Towards Zero-Emission Shipping for India — The Case for Ammonia versus Hydrogen as the Fuel of Choice

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As the maritime sector charts its course into the future, it finds itself at a critical juncture, confronting the challenges of decarbonisation amidst economic and geopolitical uncertainties. Greenhouse gas emissions from the shipping industry, constituting 3% of the global total, have surged by 20% in the past decade and, in the absence of decisive action by all stakeholders, threaten to soar to 130% of 2008 levels by 2050.[1] Adding to the complexity is an ageing global fleet, one wherein the average ship's age, as of early 2023, is over 22 years, presenting a dilemma where many vessels are either too old for retrofitting or too new to be scrapped.[2]

The urgency to reduce emissions is palpable, yet the sector grapples with substantial uncertainty in terms of identifying optimal transition strategies. While alternative fuels hold promise, their current utilisation remains in a nascent stage, with a staggering 98.8% of ships still being reliant upon fossil fuels. Encouragingly, however, a notable 21% of vessels on order are slated to operate on cleaner alternatives such as liquefied natural gas, methanol, and hybrid technologies.

Adding another layer of complexity is the question of accountability in this transition. While major flag States, such as Liberia, Panama, and the Marshall Islands, which taken in aggregate, are responsible for a third of shipping's carbon emissions, are indeed poised to enforce new green standards, the economic burden of investing in alternative fuels, bunkering infrastructure, and greener vessels largely falls upon ship owners, ports, and the energy sector as a whole. Navigating this intricate web of economic, regulatory, and environmental imperatives constitutes the industry's next significant trial.[3]

At COP 21 in Paris, on 12 December 2015, the "United Nations Framework Convention on Climate Change" (UNFCCC) adopted the "Paris Agreement", which aims to achieve global

[1] The choice of 2008 as the baseline year for measuring and reducing greenhouse gas emissions from international shipping by the International Maritime Organization (IMO) and the United Nations Conference on Trade and Development (UNCTAD) was likely influenced by several factors. Firstly, 2008 represented a significant year for climate action, with growing global momentum to address emissions across various sectors. Additionally, the 2008 global financial crisis may possibly have provided a representative snapshot of shipping activity and emissions before the impacts of the economic downturn. By aligning on a common 2008 baseline, the IMO, UNCTAD, and the broader international community could more effectively track progress and coordinate their emissions reduction efforts in the maritime industry over time.

[2] "Review of Maritime Transport 2023", United Nations Conference on Trade and Development (UNCTAD), 27 September 2023 https://unctad.org/system/files/official-document/rmt2023_en.pdf

[3] *Ibid*

climate-neutrality by the middle of the current century.[4] For its part, the global shipping industry is aware of its adverse impact on the climate, and has vowed to achieve net-zero CO_2 emissions by 2050.[5] The "International Maritime Organisation" (IMO), too, is focusing upon controlling GHG emissions, and its "Marine Environment Protection "Committee (MEPC), has taken a number of remedial measures in this regard. On 13 April 2018, for instance, the 72nd meeting of the MEPC (MEPC-72) adopted the "Initial IMO Strategy on Reduction of GHG emissions from Ships" vide 'Resolution MEPC.304(72)'.[6]

The principal objectives of this 'Initial Strategy' are to enhance IMO's contribution in addressing GHG emissions and identifying actions and measures to reduce the GHG emissions from international shipping by at least 50 per cent by 2050, when compared to 2008. The strategy envisages a decline in carbon intensity through the phased implementation of the "Energy Efficiency Design Index "(EEDI) for new ships and sets a target of reducing CO_2 emissions per transport work, by at least 40 per cent by 2030, and 70 per cent by 2050, compared to 2008.[7]

In July of 2023, IMO member States unanimously endorsed the "2023 IMO Strategy for the Reduction of Greenhouse Gas (GHG) Emissions from Ships", which incorporates even more ambitious targets to address the detrimental impact of emissions.[8] This updated IMO GHG Strategy, adopted in the 80th session of the MEPC (MEPC 80), features a strengthened shared vision to achieve near-zero GHG emissions from international shipping by the vicinity of 2050. It also emphasises a firm commitment to promoting the adoption of alternative 'zero- and near-zero GHG-emitting fuels by year 2030. Additionally, the strategy establishes key interim milestones, with a baseline reduction target of at least 20%, while striving for 30%; and with a base reduction goal of at least 70%, striving for 80%, by 2040. This marks a significant advancement in global efforts to mitigate the environmental impact of maritime transportation.[9]

Heavy Fuel Oil (HFO) is, even today, the predominant fuel used in ships undertaking long distance voyages. However, it has a high sulphur content and, hence, results in high levels of environmental pollution. "Exhaust Gas Cleaning Systems" (EGCS), commonly referred-to as "scrubbers", are being retrofitted in the machinery of merchant ships, with an aim of reducing

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[4] "The Paris Agreement", United Nations Framework Convention on Climate Change (UNFCCC) https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement

[5] Dr Stefan Ulreich, *Fuelling the Fourth Propulsion Revolution- an Opportunity for All* (London: International Chamber of Shipping, 2022), 6 https://www.ics-shipping.org/wp-content/uploads/2022/05/Fuelling-the-Fourth-Propulsion-Revolution_Full-Report.pdf

[6] "Initial IMO Strategy on reduction of GHG emissions from ships", International Maritime Organisation (IMO), Annex 11, Resolution MEPC.304(72), 13 April 2018 https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/Resolution%20MEPC.304(72)_E.pdf

[7] *Ibid*

[8] "Revised GHG reduction strategy for global shipping adopted", Press briefing, International Maritime Organisation (IMO), 07 July 2023 https://www.imo.org/en/MediaCentre/PressBriefings/pages/Revised-GHG-reduction-strategy-for-global-shipping-adopted-.aspx

[9] "2023 IMO Strategy on reduction of GHG Emissions from ships", Marine Environment, International Maritime Organisation (IMO) https://www.imo.org/en/OurWork/Environment/Pages/2023-IMO-Strategy-on-Reduction-of-GHG-Emissions-from-Ships.aspx

sulphur emissions from 3.5% to 0.5%. However, this measure alone is considered insufficient to achieve IMO targets, at least not by its 2050 deadline. Consequently, alternative fuels need to be considered in order to decarbonise shipping.

Shipping is a complex and capital-intensive industry. A 2020 study undertaken by the "University Maritime Advisory Services" (UMAS) and the "Energy Transitions Commission" found that to achieve the IMO's carbon reduction ambition by 2050, funding support of the order of US$ 1 to 1.9 trillion would be needed.[10] Moreover, at least at this point in time, there is no readily available and affordable replacement for conventional fossil fuels. Thus, the decarbonisation of shipping is unlikely in the near-term.

The transition of the shipping industry away from fossil fuels has certainly begun but there is much that must be done before merchant ships can be propelled by zero-carbon fuels. This sobering realisation notwithstanding, there are a variety of non-fossil fuels that have been tentatively identified as having the potential to reduce GHGs emission. Amongst these, hydrogen (H_2) and ammonia (NH_3) are notable. Both consist of carbon-free and sulphur-free molecules; are versatile; and can power applications using fuel cells or internal combustion engines (ICEs).

Comparative Analysis of H_2 and NH_3 Properties

Both hydrogen and ammonia, whether produced from renewable energy or fossil fuel associated with carbon capture technology, can become carbon-neutral fuels. However, the combustion of ammonia and hydrogen can generate nitrogen oxides (NO_x), which have a "Global Warming Potential" (GWP)[11] 273 times that of CO_2. GWP measures how much energy one tonne of a gas absorbs over a given period, relative to one tonne of CO_2 emission. The period generally used for GWPs is 100 years. So, NO_x emitted today would remain in the atmosphere for more than a century.[12] Thus, H_2 and NH_3 might well be carbon-free, but they will require additional technology capable of capturing or significantly reducing NO_x emissions.

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[10] Raucci Carlo, Bonello Jean Marc, Suarez de la Fuente Santiago, Tristan Smith, Kasper Søgaard. "Aggregate investment for the decarbonisation of the shipping industry" (PowerPoint presentation, *University Maritime Advisory Services* (UMAS), January 2020) https://www.globalmaritimeforum.org/content/2020/01/Aggregate-investment-for-the-decarbonisation-of-the-shipping-industry.pdf

[11] GWP is a metric used to measure and compare the potential climate impact of different greenhouse gases. It ~~GWP~~ is defined as the cumulative radiative forcing, both direct and indirect effects, over a specified time horizon resulting from the emission of a unit mass of a given greenhouse gas, relative to a reference gas. In other words, it is an index that measures how much energy the emissions of one tonne of a gas will absorb over a given period of time, relative to the emissions of one tonne of CO_2. Gases with a higher GWP value absorb more energy, per unit mass than gases with a lower GWP, and thus contribute more to warming the Earth.

[12] "Understanding Global Warming Potentials, Greenhous Gas Emissions", United States Environmental Protection Agency (EPA) https://www.epa.gov/ghgemissions/understanding-global-warming-potentials

Hydrogen has an impressive energy content per unit mass, with a value of 120.2 MJ/kg[13], which compares very favourably with HFO (40.2 MJ/kg) and ammonia (a poor 18.6 MJ/kg).[14] Clearly, hydrogen can increase the effective efficiency of an engine and reduce specific fuel consumption[15] far better than can other fuels. However, motorised ships are seagoing vehicles that must, until replenished from an external source, carry the fuel that they consume. Therefore, the amount of fuel that can be carried for a given delivery of energy is another important factor. This is indicated by the "volumetric energy density" (the amount of energy that can be contained within a given volume) of a given fuel.

Here, unlike the case with energy content per unit mass, hydrogen fares the poorest amongst the fuels under consideration, namely, HFO, ammonia, and hydrogen. While HFO has a volumetric energy density that varies from 39,564 MJ/m^3 to 42,036 MJ/m^3, hydrogen gas (even when compressed to 350 bar of pressure) yields a 'volumetric energy density' of just 5,040 MJ/m^3. Even if it is liquified, the 'volumetric energy density' of hydrogen is 8,500 MJ/m^3 — a mere quarter of that of HFO.[16] Thus, to deliver the same quantum of energy as HFO, hydrogen requires around four times the volume of space than HFO would have needed.

Even in comparison with liquid ammonia, which has a 'volumetric energy density' of 14,100 MJ/m^3,[17] hydrogen would require almost double the space for an equivalent amount of energy. Moreover, since liquid hydrogen requires a temperature of less than minus 253^o C, the requirement of space would increase in order to allow for the necessary layers of insulating material for cryogenic storage[18], as also other ancillary structural arrangements.

Ammonia, on the other hand, can be brought to liquid form at room temperature (25^o C) when pressurised to 9.9 atm or, if the temperature is lower than minus 33.4^o C, at normal atmospheric pressure (one atm). Being 10.6 to 30.2 times cheaper than hydrogen, it is clearly a more cost-efficient option, particularly since its facilities for its transportation and storage already exist, with

[13] Hydrogen has the highest energy density per unit of mass, providing approximately 120 MJ/kg. This high gravimetric energy density makes hydrogen an efficient and lightweight energy carrier. Energy density refers to the amount of energy stored in a given system or region of space per unit volume, which can be measured in energy per unit volume. In the context of fuels, energy density can be measured in gravimetric energy density (energy per unit of mass) and volumetric energy density (energy per unit of volume).

[14] Kyunghwa Kim, Gilltae Roh, Wook Kim, and Kangwoo Chun, "A Preliminary Study on an Alternative Ship Propulsion System Fuelled by Ammonia: Environmental and Economic Assessments", *Journal of Marine Science and Engineering* 8, No 3 (7 March 2020): 183 https://doi.org/10.3390/jmse8030183

[15] Specific fuel consumption (SFC) is a measure of the fuel efficiency of an engine, defined as the amount of fuel consumed per unit of power output. It is typically expressed in grams per kilowatt-hour (g/kWh) or pounds per horsepower-hour (lb/hp-h). Compared to traditional marine diesel engines, hydrogen combustion engines can achieve higher efficiencies, with SFC values in the range of 0.2-0.4 kg/kWh. This represents a significant improvement over diesel engines, which typically have SFC between 155-225 g/kWh under optimal conditions.

[16] *Ibid*

[17] *Ibid*

[18] Cryogenic storage is essential for liquid hydrogen on ships. Key design considerations include maintaining the critical -253°C temperature, slight overpressure, effective thermal insulation, and safety features like pressure relief systems. Spherical tanks are preferred to minimize heat transfer and interaction with the environment. The tank connection space (TCS) provides a gas-tight enclosure for components, facilitates safety integration, and supports efficient operation.

over 18 million tonnes of ammonia being traded internationally on an annual basis (as of the year 2020).[19]

It may thus be seen that although hydrogen as a marine fuel is characterised by low Greenhouse Gas (GHG) emissions, its storage and handling are challenging. The development of this form of marine fuel requires more advanced technology, considerable innovation, and significant cost reduction. Moreover, the shipping industry has fairly limited experience in dealing with hydrogen as a marine fuel, when compared with ammonia and HFO. The technology maturity[20] of both hydrogen and ammonia need time and the infusion of considerable capital if either is to achieve the end goal of zero-carbon emissions.[21] A brief comparison of maritime fuel characteristics can be found in Table 1,[22] which compares HFO, hydrogen, and ammonia on various aspects.

Fuel		Technology maturity	Applicability to shipping	Well-to-tank	Tank-to-wake	Fuel Safety & Storage	Fuel cost
Hydrogen	Combustion	Medium	Medium	Low	Low	Low	High
	Electric (Fuel cell)	Low	High				
Ammonia	Combustion	Medium	High	Low	Low	Medium	Medium
	Electric (Fuel cell)	Low	High				
HFO	Combustion	High	High	High	High	High	Low

Low	Medium	High

Table 1. Matrix for maritime fuel characteristic
Source: Collated by the Author

[19] Kyunghwa Kim, Gilltae Roh, Wook Kim, and Kangwoo Chun, "A Preliminary Study on an Alternative Ship Propulsion System Fuelled by Ammonia: Environmental and Economic Assessments", *Journal of Marine Science and Engineering* 8, No 3 (7 March 2020): 183 https://doi.org/10.3390/jmse8030183

[20] Technology maturity refers to the state of development or evolution of a particular technology. It describes how advanced and refined a technology is, and whether it has reached a stable and reliable state.

[21] Tristan Smith et al. *A strategy for the Transition to Zero-Emission Shipping.* University Maritime Advisory Services (UMAS) on behalf of the Getting to Zero Coalition, October 2021 https://www.globalmaritimeforum.org/content/2021/10/A-Strategy-for-the-Transition-to-Zero-Emission-Shipping.pdf

[22] "Decarbonising Shipping: All hands on deck 2.0", Shell Global in collaboration with Deloitte, 2023 All Hands on Deck 2.0

See Also: Joseph Taylor, Dr Jean-Marc Bonello, Dr Domagoj Baresic and Dr Tristan Smith, *Future Maritime Fuels in the USA – the options and their potential pathways,* (London: University Maritime Advisory Services (UMAS), January 2022), 59, https://oceanconservancy.org/wp-content/uploads/2022/04/oc_fuels_final_report_20220117.pdf

See Also: "Ammonfuel – an industrial view of ammonia as a marine fuel", Alfa Laval, Hafnia, Haldor Topsoe, Vestas, and Siemens Gamesa, 2020 https://hafniabw.com/news/ammonfuel-an-industrial-view-of-ammonia-as-a-marine-fuel/

See Also: "Hydrogen as Marine Fuel", American Bureau of Shipping (ABS), June 2021 https://ww2.eagle.org/content/dam/eagle/publications/whitepapers/hydrogen-as-marine-fuel-whitepaper-21111.pdf

See Also: Charlie McKinlay, Stephen R Turnock, and Dominic Antony Hudson, "A comparison of hydrogen and ammonia for future long distance shipping fuels", (Paper presented at LNG/LPG and Alternative Fuel Ships, London, January 2020), 13 https://www.researchgate.net/publication/339106527_A_Comparison_of_hydrogen_and_ammonia_for_future_long_distance_shipping_fuels

A 2017 study by Lloyd's Register (LR) and the University Maritime Advisory Services (UMAS) suggests that as a shipboard fuel, ammonia is more economically viable than hydrogen as there are lower costs that are associated with its onboard storage.[23] This notwithstanding, there is no gainsaying the fact that the cost of either of these alternative fuels is, at present, much higher than that of HFO. Likewise, while both hydrogen and ammonia have much lower values of GHG emission when compared to that of HFO, the impact of their respective production processes is likely to erode this advantage. There are four types of hydrogen and ammonia in terms of emissions released during production:[24]

- 'Brown', produced from the processing of coal.
- 'Grey', produced from natural gas or by processing of fossil fuels other than coal,
- 'Blue', produced from processing of fossil fuels but with carbon-capture technologies.
- 'Green', produced from renewable energy sources such as wind, solar, geothermal, water, etc.

Currently, 'grey' production is dominant, although a definitive shift to 'blue' or 'green' hydrogen and ammonia is clearly needed. In the case of hydrogen, this could be achieved by electrolysis, high-temperature water-splitting, or by photobiological water-splitting, or by photoelectrochemical water-splitting. However, none of these methods are as yet capable of large-scale hydrogen production.[25] The situation is respect of ammonia is far more encouraging, given that its production through alkaline electrolysis and air separation powered by hydropower (the Haber-Bosch process), is an industrial method that has been around for the past 100 years — since 1920 at least.[26]

There are several research and development projects that are focussed upon using hydrogen and ammonia as marine fuels for sustainable shipping. These include, *inter alia*, "*The Green Ammonia Consortium*", in Japan (active since 2019),[27] and the "*Zero Emission Energy Distribution at Sea*" (ZEEDS) project (ongoing since 2019 in Northern Europe).[28] The "*Golden Gate Zero Emission Marine Hydrogen Fuel Cell Vessel*", initiated by Zero Emission Industries, incorporated the launch of a catamaran fuelled by a proton-exchange membrane fuel cell (PEMFC) in 2021.[29] Likewise, for liquid hydrogen, there are Norway's "*PILOT-E*" project[30] and Australia and Japan's

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[23] "Zero-Emission Vessels 2030—How Do We Get There", Lloyd's Register (LR) & University Maritime Advisory Services (UMAS), 2017.
https://maritime.lr.org/zero-emission-vessels-report

[24] Joseph Taylor, Dr Jean-Marc Bonello, Dr Domagoj Baresic and Dr Tristan Smith, *Future Maritime Fuels in the USA – the options and their potential pathways,* (London: University Maritime Advisory Services (UMAS), January 2022), 59.
https://oceanconservancy.org/wp-content/uploads/2022/04/oc_fuels_final_report_20220117.pdf

[25] "Hydrogen as Marine Fuel", American Bureau of Shipping (ABS), June 2021
https://ww2.eagle.org/content/dam/eagle/publications/whitepapers/hydrogen-as-marine-fuel-whitepaper-21111.pdf

[26] "Ammonfuel – an industrial view of ammonia as a marine fuel", Alfa Laval, Hafnia, Haldor Topsoe, Vestas, and Siemens Gamesa, 2020
https://hafniabw.com/news/ammonfuel-an-industrial-view-of-ammonia-as-a-marine-fuel/

[27] Bunro Shiozawa, "CO2 Free Ammonia as CO2 Free Fuel and Hydrogen Carrier" (PowerPoint Presentation, Cross-ministerial Strategic Innovation Promotion Program (SIP), Tokyo, Japan, 2019)

[28] Zero Emission Energy Distribution at Sea (ZEEDS) https://zeedsinitiative.com/

[29] Zero Emission Industries https://www.zeroei.com/

[30] PILOT-E Funds to develop a supply chain for liquid hydrogen for ships, FuelCellsWorks, 1 May 2021

"Hydrogen Energy Supply Chain Project".[31] Several commercial industries, too, are working on clean energy — MAN Energy Solutions, for instance, which has announced that its first ammonia unit could soon be in operation.[32] Likewise, M/s Alfa Laval, a marine fuel system developer, has announced its move to a next generation of fuel gas supply system to replace LPG by ammonia.[33]

As would be evident, the world is still in a transition phase, despite several projects throwing up very encouraging results, especially for vessels of limited size. However, large merchant vessels designed for global cargo movement still have a long way to go before they can reach the goal of zero-carbon emission. According to a report by the "International Chamber of Shipping" (ICC), significantly higher levels of investment and research are required for ongoing projects to reach technical maturity. The report identifies 265 projects that address key technical and systemic challenges to accelerate zero-carbon emissions and opines that to reach even a pre-commercial deployment stage, funding of around US$ five billion would be required.[34]

India and its Transition

As highlighted in the recently released "Climate Change Performance Index 2023"[35] report, India has secured the 8th position, marking a remarkable jump of 2 positions from the previous edition, and now holds the highest rank among the G20 nations in transitioning to a greener future.[36] India has also presented its "Nationally Determined Contributions" (NDC) to the UNFCCC through an initiative known as LiFE, which stands for "Lifestyle for Environment." LiFE is a widespread movement that advocates the thoughtful and purposeful utilisation of resources

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https://fuelcellsworks.com/news/pilot-e-funds-to-develop-a-supply-chain-for-liquid-hydrogen-for-ships/

31 Hydrogen Energy Supply Chain (HESC) https://www.hydrogenenergysupplychain.com/

32 Nils Lindstrand, "Unlocking ammonia's potential for shipping", MAN Energy Solutions https://www.man-es.com/discover/two-stroke-ammonia-engine

33 "The Alfa Laval FCM LPG Booster System Excels with the New LPG-Fuelled Engine from MAN Energy Solutions", Alfa Laval, 17 April 2019.
Alfa Laval - Press Release

34 "A zero emission blueprint for shipping", International Chamber of shipping and in collaboration with Ricardo, November 2021
https://www.ics-shipping.org/wp-content/uploads/2021/11/A-zero-emission-blueprint-for-shipping.pdf

35 The Climate Change Performance Index (CCPI) 2023 is an annual report that evaluates and compares the climate protection performance of 63 countries and the EU, which collectively account for more than 90% of global greenhouse gas emissions. The index measures countries' efforts in four key categories: Greenhouse Gas Emissions (40% weighting), Renewable Energy (20% weighting), Energy Use (20% weighting), and Climate Policy (20% weighting).
Achieving a good ranking in the CCPI has significant implications. It reflects a country's strong commitment to rapid improvements in energy efficiency, renewable energy, and ambitious climate policy.A high ranking showcases a country's alignment with the well-below 2°C pathway set out in the Paris Agreement, signalling its dedication to meeting climate targets. It also serves as a powerful incentive for countries to further advance their climate action efforts. Overall, a good CCPI ranking is a recognition of a country's progress in climate change mitigation and a catalyst for continued environmental progress.

36 "Climate Change Performance Index", Ministry of Environment, Forest and Climate Change, Press Release, 19 December 2022
https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1884764#:~:text=The%20Climate%20Change%20Performance%20Index,i.e%201%2D3%20are%20vacant

instead of thoughtless and harmful consumption practices. This commitment entails eight overarching goals, including three specific quantitative targets for the year 2030,[37] namely:

1. Increasing the capacity for non-fossil power generation to 50%.
2. Reducing the emissions intensity of GDP by 45% compared to 2005 levels.
3. Establishing a cumulative additional carbon sink of 2.5-3 billion tonnes of CO_2 equivalent through the expansion of forest and tree cover.

However, if we look into the maritime sector of India as of 2019, the Inland Waterways Transport (IWT) sector was responsible for approximately 277,000 tonnes of CO_2 (t CO_2) emissions. During the same year, India had a fleet of approximately 970 coastal shipping vessels, resulting in the consumption of 1.6 million tonnes of fuel oil and the emission of 5.1 million tonnes of CO_2 (Mt CO_2).[38] Government policies anticipate a nearly threefold increase in annual cargo and passenger movement on inland waterways and a 1.2-fold increase in cargo movement via coastal shipping from 2019 to 2030. It is clear that the growth in fuel consumption and emissions will more than offset the benefits of increased trade or human connectivity, making it imperative to implement appropriate measures to mitigate these adverse consequences.[39]

The government has put into action several initiatives, including the "SAGARMALA" programme,[40] the National Waterways Act,[41] and the Inland Vessels Bill,[42] with the aim of advancing the waterways sector and promoting a shift in transportation modes. However, these policies have a constrained emphasis on transitioning to cleaner fuels. On the other hand, "Maritime India Vision 2023" (MIV 2030) introduces measures to ensure that all ports and maritime bodies adhere to global benchmarks for health, safety, security, and environmental standards, thus addressing broader concerns within the sector.[43] Additionally, under the ambit of the "Maritime *Amrit Kaal* Vision 2047",[44] a concerted effort is being made to decarbonise the maritime industry. This vision outlines specific targets, indicated in Table 2 as Target (2030) and Target (2047), to gauge progress against the 2021[45] status of the shipping sector.

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[37] "India's Updated First Nationally Determined Contribution Under Paris Agreement (2021-2030)", Government of India, August 2022 https://unfccc.int/sites/default/files/NDC/202208/India%20Updated%20First%20Nationally%20Determined%20Contrib.pdf

[38] Nilanshu Ghosh, Abhinav Soman, Harsimran Kaur, and Himani Jain, *Decarbonising Shipping Vessels in Indian Waterways through Clean Fuel*, (CEEW The Council and Shell Foundation, March 2023) 18.

[39] *Ibid*

[40] "Sagarmala programme", Press Information Bureau, Ministry of Shipping, Government of India, 12 March 2020 https://pib.gov.in/newsite/PrintRelease.aspx?relid=200158

[41] "The National Waterways Act 2016", Law and Environment Assistance Platform (LEAP), UN environment programme https://leap.unep.org/countries/in/national-legislation/national-waterways-act-2016

[42] "The Inland Vessels Act 2021", The Gazette of India, Ministry of Law and Justice, August 2021 https://iwai.nic.in/sites/default/files/IV%20Act%202021%20Gazette_0.pdf

[43] "Maritime India Vision 2030", Ministry of Ports, Shipping and Waterways (MoPSW), Government of India, 2021 https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/Air%20pollution/Maritime%20India%20vision%202030.pdf

[44] "Maritime Amrit Kaal Vision 2047", Ministry of Ports, Shipping and Waterways, Government of India, 2023 Maritime Amrit Kaal Vision 2047

[45] The targets set in the Maritime Amrit Kaal Vision 2047 are compared with the 2021 status to establish a clear baseline and measure the progress over time.

Plan	Status (as of 2021)	Target (2030)	Target (2047)
Carbon neutral ports	-	1	14
Developing hydrogen/ ammonia hubs at major ports	-	3	14
Develop circular ports	-	-	14
LNG Bunkering in major ports	1	4	8
Port equipment electrification (%)	-	50	>90
Area under green belt (%)	<10	20	33
Share of renewable energy at ports (%)	<10	>60	>90
GHG emission reduction in domestic/ short sea shipping ferries, port vessels (tugs/craft/dredgers) & OSVs/PSVs	-	30	70
GHG emission reduction in all coastal/ EXIM vessels	-	10	50

Table 2. Targeted Benchmarks for Decarbonising India's Shipping Sector by 2030 and 2047
Source: Maritime *Amrit Kaal* Vision 2047

India's Ministry of Ports, Shipping & Waterways has launched a "National Centre of Excellence for Green Port and Shipping" (NCoEGPS), whose mission is to develop a regulatory framework and technology roadmap for Green Shipping, promoting carbon neutrality and a circular economy in India's maritime sector. India also aims to boost the share of renewable energy in major ports to 60% from the current value of less than 10%, primarily through solar and wind power.[46] In line with India's vision to become a global leader in green shipbuilding by 2030, the Ministry also introduced the "Green Tug Transition Programme" (GTTP). This programme, launched during the inauguration of the NCoEGPS in Gurugram, Haryana, begins with the introduction of "Green Hybrid Tugs" equipped with advanced green hybrid propulsion systems. The GTTP will gradually integrate alternative fuels such as methanol, ammonia, and hydrogen. Targets have been set for deploying these "green" tugs in major ports by 2025, with a goal of converting at least 50% of the entire tug fleet into "green" tugs by 2030. This will play a significant role in reducing emissions and advancing India's sustainable development efforts.[47]

India also recently came up with a major policy enabler by the government for the production of green hydrogen/ green ammonia, using renewable sources of energy. The implementation of this policy is expected to provide clean fuel to the common people of the country, while reducing dependence on fossil fuel and also reduce crude oil imports. Another objective is to have India emerge as an export hub for green hydrogen and green ammonia.[48] While these are steps in the right direction, further research and innovation on future marine fuels is needed to ensure a smooth transition. Fortunately, India's engineering capacity for large-scale renewable hydrogen and ammonia projects is not likely to be a bottleneck.[49]

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[46] "National Centre of Excellence for Green Port & Shipping (NCoEGPS) aimed at providing Green solutions to transform Ports & Shipping: Shri Sonowal", Press Release, Ministry of Ports, Shipping and Waterways, Government of India, 2022
https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1877297

[47] "India aims at becoming 'Global Hub for Green Ship' building by 2030 with launch of Green Tug Transition Programme (GTTP): Shri Sarbananda Sonowal", Press Release, Ministry of Ports, Shipping and Waterways, Government of India, 22 March 2023
https://pib.gov.in/PressReleasePage.aspx?PRID=1909599

[48] "Ministry of Power notifies Green Hydrogen/ Green Ammonia Policy", Press Release, Ministry of Power, Government of India, 2022
https://pib.gov.in/PressReleasePage.aspx?PRID=1799067

[49] Kevin Rouwenhorst, "India: a future ammonia energy giant", Ammonia Energy Association, 13 April 2023

To unlock India's potential in the field of renewable hydrogen and ammonia, the Cabinet has recently introduced the "National Green Hydrogen Mission" (NGHM), with substantial ($2.4 billion) funding support.[50] The "India Hydrogen Alliance" (IH2A), an industry-driven coalition, is actively engaged in the conversion of the NGHM into large-scale commercial projects. An essential element of this initiative involves establishing "Hydrogen Valleys", where production and consumption centres are co-located, thereby adopting a comprehensive value-chain approach, and fostering public-private partnerships, along the lines of similar hubs currently being developed in Europe. This approach encompasses not only hydrogen production and utilisation, but also encompasses the vital aspects of storage and infrastructure of hydrogen and its derivatives. This comprehensive strategy is critical to ensuring that production and utilisation centres are interconnected, preventing investments from turning into stranded assets.[51]

It is crucial for India to consider the establishment of "Green Shipping Corridors", aligning with the "Clydebank Declaration", which aims to support the creation of at least six green corridors by the middle of this decade, with aspirations for additional ones by 2030.[52] Although India is not a signatory to this declaration,[53] embracing green shipping corridors can pave the way for decarbonisation by establishing a green marine fuel value chain and accelerating the transition from 'brown' to 'green' practices.

However, the "Climate Action Tracker", an international scientific initiative monitoring global government efforts to combat climate change, has assessed India's net zero goals as "inadequate".[54] According to its assessment, India's "Long-Term Low-Carbon Development Strategy", while addressing specific sectors such as power, industry, transport, buildings, and urban development, lacks a clear direction on achieving net zero emissions beyond the existing initiatives. The strategy fails to present emissions reduction pathways or demonstrate how current policies will lead to the necessary emissions reductions by 2070. Additionally, it lacks transparency regarding the use of technologies such as CCUS (carbon capture, utilisation, and storage)[55] for meeting the net-zero target. India's net zero objective falls short in terms of its comprehensiveness, target framework, and transparency.[56]

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https://www.ammoniaenergy.org/articles/india-a-future-ammonia-energy-giant/

[50] "National Green Hydrogen Mission", Press Release, Ministry of New and Renewable Energy, Government of India, January 2023
https://mnre.gov.in/img/documents/uploads/file_f-1673581748609.pdf

[51] Kevin Rouwenhorst, "India: a future ammonia energy giant", Ammonia Energy Association, 13 April 2023
https://www.ammoniaenergy.org/articles/india-a-future-ammonia-energy-giant/

[52] "COP26: Clydebank Declaration for green shipping corridors", policy paper, Department of Transport, GOV.UK, updated on 13 April 2022
https://www.gov.uk/government/publications/cop-26-clydebank-declaration-for-green-shipping-corridors/cop-26-clydebank-declaration-for-green-shipping-corridors

[53] *Ibid*

[54] Climate Action Tracker, Climate Analytics and New Climate Institute
https://climateactiontracker.org/#:~:text=The%20Climate%20Action%20Tracker%20is,warming%20to%201.5%C2%B0C.%22

[55] Carbon capture, utilization, and storage (CCUS) is a process that involves capturing CO_2 emissions from industrial operations, transporting it, and then either utilizing it in various industrial processes or permanently storing it deep underground.

[56] "Understanding India's Net Zero Policies: A Primer for Journalists", Earth Journalism Network, 27 July 2023
https://earthjournalism.net/resources/understanding-indias-net-zero-policies-a-primer-for-jou-rnalists

Thus, it is necessary to understand the fuel pathway for the shipping sector for a proper transition, and for a balance to be struck between policies and their implementation. Indian shipping industries, too, have to get more actively involved in innovations and could help in achieving the country's net-zero target by specifying the scope of emissions, quantifying mitigation measures and pathways, and establishing a review process for the target.[57]

Recommendations

- Indian policymakers must commit themselves to establishing green shipping corridors to accelerate the development of zero-emission fuels, low-carbon enabling infrastructure, and effective legislation and regulation. These corridors would serve as testbeds for alternative fuel infrastructure and operations, promoting the adoption of low-carbon fuels, encouraging the development of sustainable infrastructure, and facilitating the transition to eco-friendly practices along key maritime routes.

- India should collaborate with leading global green-transition countries such as the US, the UK, Denmark, and Norway, to access best practices, technology, and resources for developing green shipping corridors and promoting sustainable maritime practices, aligning with international initiatives such as the Clydebank Declaration and the Zero Emission Shipping Mission.[58]

- The government needs to leverage digital innovations such as GHG emission calculators, digital twinning, and collaborative platforms, to raise energy efficiency in the maritime sector.

- Leverage the "LeadIT 2.0 Initiative" announced at COP28. The ITP represents a pivotal partnership between India and Sweden, targeting expedited and more ambitious transitions within the industry sector. Facilitated by LeadIT, the ITP would facilitate collaboration between governments, industries, technology providers, researchers, and think tanks of both nations, offering customised bilateral and multilateral technical and financial assistance to support India's transition priorities.[59]

- Increase funding for research and development (R&D) initiatives focused on advancing technologies for green shipping, including hydrogen fuel cells, ammonia propulsion systems, and carbon capture and storage (CCS) technologies. Establish collaborative

[57] *Ibid*

[58] India, as one of the four core mission members in the Zero Emission Shipping Mission of the Mission Innovation to support the decarbonization of the maritime sector and achieve net-zero greenhouse gas emissions by 2050.
[59] LeadIT 2.0 launched at COP28: driving inclusive industry transition forward, Leadit Leadership Group for Industry Transition, 12 December 2023 https://www.industrytransition.org/insights/leadit-2-0-launched-at-cop28-driving-inclusive-industry-transition-forward/

research partnerships between industry, academia, and government agencies to drive innovation in sustainable maritime solutions.

Conclusion

While maritime transport is undeniably a linchpin of global trade and supply chains, the sector faces formidable challenges in terms of reducing GHG emissions. Yet, a transition away from conventional marine fossil fuels is crucial, especially given the fact that alternative fuels like hydrogen (H_2) and ammonia (NH_3) offer promising paths toward decarbonisation. However, the challenges should not be underestimated, as transitioning to these alternative fuels is a complex and costly endeavour, requiring significant technology innovation and capital investment.

Hydrogen boasts a high energy content but suffers from low volumetric energy density, necessitating larger storage space. Ammonia presents itself as a more cost-efficient option due to its existing infrastructure and lower storage costs. However, both hydrogen and ammonia face similar challenges related to NOx emissions, the addressal of which requires significant additional investments of time, money, and effort, in technology. Further, the production of green hydrogen and ammonia using renewable energy sources is essential to minimise their carbon footprint. Currently, grey production methods predominate, underscoring the need for a shift to 'blue' or 'green' production techniques. Numerous research and development projects are underway to harness hydrogen and ammonia as marine fuels, with promising results for smaller vessels. However, achieving zero-carbon emissions for large merchant vessels involved in global cargo transportation remains a formidable challenge.

Given the ambitious targets set by multiple stakeholders, including those within India, concerted efforts by policymakers, the shipping industry, and the research community, are imperative. Scaling up investment in research, development, and innovation, along with government subsidies for alternative fuel infrastructure, will be crucial to navigate these challenges and steer the maritime sector toward a sustainable, low-carbon future.

About the Author

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