNFCCC is not contained in this list provided by IMO, nor is it a UN specialized agency like the ILO found in other lists: 'Intergovernmental Organizations Which Have Concluded Agreements of Cooperation with IMO' <https://www.imo.org/en/OurWork/ERO/Pages/IGOsWithObserverStatus.aspx> accessed 28 March 2024.

206 There had been past situations where IMO had to cooperate with other international organizations such as ILO and WHO including during the COVID-19 crew change crisis and faced considerable challenges.

as transparency and certification of upstream supplies of alternative fuels produced on *land* (i.e., outside of IMO's remit which requires cooperation with land-based authorities to properly implement lifecycle assessments), it might be beneficial to have greater involvement and cooperation with UNFCCC.

3. Promoting Uptake of New Fuels

Another challenge for the IMO is the first-mover problem, and promoting or incentivizing shipowners and carriers to transition while maintaining their goals-based, technology-agnostic philosophy towards regulation. For instance, while the IMO adopted a 5% fuel uptake target in its 2023 Strategy, the Strategy is a policy document that is technically non-binding [207]. The uncertainties due to lack of a longer-term regulatory framework and available supplies of new fuels created challenges for many stakeholders [208]. Private maritime law frameworks for charterparties and shipping contracts would have to be re-designed [209]. While there is consensus on *what* needs to be achieved especially with increasing environmental pressures to decarbonize shipping, *how* the regulations would implement the Strategy in a consistent and uniform manner remains deeply divided among IMO members [210]. On the other hand, technologies for the different fuels have yet to reach maturity, so it is similarly difficult for stakeholders to discern which fuel would be the winning solution[211] to commit to over another, with potentially costly consequences if they bet on the wrong horse [212]. With mixed market and regulatory signals, arbitration exists between different shipowners, operators, suppliers in industry and among IMO Member States. This drives up costs as the industry is "forced to diversify their investments across multiple fuel options", hampering the development of a harmonised approach towards decarbonization [213].

One such divide at the IMO pertains to market-based measures intended to make investments in green fuels economic compared to conventional fuels [214]. A candidate economic mid-term measure considered by the IMO is a GHG pricing mechanism which would impose a fee on emissions generated by ships. However, deep divisions existed over emissions price as well as pricing methodology. At MEPC 81, four different proposals with a combined 47 backers were discussed but no agreement was reached although an overarching structure for the needed regulatory amendments was agreed upon – the "IMO net-zero framework" [215]. In terms of price, the Inter-

207 It must then be implemented through the IMO Conventions such as MARPOL.

208 In 2030 more than 3 million tonnes of clean methanol and a minimum of 280,000 tonnes of clean ammonia will be needed to meet the demand of 137 alternative fuelled ships within the 359 vessel baseline fleet of the Silk Alliance cluster, envisioned as mainly bunkering in Singapore: 'Shipping Is Sizing up Energy Transition Opportunities | LR' <https://www.lr.org/en/knowledge/insights-articles/shipping-is-sizing-up-energy-transition-opportunities/> accessed 9 February 2024; Further, retrofitting ship engines or purchasing new vessels have an inherent sunk cost of the lifespan of such vessels which could be 20-30 years: Georgina Mccartney, 'Shipping Industry Faces Fuel Dilemma in Bid to Cut Emissions' *Reuters* (26 March 2024) <https://www.reuters.com/sustainability/boards-policy-regulation/shipping-industry-faces-fuel-dilemma-bid-cut-emissions-2024-03-26/> accessed 28 March 2024.

209 'NorthStandard: Contractual Issues for Methanol in Alternative and Dual-Fuel Future | Manifold Times' (28 March 2024) <https://www.manifoldtimes.com/news/northstandard-contractual-issues-for-methanol-in-alternative-and-dual-fuel-future/> accessed 30 March 2024.

210 China, Brazil and Argentina pushed back on the idea of a CO2 levy in IMO talks…A proposal by Argentina, Brazil, China, Norway, South Africa, the United Arab Emirates and Uruguay advocates a global fuel emissions intensity limit, with a financial penalty for breaches, as an alternative to a levy on all shipping emissions.
That would mean if countries fully complied with the fuel standard, no emissions would face the fee. "We will not be in favour of a flat levy likely to hurt developing countries, but we would be in favour of a good levy only applied to the emissions over a certain benchmark," the Brazilian negotiator said: Kate Abnett and Kate Abnett, 'Pressure Builds for Charge on Global Shipping Sector's CO2 Emissions' *Reuters* (18 March 2024) <https://www.reuters.com/sustainability/climate-energy/pressure-builds-charge-global-shipping-sectors-co2-emissions-2024-03-18/> accessed 28 March 2024.

211 Mccartney (n 208).

212 A newbuild ship could cost hundreds of millions to construct.

213 Mccartney (n 208).

214 Researchers have said a $150 carbon price could make investments in low-carbon ammonia-fuelled systems economic compared with conventional ships: Abnett and Abnett (n 210); Sotiria Lagouvardou and others, 'Marginal Abatement Cost of Alternative Marine Fuels and the Role of Market-Based Measures' (2023) 8 Nature Energy 1209. There would also be no disproportionately negative impacts on national economies in terms of delivered cargo prices from an added cost of US$20 to $300 per tonne of fuel oil consumed based on Clarksons Research for ICS: 'ICS Submits Proposal on Zero Emission Shipping Fund to IMO | Manifold Times' (n 83).

215 The "IMO net-zero framework" is envisaged to outline the necessary regulatory amendments to the International Convention for the Prevention of Pollution from Ships (MARPOL) Annex VI which regulates air pollution from ships, including adding a new Chapter 5 to Annex VI: 'DNV on IMO MEPC 81: Negotiations on New GHG Reduction Requirements Continue | Manifold Times' (n 192); Abnett and Abnett (n 210). For more details, see, SAFETY4SEA Editor, 'IMO MEPC 81 Proposes New Chapter 5 of MARPOL Annex VI' (*SAFETY4SEA*, 23 March 2024) <https://safety4sea.com/imo-mepc-81-proposes-new-chapter-5-of-marpol-annex-vi/> accessed 28 March 2024.

national Chamber of Shipping (**ICS**)[216], Liberia and the Bahamas[217] proposed a $20-40 carbon levy price; Japan called for a progressive tax starting at $175 from 2025 to $2000 by 2040; the Marshall Islands called for $300; former Maersk CEO Soren Skou has called for $450; and Trafigura has advocated for as much as $900 per tonne [218]. Maersk had even withdrew from ICS's Board over differences in climate aspirations [219]. In terms of methodology, ICS proposed a "tax and subsidy system" and the World Shipping Council proposed a 'Green Balance Mechanism' which raises the costs of conventional fuels and lowers that of expensive green fuels [220], while some States such as Japan and EU member States advocated for a "flat-rate" carbon levy, and others preferred a "feebate" mechanism [221].

Further politically divisive issues include climate financing and equity (including administering the charge and management of proceeds collected) which had upended past negotiations [222]. ICS, Bahamas and Liberia co-proposed a 'Zero Emission Shipping Fund' which would include support for the development of bunkering infrastructure in developing countries' ports worldwide, and argued that shipowners consuming fuel oil should contribute to the fund and subsidize those who consume alternative fuels [223].

Amidst the ongoing debate at the IMO, several States including India[224] and the EU have taken the initiative to introduce national and regional subsidy schemes in the hydrogen space, and shipping-specific R&D and capital expenditure subsidies [225] to enhance investor confidence and create demand and supply for the uptake of alternative fuels and related infrastructure outside of the IMO[226]. The Net Zero Insurance Alliance and Poseidon Principles for Insurance proposed coupling insurance costs to decarbonization ambitions, such as lowering premiums for using carbon-neutral fuels [227].

4. Harmonization of Standards

Another challenge is harmonization of standards – important to avoid unilateralism by individual or blocs of countries which would cause varying local standards and fragmentation of international shipping[228] – the EU introduced its regional Emissions Trading System[229] and said it may "bring more inter-

216 The world's largest shipowners' association and an influential industry body at IMO.

217 Two of the largest flag States in the world.

218 'ICS Proposes $20-40 Carbon Levy With No Automatic Increases' (*The Maritime Executive*) <https://maritime-executive.com/article/ics-proposes-20-40-carbon-levy-with-no-automatic-increases> accessed 28 March 2024.

219 'Maersk Withdraws From Board Membership at ICS, Citing Climate Goals' (*The Maritime Executive*) <https://maritime-executive.com/article/maersk-withdraws-from-board-membership-at-ics-citing-climate-goals> accessed 28 March 2024.

220 'ICS Proposes $20-40 Carbon Levy With No Automatic Increases' (n 218); Drewry, 'IMO Ponders New GHG Policies, While Shipping Sector Awaits Low-Carbon Economic Incentive' (8 March 2024) <https://www.hellenicshippingnews.com/imo-ponders-new-ghg-policies-while-shipping-sector-awaits-low-carbon-economic-incentive/> accessed 28 March 2024.

221 'ICS Proposes $20-40 Carbon Levy With No Automatic Increases' (n 218); Drewry (n 220); 'Ocean Carriers Propose "Feebate" Carbon Levy With Annual Increases' (*The Maritime Executive*) <https://maritime-executive.com/article/ocean-carriers-propose-feebate-carbon-levy-with-annual-increases> accessed 28 March 2024.

222 Abnett and Abnett (n 210).

223 Bahamas, Liberia and ICS, 'ISWG-GHG 16/2/3, Possible Draft Amendments to MARPOL Annex VI to Establish a Fund and Reward (Feebate) Mechanism as a Maritime GHG Emissions Pricing Mechanism' <https://view.officeapps.live.com/op/view.aspx?src=https%3A%2F%2Fwww.ics-shipping.org%2Fwp-content%2Fuploads%2F2024%2F01%2FISWG-GHG-16-2-3-ZESF-Possible-amendments-to-MARPOL-Annex-VI-final-Thurs-25-Jan.docx&wdOrigin=BROWSELINK> accessed 28 March 2024; 'ICS Submits Proposal on Zero Emission Shipping Fund to IMO | Manifold Times' (n 83); Max Lin, 'IMO Should Require Oil Bunker Users to Subsidize Alternative Fuels: ICS' (1 February 2024) <https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/shipping/020124-imo-should-require-oil-bunker-users-to-subsidize-alternative-fuels-ics> accessed 28 March 2024.

224 'Indian Government to Pay 30% Subsidy to Build Green Shipping' (*The Maritime Executive*) <https://maritime-executive.com/article/indian-government-to-pay-30-subsidy-to-build-green-shipping> accessed 28 March 2024.

225 For e.g., Norway has $187M total in funding for 16 ships and hydrogen hubs to date under their R&D grant for larger ammonia- and hydrogen- powered vessels. But note that these domestic subsidies fall outside the IMO's remit: Elena Talalasova and Jesse Fahnestock, 'National and Regional Policy for Green Shipping Corridors' (Global Maritime Forum, Getting to Zero Coalition 2023) 13–16 <https://cms.globalmaritimeforum.org/wp-content/uploads/2023/09/Global-Maritime-Forum_Insight-Brief_National-and-regional-policy-for-green-shipping-corridors-1.pdf> accessed 28 March 2024; Ana Swanson, 'Shipping Contributes Heavily to Climate Change. Are Green Ships the Solution?' *The New York Times* (30 October 2023) <https://www.nytimes.com/2023/10/30/business/economy/shipping-climate-change-green-fuel.html> accessed 28 March 2024.

226 New fuels are not only consumed as bunker by shipping but also international aviation, and used as hydrogen carriers for power generation needs.

227 'Alternative Fuels for Containerships: Methanol and Ammonia' (n 55) 73.

228 Brazil, 'Brazil's Request to COP28 on Behalf of BASIC' <https://unfccc.int/sites/default/files/resource/COP28_BASIC-Agenda%20proposal.pdf> accessed 28 March 2024.

229 'EU Emissions Trading System (EU ETS) - European Commission' <https://climate.ec.europa.eu/eu-action/eu-emissions-trading-system-eu-ets_en> accessed 30 March 2024.

national shipping emissions into its local CO2 market if the IMO does not agree a global emissions price by 2028" [230].

Port authorities have taken the initiative of forming public-private partnerships with other port States and industry to establish the necessary frameworks and infrastructure to support the energy transition while awaiting IMO regulations and technological maturity of alternative fuels. These include networks[231] and green shipping corridors[232] to coordinate and develop common understandings and policies for the safe, affordable and available use of new fuels across different countries [233]. As of February 2024, there are 57 such corridors [234]. They serve as demonstration projects of technical and regulatory feasibility and socio-economic and environmental impacts [235]. For instance, as a major Port State, Singapore aims to "establish green and digital corridors with like-minded ports and countries to build low-carbon marine fuel supply chains, conduct joint bunkering pilots and trials, and develop bunkering infrastructure" [236]. These include the Rotterdam-Singapore Green & Digital Shipping Corridor with the Netherlands in 2022 [237]. However, ITOPF warned that an accident could result in an explosion which could cause a drastic loss of life, loss of the vessel, and severe damage to port infrastructures (and by extension nearby vessels and cargo) [238]. Major shipping lanes also have a high concentration of vessels so a toxic ammonia-plume cloud generated from a spill could endanger the lives of crew onboard nearby conventional vessels (not equipped with appropriate PPE) and cause trade disruptions at critical maritime chokepoints.

LR had strongly recommended the implementation of toxic buffer zones onboard ammonia-fuelled vessels to minimise exposure to crew [239]. The International Association of Classification Societies 'Safe Decarbonisation Panel' is developing unified requirements, interpretations and recommendations with industry which may be submitted to IMO to support the making of detailed regulations [240]. However, onboard zoning would not ensure the safety of nearby vessels and infrastructure. Yet, having safety zones outside the ship or dedicated sea corridors is impractical because firstly, other ships have freedom of navigation seaward of the territorial sea, and second due to space constraints. Perhaps alternatively-fuelled vessels may have to take alternative routes but increased costs and voyage distances would have to be evaluated for feasibility.

As discussed, standards are set by flag States[241] assisted by classification societies[242] in the absence of

230 Abnett and Abnett (n 210).

231 For instance, the DNV Decarbonization Network, aimed to share insights on technical and regulatory challenges and solutions.

232 A green shipping corridor is a route from one port to another where carbon-neutral ships start using carbon-neutral fuels (well-to-wake) earlier than required by existing rules and incentives. This makes green shipping corridors key enablers in accelerating the early adoption of these fuels: Slide 1, 'Key Considerations for Establishing a Green Shipping Corridor' <https://www.dnv.com/expert-story/maritime-impact/key-considerations-for-establishing-a-green-shipping-corridor/> accessed 28 March 2024.

233 For example, bunkering at ports along the corridor. 'LogiSYM | Pushing the Boundaries of Sustainable Shipping' <https://logisym.org/pushing-the-boundaries-of-sustainable-shipping/> accessed 28 March 2024.

234 Green shipping corridors first came to real prominence in Glasgow at 2021's COP26, the major international climate summit, when 19 countries joined the first ever framework to create zero-emission ocean shipping corridors, with the signing of the Clydebank Declaration for clean shipping corridors: Sam Chambers, 'Green Shipping Corridor Initiatives Mushroom' (*Splash247*, 28 March 2024) <https://splash247.com/green-shipping-corridor-initiatives-mushroom/> accessed 30 March 2024; Slide 2, 'Key Considerations for Establishing a Green Shipping Corridor' (n 232).

235 'A Framework for Developing Just and Inclusive Green Shipping Corridors' <https://www.zerocarbonshipping.com/publications/tides-of-change-a-framework-for-developing-just-and-inclusive-green-shipping-corridors/> accessed 28 March 2024; American Bureau of Shipping (ABS) (n 39).

236 'Singapore's National Hydrogen Strategy' (n 84).

237 The development and uptake of zero and near-zero emission fuels in large containers vessels (of at least 8,000 TEU) deployed on the 15,000 km route, supported by a combination of operational and digital efficiencies: Maritime & Port Authority of Singapore (MPA), 'Partners Support Emission Reductions on Rotterdam-Singapore Green & Digital Shipping Corridor' (*Maritime & Port Authority of Singapore (MPA)*, 20 September 2023) <https://www.mpa.gov.sg/media-centre/details/partners-support-emission-reductions-on-rotterdam-singapore-green-digital-shipping-corridor> accessed 28 March 2024; Maritime & Port Authority of Singapore (MPA), 'Maritime and Port Authority of Singapore and Port of Rotterdam to Establish World's Longest Green and Digital Corridor for Efficient and Sustainable Shipping' (*Maritime & Port Authority of Singapore (MPA)*, 2 August 2022) <https://www.mpa.gov.sg/media-centre/details/maritime-and-port-authority-of-singapore-and-port-of-rotterdam-to-establish-world-s-longest-green-and-digital-corridor-for-efficient-and-sustainable-shipping> accessed 28 March 2024.

238 Le Masurier and Pinzon (n 14).

239 'Fuel for Thought: Introduction to Ammonia | LR' (n 35).

240 ibid; 'Safer and Cleaner Shipping - IACS' <https://iacs.org.uk/news/iacs-council-launches-new-safe-decarbonisation-panel-to-support-the-implementation-of-new-fuels-and-technologies/> accessed 2 April 2024.

241 Art 94 and 211(2), *1982 United Nations Convention on the Law of the Sea, 1833 UNTS 397, Adopted on 10 December 1982, Entered into Force on 16 November 1994.*

242 For example, 'Classification of Ships Using Gases or Other Low-Flashpoint Fuels | LR' (n 46).

IMO rules; and States have sovereignty over key activities in their territory including bunkering in its port waters and production of new fuels on its land [243]. However, coastal States cannot adopt laws and regulations on the "design, construction, manning or equipment of foreign ships" unless they give effect to IMO rules [244]. Since there are no such IMO rules in force yet, coastal States cannot regulate innocent passage of foreign alternatively-fuelled vessels through their territorial sea by reason of their design, construction, manning or equipment alone (i.e., by being a vessel which burns dangerous bunker fuels). It can take measures only if an act of wilful and serious pollution amounting to non-innocent passage is committed [245]. In the territorial sea, coastal States can designate sea lanes and traffic separation schemes for purposes of safety of navigation [246], but in so doing, cannot prevent or impair ships from exercising innocent passage through their territorial sea [247]. Moreover, outside of their territorial sea, States cannot regulate activities of foreign-flagged vessels as flag states have exclusive jurisdiction over vessels flying their flag in exclusive economic zones and on the high seas [248]. In straits used for international navigation such as the Straits of Malacca and Singapore, coastal States cannot impose restrictions on transit passage of foreign ships related to safety of navigation and regulation of maritime traffic (including sea lanes or traffic separation schemes) without IMO's approval, nor laws and regulations on prevention of pollution unless they give effect to IMO regulations, including MARPOL[249].

Therefore, to ensure that alternatively-fuelled vessels comply with high safety and environmental standards along the entire green corridor, port States who are project partners are likely only able to coordinate on common safety and environmental standards for alternatively-fuelled vessels flying their flags. Selection of corridor partners and ports are crucial, and a risk assessment of their interaction with other conventional vessels along the various maritime zones applicable to the corridor will have to be conducted. However, serious gaps exist given the limits of the coastal State's ability to regulate activities or impose laws and regulations on foreign alternatively-fuelled vessels in its maritime zones unless applicable IMO regulations enter into force, and that a huge liability and compensation gap exists on the use of ammonia and methanol (and other non-oil substances) as bunker fuels [250] should an accident arise.

Identification of alternative-fuelled vessels on their AIS data or IMO numbers to notify other ships and port authorities about the presence of a potential hazard is another option. Nevertheless, this should be balanced against countervailing security considerations where marking a vessel carrying inherently hazardous bunker fuel could lend itself to become an easier target for attack or sabotage.

On manning, without qualified seafarers to operate alternative-fuelled vessels, shipping cannot be decarbonized – extra training for up to 800,000 seafarers by 2050 for alternative fuels is required [251]. Coordinating training of seafarers between the IMO through its Technical Cooperation (**IMO-TC**) branch and "The Maritime Just Transition Taskforce" (**MJT-TF**) further strengthens collaboration on a human-centric approach to the decarbonization transition[252]. A joint IMO-MJTTF "Training for Decarbonization" project was created on three fuels not covered by STCW (methanol, ammonia and hydrogen) to develop competency standards and training materials incorporating best practices and inputs from fuel experts on how to handle alternative fuels [253]. The project partners are expected to submit a proposal to the IMO Sub-Committee on Human Ele-

243 Art 2, *1982 United Nations Convention on the Law of the Sea, 1833 UNTS 397, Adopted on 10 December 1982, Entered into Force on 16 November 1994.* (n 241).

244 Art 21(2), ibid.

245 where coastal State may take necessary steps to prevent this: Art 19(2)(h) & 25(1), ibid.

246 Art 22, ibid.

247 Art 24, ibid.

248 Art 92, ibid.

249 'laws and regulations relating to transit passage through straits, in respect of...safety of navigation and the regulation of maritime traffic, as provided in article 41...prevention, reduction and control of pollution, by giving effect to applicable international regulations regarding the discharge of...other noxious substances in the strait': Arts 41 and 42(1)(a) & (b), ibid.

250 Le Masurier and Pinzon (n 14).

251 Aass and Natrajan (n 123) 81.

252 The Workforce was established by ICS, the International Transport Workers' Federation (ITF), the United Nations Global Compact (UNGC), the International Labour Organization (ILO) and the International Maritime Organization (IMO) and is the first global sectoral workforce to facilitating a just transition. Its primary funders are the IMO and Lloyd's Register Foundation, supported by programme partner Singapore Maritime Foundation: Aass and Natrajan (n 123); 'Maritime Just Transition Task Force | UN Global Compact' <https://unglobalcompact.org/take-action/think-labs/just-transition/about> accessed 28 March 2024.

253 IMO, 'Training Seafarers for a Decarbonized Future' (6 December 2023) <https://www.imo.org/en/MediaCentre/Pages/WhatsNew-2014.aspx> accessed 28 March 2024.

ment, Training and Watchkeeping [254]. The "Training the Trainer" project is developing competency and training guidelines[255] – including an instructor handbook and Baseline Training Framework for Seafarers in Decarbonization – for maritime training institutions whilst the IMO develops interim safety guidance on methanol, ammonia, and hydrogen under the IGF Code. Nevertheless, receiving adequate time at sea and in bunkering operations onboard alternative-fuelled vessels remains a challenge (even now for seafarers on board LNG-fuelled ships) given the lack of available alternative-fuelled ships [256]. Although many administrations could rely on training simulations, collecting accurate and reliable data to design simulations representative of real-world operations would be particularly challenging in the initial stages. With the added complexity and costs of training seafarers, training institutions from developing states might find it challenging to meet the future STCW "white-list" requirements [257].

Further, as highlighted by MEPC 81 discussions, the biggest challenge is in ensuring that training standards are fit-for-purpose for alternative fuel systems developed in the future where there is no proper certainty currently with regard to STCW and certification due to lack of common understanding on a global set of objectives and standards for training. However, the IMO should consider not only training of crew onboard alternative-fuelled vessels, but also educating the mariners of *conventional* ships on the characteristics of alternative-fuelled vessels so that they are equipped with the knowledge to react in an accident and exercise better judgment in the vicinity of such vessels.

V. Conclusions

The IMO faces a herculean task of regulating future marine fuels with complex technical characteristics and significant implications for a multitude of stakeholders. Two leading alternative fuels considered by IMO and the industry for the mid- to long-term are ammonia and methanol. This article provides a basic structure of analysis, comparing ammonia and methanol to traditional bunker fuels using metrics of comparative efficiency (cost), safety, and environmental impact (air and water). While efforts to develop the feasibility of ammonia and methanol as low-GHG fuels is important, as next steps, the IMO should adopt a broader view of impact assessments and place particular attention on not just GHG emissions aspects, but also the impact of the new fuels on human safety and the marine environment, particularly from the use of ammonia as fuel given existing knowledge gaps. It is further recommended that the IMO make safety and marine environmental assessments pre-requisites to allowing the use of methanol and ammonia as fuel for ships, and to include them as key guiding principles driving the GHG Strategy. Greater emphasis may be placed on conducting EIAs, and reviewing protected areas for ammonia-fuelled vessels which could pose grave dangers to marine biodiversity. National or regional subsidies could promote the uptake of fuels, but must be balanced against the dangers of unilateralism. However, proactive harmonization of standards and coordination among Port States through green shipping corridors is beneficial, but faces practical limitations whereby ships outside the territorial sea are subject only to their flag State's exclusive jurisdiction. Greater considerations must be given towards safety precautions including possibly imposing toxic buffer zones around such ships, identifying them on AIS data but it is doubtful that separate sea lanes for alternatively-fuelled vessels can be established along major shipping lanes. Particularly, there are serious gaps given the limits of the coastal State's ability to regulate activities or impose laws and regulations on foreign-flagged alternatively-fuelled vessels in its maritime zones, and the liability and compensation gaps should an accident arise. More attention must be paid towards crew training and ensuring they are fit-for-purpose. Admittedly, this paper does not closely examine the liability issues including transboundary pollution arising from a spill of new fuels, or elaborate on the historical background of climate change and how it was incorporated into the IMO's mandate, or issues of regime interaction with the climate change framework. These are issues which could be possible future extensions to this paper.

254 Aass and Natrajan (n 123).

255 I.e., basic and advanced training requirements.

256 Seafarers may need adequate operational experience to qualify for advanced levels of training and qualification: Aass and Natrajan (n 123) 81.

257 Maria Pia Benosa and Robert Beckman (n 173) 56–7.

Appendix

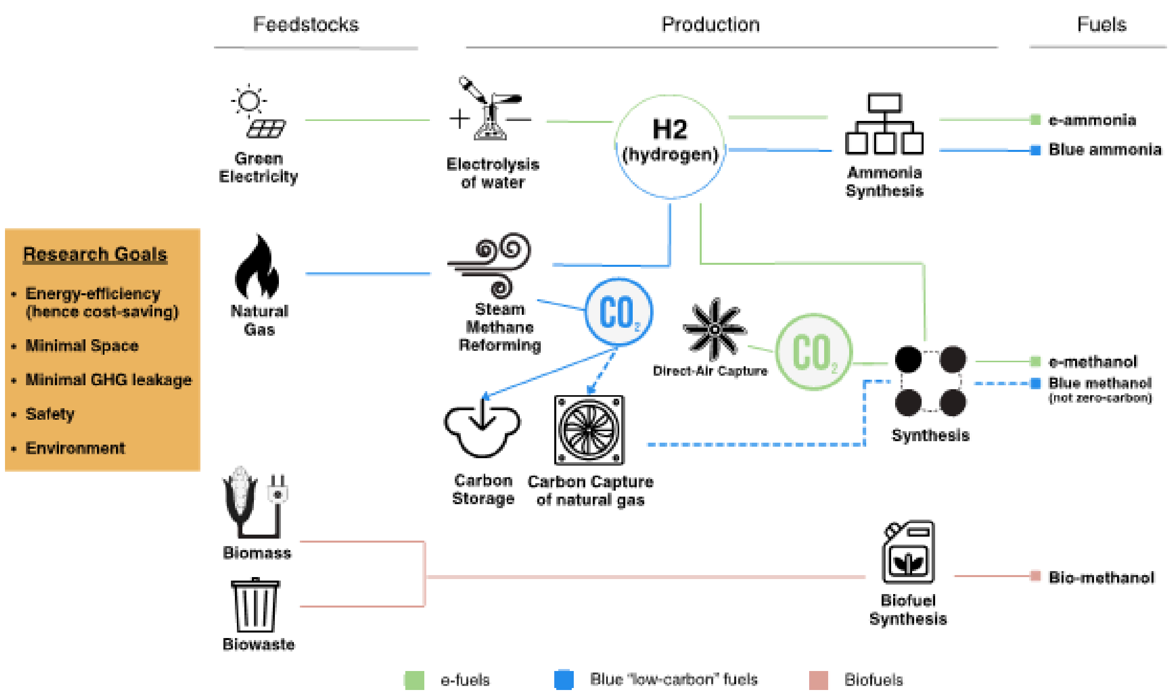

Fig. 1 - Pathways for Ammonia and Methanol as Alternative Fuel Candidates. Adapted from Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping

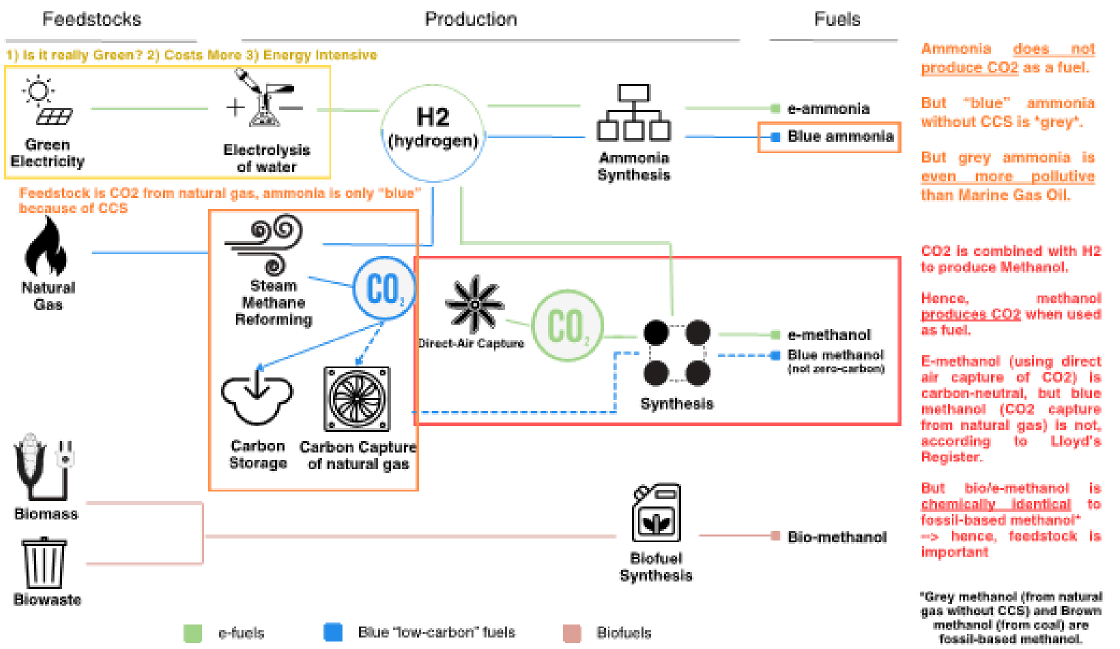

Fig. 2 - Analysis of Ammonia and Methanol as Alternative Fuels. Adapted from Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping and Lloyd's Register

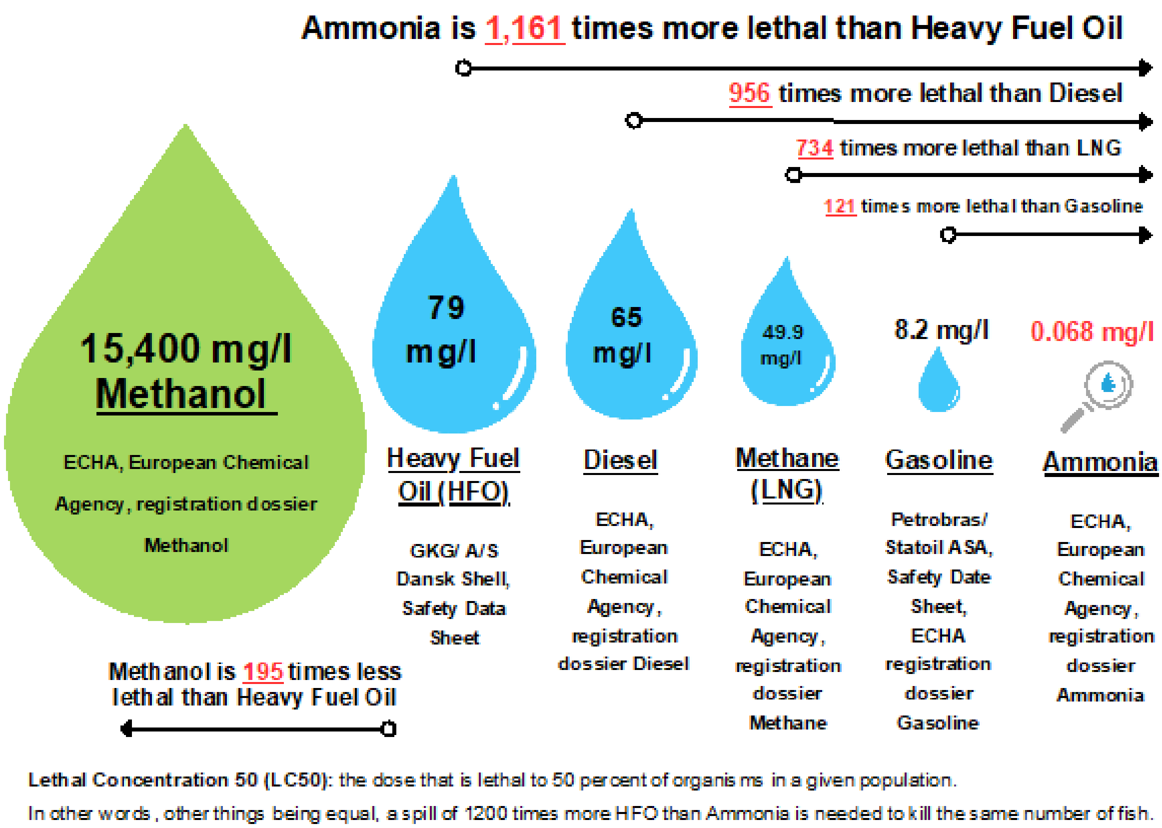

Fig. 3. - Comparison of Ammonia and Methanol's lethal dose to 50 percent (LC50) of a fish population to traditional bunker fuel. Adapted from Methanol Institute

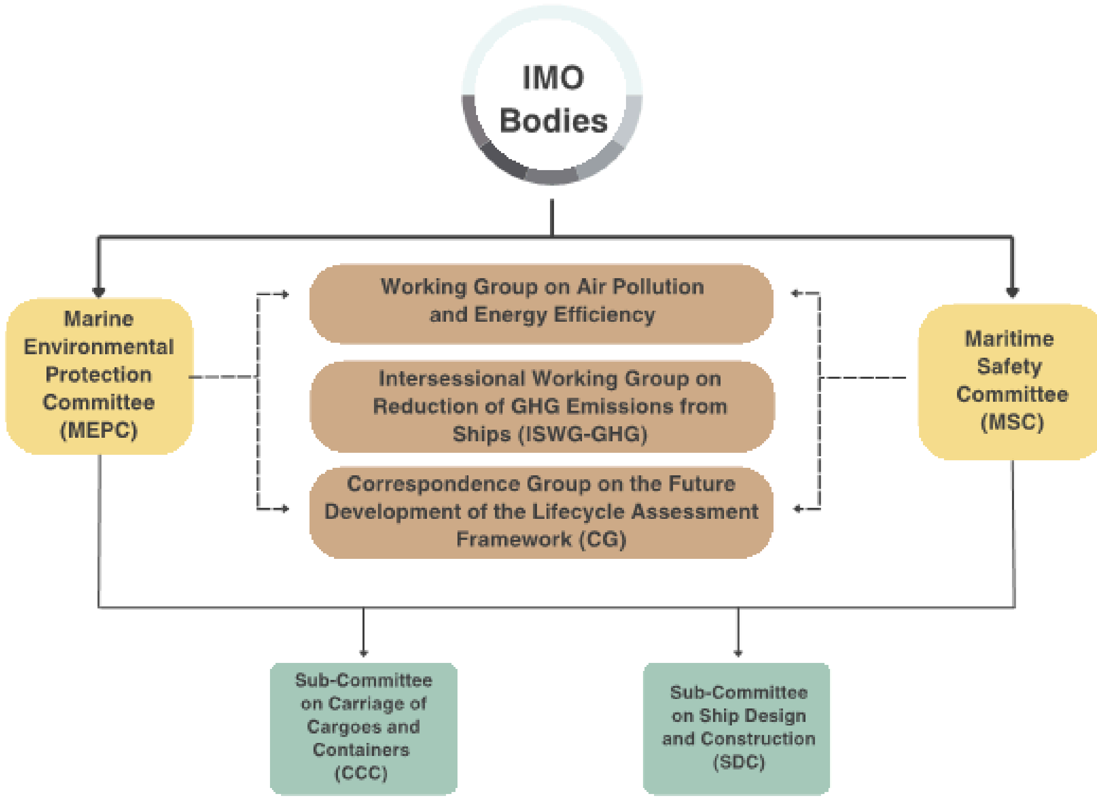

Fig. 4. - Applicable IMO Bodies responsible for regulating alternative fuels. Adapted from CIL Guide to IMO

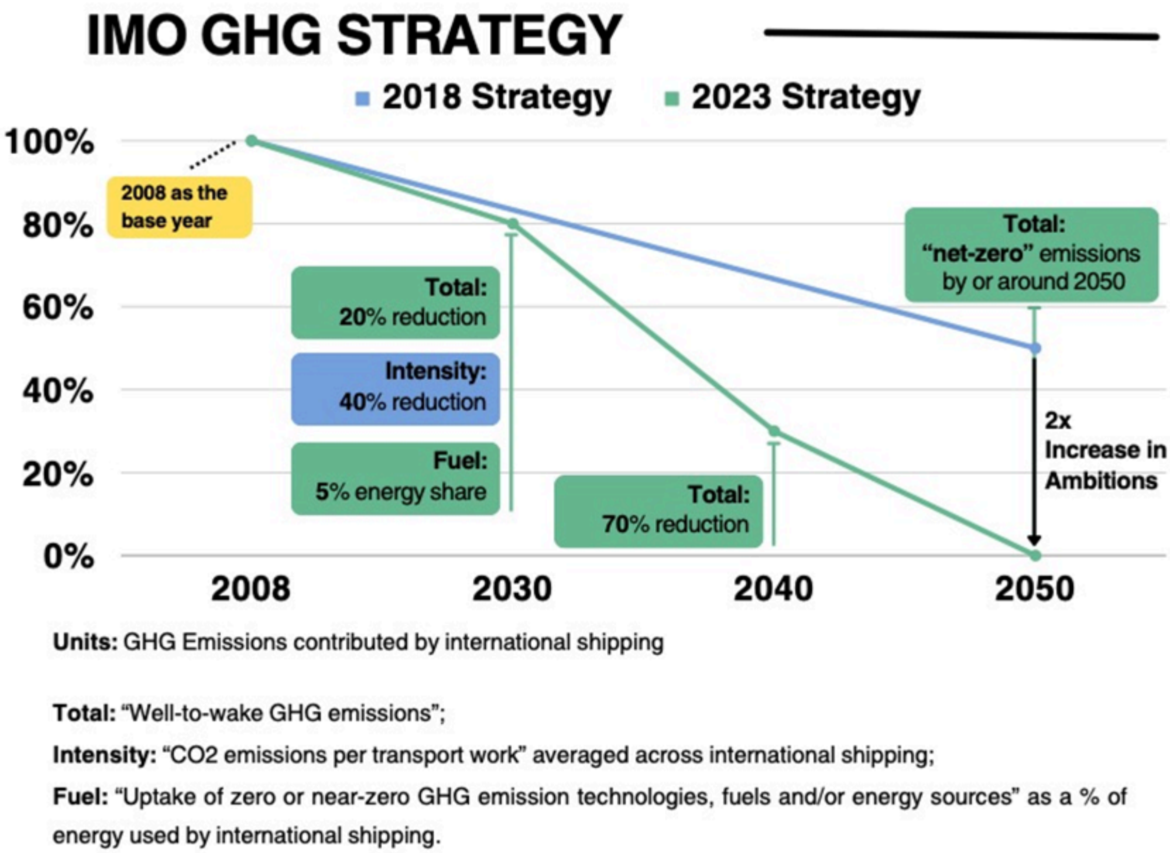

Fig. 5. - Key Changes to ambitions and indicative checkpoints from the IMO's 2018 Initial Strategy to its 2023 Revised Strategy. Adapted from DNV