IRCLASS
Indian Register of Shipping

Future Fuel Strategy (FFS) For Maritime India

Introduction

India's maritime sector while embarking on a transformative journey towards sustainability requires a comprehensive Future Fuel Strategy (FFS). This Base document proposing a FFS for maritime India along with a roadmap for its implementation aims to position India as a global leader in green fuel market for maritime by focusing on cleaner fuels, upgraded infrastructure, and international collaboration. With clear timelines and actionable steps, India is set to drive the global green shipping movement forward. This document presents a roadmap to enable the maritime industry to proceed further and accomplish the targets envisioned by the Government of India through various initiatives.

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नौवहन महानिदेशक
एवं अपर सचिव, भारत सरकार
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सत्यमेव जयते

भारत सरकार
Government of India
पत्तन, पोत परिवहन और जलमार्ग मंत्रालय
MINISTRY OF PORTS, SHIPPING AND WATERWAYS
नौवहन महानिदेशालय
Directorate General of Shipping

Date 14.02.2025

Message from the Director General of Shipping

As we stand at the threshold of a transformative era for India's maritime sector, I am privileged to introduce the Consultative Document on the Future Fuel Strategy (FFS) for Maritime India. This insightful and forward-looking draft, formulated by the Indian Register of Shipping (IRS) in partnership with the Directorate General of Shipping (DGS), highlights India's proactive approach in addressing the pressing need for sustainable maritime energy solutions.

The Future Fuel Strategy sets forth a dynamic blueprint, emphasizing the integration of cleaner, alternative fuels and the development of supporting infrastructure to propel India towards becoming a pivotal player in the global green maritime industry. This strategy is not merely a response to global environmental imperatives; it is a bold statement of India's ambition to lead in the adoption of green technologies, fostering innovation and resilience within our maritime operations.

I commend the Indian Register of Shipping for their diligent efforts in crafting this document. Their technical acumen and strategic foresight have been instrumental in laying out a pathway that addresses both the opportunities and challenges of transitioning to sustainable fuels like green hydrogen, ammonia, methanol, and biofuels, while also exploring electrification and other emerging technologies.

This document now enters a crucial phase of stakeholder engagement. I kindly solicit the insight and domain specific input of maritime professionals, industry leaders, academic experts, policymakers, and environmental advocates to contribute their perspectives. Your feedback is essential in ensuring that the strategy is robust, inclusive, and aligned with the broader goals of national development and environmental stewardship.

Following comprehensive consultations and subsequent approval by the Ministry of Ports, Shipping, and Waterways (MoPSW), this strategy document will be formally institutionalised as India's guiding document for future maritime fuels. It is through the engagement framework dynamically evolving that Indian Maritime will complete the transition to net zero while laying the edifice for the growth and leveraging of energy sufficiency in renewable and net zero alternative fuels. It aims to position our nation not just as a participant, but as a frontrunner in the journey towards sustainable maritime practices.

I extend my deepest gratitude to the Indian Register of Shipping for their commendable efforts in shaping this strategy. I also appreciate the involvement of all stakeholders who will contribute to refining this document. Your collaborative efforts will be instrumental in steering India's maritime industry towards a future that champions sustainability, embraces innovation, and asserts our leadership on the global stage.

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Foreword

It is a well-known fact that all countries are putting in tremendous efforts to curb their greenhouse gas emissions to achieve the United Nations Sustainable Development Goals. In this regard, it is heartening to note that India has been consistently placed amongst the high ranked performers on the global Climate Change Performance Index (CCPI) which evaluates countries based on their climate policies, renewable energy, and emissions performance.

To build upon this foundation and to sustain India's drive towards a greener future, the role of it's maritime sector is pivotal since it contributes to a major proportion of India's trade both by volume and by value. This has been recognised with various policies and schemes of the Government of India, notably the Maritime India Vision 2030, Maritime India Amritkaal Vision 2047, Harit Sagar, and Harit Nauka Schemes.

In terms of adoption of alternative fuels and technologies, we acknowledge that the maritime industry is navigating uncharted waters. It faces several uncertainties in both short and medium term. These uncertainties need to be adequately addressed to provide a clear goal to the various stakeholders in the Indian maritime industry so that they can plan their future steps in synchrony with the global status as well as taking India's strengths and vulnerabilities in account. A synergized approach will therefore enable the Indian Maritime Industry to progress on this issue and is therefore much required.

The Future Fuels and Technologies Roadmap is an attempt to paint a picture of India's future maritime landscape in the short to medium term as well as the long term. Adoption to new fuels and technologies eventually bring in a whole new gamut of technological, economic, infrastructural and manpower challenges which need to be surmounted. The report identifies these factors and proposes a way forward on the way India can leverage her strong maritime heritage to navigate confidently through these uncharted waters.

This occasion also lauds a significant milestone as the Indian Register of Shipping and the Directorate General of Shipping mark their 50th and 75th anniversaries respectively, affirming our commitment to provide the finest technical expertise to ensure that the Indian maritime industry and stakeholders are primed to fulfil our nation's goal to lead the world in Safe, Sustainable and Green Shipping.

Arun Sharma
Executive Chairman
Indian Register of Shipping

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Executive Summary

India's maritime sector is poised to transition towards sustainability with the formulation of a comprehensive Future Fuel Strategy (FFS). This strategy aims to position India as a leader in the global green fuel market by adopting cleaner fuels, developing essential infrastructure, and fostering international collaboration. The strategy's roadmap for implementation is structured around multiple scenarios to ensure a resilient and adaptable approach, aligning with India's broader decarbonization goals and commitments under the Maritime India Vision 2030 (MIV2030), Maritime India Amrit Kaal 2047, Harit Sagar and Harit Nauka vision.

Future Fuel Strategy for India: India's Future Fuel Strategy (FFS) is designed to transform the maritime sector by focusing on the adoption of sustainable fuels, infrastructure development, and supportive policy frameworks. The strategy aims to ensure energy security, reduce carbon emissions, and enhance India's position in the global green fuel market.

- **Adoption of Green Fuels**: The strategy includes a multi-fuel approach, focusing on green hydrogen, green methanol, green ammonia, advanced biofuels, and electrification to meet the energy demands of the maritime sector.
- **Infrastructure Development**: Establishing bunkering facilities, upgrading port electrical grids, and integrating renewable energy sources to support the adoption of green fuels.
- **Policy and Regulatory Framework**: Developing policies that provide incentives, subsidies, and support for green fuel adoption and infrastructure investments, ensuring alignment with international standards and commitments.

Future Fuel Scenarios and Analysis: The report extensively analyzes various scenarios to guide India's transition towards sustainable fuels in the maritime sector.

Executive Summary (Contd.)

The Future Fuel Strategy for Maritime India considers scenarios which are based upon the maritime energy scenario forecast by the International Energy Agency 2023

- Green Hydrogen: Green Hydrogen Fuel demand is expected to be 0.026 million tonnes by 2030 and 0.3 million tonnes by 2050.
- Green Ammonia: Green Ammonia Fuel demand is expected to be 0.025 million tonnes by 2030 and 4.4 million tonnes by 2050.
- LNG: LNG fuel demand is expected to be 0.66 million tonnes by 2030 and 0.3 million tonnes by 2050. The LNG for use in 2050 has to be green LNG or bio-LNG.
- Methanol: Methanol fuel demand is expected to be 0.037 million tonnes in 2030 and 0.272 million tonnes in 2050. The methanol used in 2050 has to be green methanol or bio-methanol
- LPG: LPG fuel demand is expected to be 0.017 million tonnes in 2030 and 0.124million tonnes in 2050.
- HFO/MDO/MGO: Conventional marine fuels will be gradually phased out. It is expected that the demand for HFO/MDO/MGO will be 1.43 million tonnes in 2030 but will fall to 0.64 million tonnes by 2050.
- It is anticipated that carbon capture systems may be a possible solution to mitigating GHG emissions. For this, it is expected that Carbon Dioxide Reception Facilities may be required at Ports with annual capacity of 13 million tonnes in 2050.
- Nuclear Propulsion offers an exciting prospect for use in the marine industry (having already been utilized in naval applications). However, the present scenario does not forecast it's use considering the sizeable uncertainties and lack of updated regulatory requirements for maritime application at international level .at present. It is expected that Nuclear Propulsion may grow in popularity from the next decade and should be kept in consideration during revision of the Future Fuels Strategy.
- Electrification of Port Operations: Shore to Ship Power Systems (SPS) aim for 80% port coverage by 2035, reducing emissions through shore power connectivity, requiring an investment of $10 billion.

Roadmap for Implementation

- Infrastructure Enhancement: Establish bunkering facilities, expand renewable energy, and upgrade port grids. Estimated total investment: $80 billion by 2050.
- Policy and Regulatory Support: Align national policies with IMO's targets for net-zero emissions by 2050, provide subsidies, tax incentives, and create a $5 billion Green Shipping Fund to support early-stage projects.

Economic and Environmental Impacts

- Economic Benefits: Green fuels could reduce greenhouse gas emissions aiming to achieve net zero by 2050 saving $15 billion annually in fuel costs and creating over 200,000 new jobs.
- Environmental Impact: Potential reduction of over 120 million tonnes of CO_2 annually, improving air quality and public health.

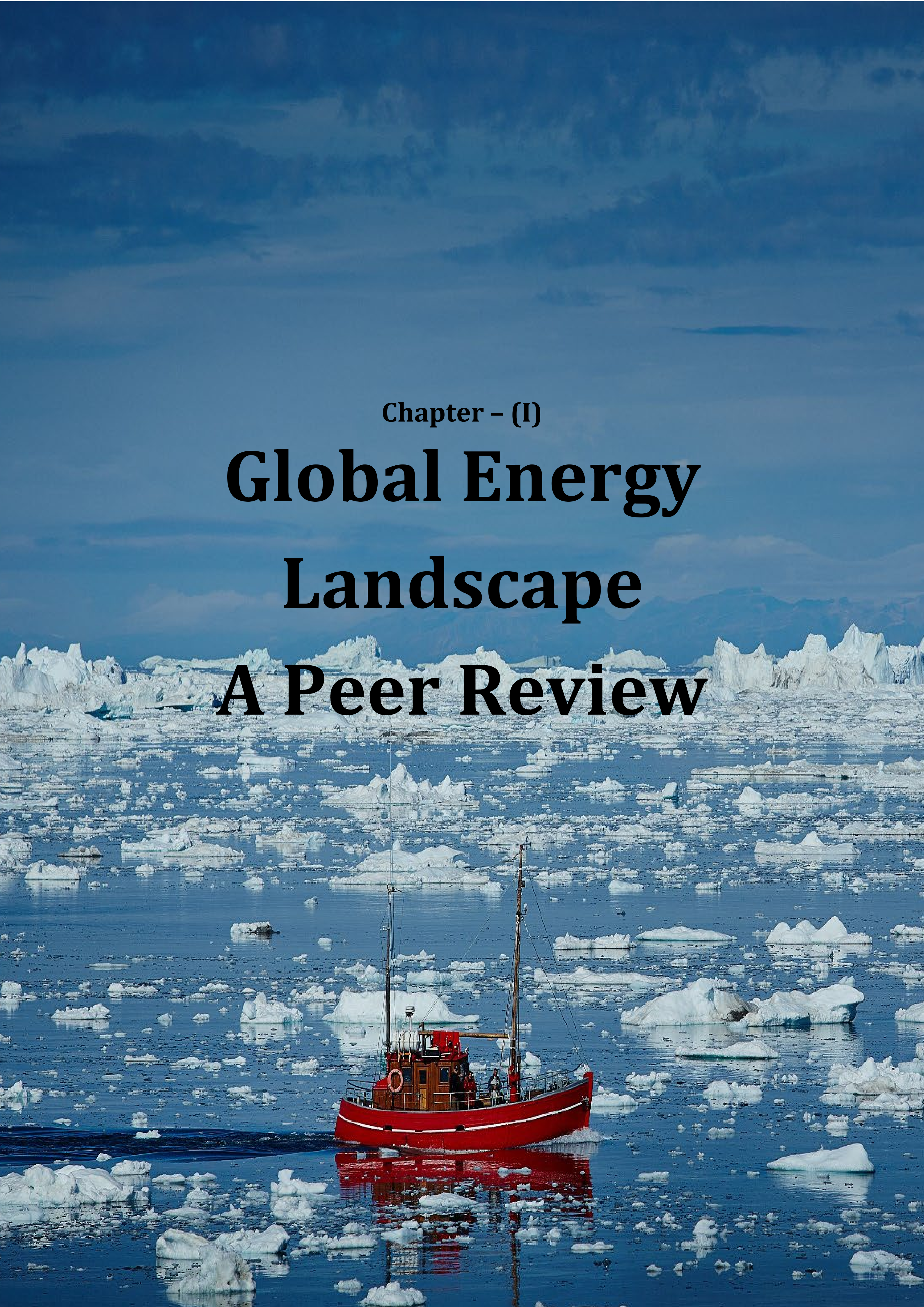
Challenges and Mitigation

Challenges include high initial capital costs, regulatory reforms, and increased logistics expenses. Mitigation strategies include phased investments, public-private partnerships, and international funding support.

India's Future Fuel Strategy provides a clear roadmap for adopting green fuels, enhancing infrastructure, and implementing supportive policies. This positions India as a leader in sustainable maritime practices, contributing significantly to global decarbonization efforts while supporting economic growth.

Chapter – (I)

Global Energy Landscape A Peer Review



Global Energy Landscape

The global energy sector is at a crucial turning point, undergoing a rapid transformation as countries around the world work to combat climate change and reduce greenhouse gas emissions. Historically dominated by fossil fuels, the energy landscape is now shifting towards renewables and green fuels to meet ambitious net-zero emissions targets by 2050. This comprehensive summary explores the evolving fuel landscape for global energy production.

Shift from Fossil Fuels to Renewables, Growth of Renewable Energy Sources and Transition to Green Fuels

According to the International Energy Agency (IEA), energy production and consumption are witnessing a marked shift from fossil fuels to renewable sources. Fossil fuels have historically dominated the energy mix, with the United States, Saudi Arabia, and Russia being the largest producers of crude oil in 2022 totalling up to approx. 33 million barrels per day(b/d).

On the consumption side, the United States, China, and India were the largest energy consumers. Coal, despite its high carbon footprint, remains crucial for electricity generation in China and India, with China producing 4.6 billion metric tons and India producing 850 million metric tons. It should however be acknowledged that India is taking actions diligently to reduce this dependency on coal.

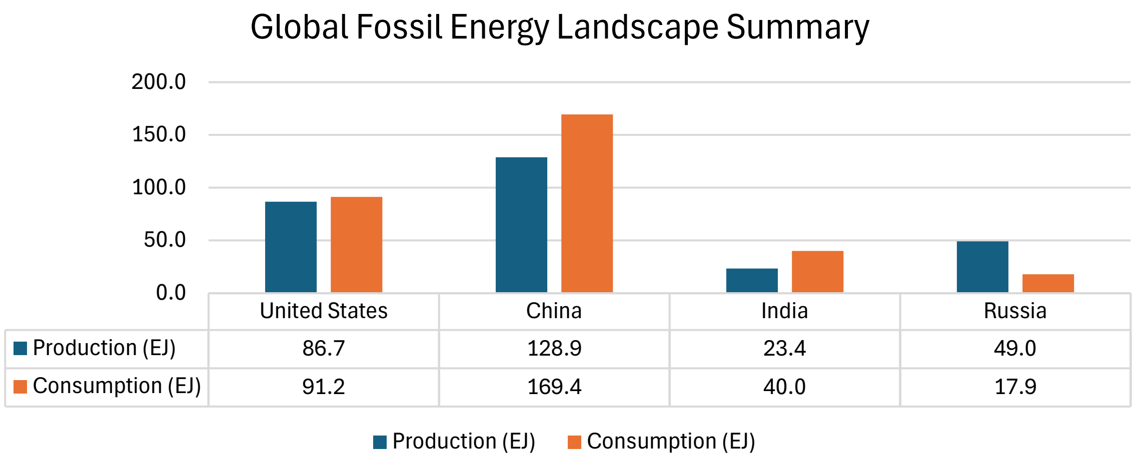
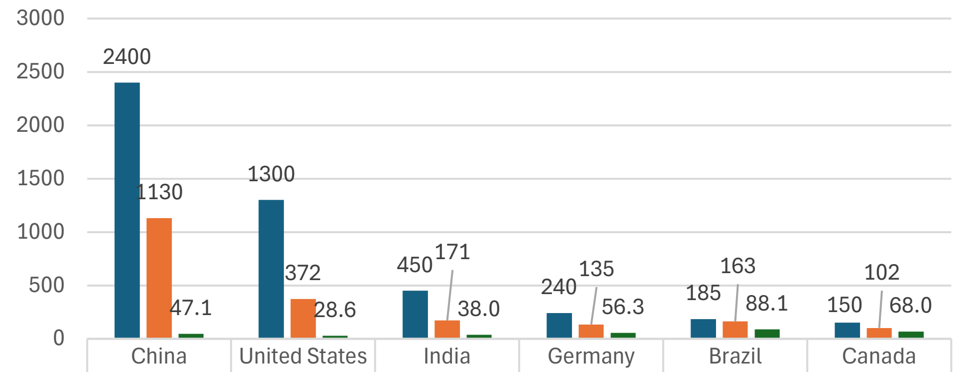


Figure 1 Global Fossil Energy Landscape Production Vs Consumption (EJ)

Renewable energy sources have seen substantial growth globally, driven by the need for decarbonisation and energy security. China, United States, and India are the top three countries in the world as regards the total renewable energy generation capacity.



	China	United States	India	Germany	Brazil	Canada
Total Generation Capacity (GW)	2400	1300	450	240	185	150
Total Renewable Production (GW)	1130	372	171	135	163	102
% Renewable Energy Share	47.1	28.6	38.0	56.3	88.1	68.0

Total Generation Capacity (GW) Total Renewable Production (GW) % Renewable Energy Share

Source: IRENA Renewable Energy Statistics 2023

Figure 2 Global Renewable Energy Landscape- Lead Country-wise (GW)

Cost Competitiveness of Green Fuels and Investment Scenarios in Green Fuels

The transition to green or zero carbon fuels, such as hydrogen, ammonia, methanol, and biofuels, is a critical focus area for the global energy sector. Green hydrogen is anticipated to play a pivotal role, particularly in hard-to-abate sectors like shipping and heavy industry.

By 2030, Europe aims to produce 10 million tonnes of green hydrogen, while Australia is targeting 5 million tonnes, primarily for export.

By 2050, India plans to produce 20 million tonnes annually, driven by the National Hydrogen Mission. Green ammonia is also being explored as a potential fuel for both the shipping industry and fertilizer production. Japan and South Korea are expected to consume about 6 million tonnes annually by 2030, largely relying on imports from Australia and the Middle East.

Biofuels are also gaining traction, with Brazil projected to produce 120 million tonnes by 2050, while the United States aims to produce 50 billion gallons annually to meet domestic demand and support exports.

With wider adoption of use of green fuels and facilitated by an enabling regulatory as well as policy framework, it is expected that the cost of green fuels would relatively be reduced as compared to conventional fuels by 2050 (this is also discussed further in Chapter IV).

Investment in green fuels is projected to exceed $1.2 trillion annually by 2050, driven by government policies, international collaborations, and the need for energy security. Europe is expected to invest $300 billion annually, focusing on hydrogen and e-fuels under the "Fit for 55" package, which aims to reduce greenhouse gas emissions by 55% by 2030. The Asia-Pacific region, including China, India, Japan, and Australia, is expected to invest around $400 billion annually in green fuels, with a focus on hydrogen and ammonia production. The Middle East and Latin America are positioning themselves as major exporters of green fuels, with substantial investments planned in hydrogen and biofuels production, aiming to leverage their abundant renewable resources.

Trends in the Global Energy Landscape and Demand & Supply Dynamics

Trends in the Global Energy Landscape

Decentralized Energy Systems: The energy landscape may see a growth in renewable energy systems facilitated by solar photovoltaics (PV) and wind turbines on a household or community level. Decentralized systems are expected to account for 25% of global energy production by 2040. (Source: IRENA Future of Solar PV 2023).

Advances in Technology: Advances in battery storage technologies and hydrogen storage solutions are expected to mitigate the intermittency of renewable energy sources, making renewables more reliable and grid friendly. The cost of lithium-ion batteries is expected to fall to $70 per kWh by 2030. (Source: Bloomberg NEF Storage Outlook 2023).

Green Hydrogen and Ammonia: Hydrogen and ammonia may play a role in decarbonizing the automotive, industrial, and shipping sectors. The production costs of green hydrogen are expected to decline to $1.5 per kg by 2030, making it competitive with fossil fuels. (Source: Hydrogen Council 2023)

Electrification of Transport: The adoption of electric vehicles (EVs) is set to accelerate, driven by declining battery costs and supportive government policies. Major car manufacturers are committing to phasing out internal combustion engines in favour of EVs, with global EV sales expected to reach 45 million by 2030. (Source: IEA Global EV Outlook 2023).

Carbon Capture Utilization and Storage (CCUS): CCUS technologies are being developed to mitigate emissions from existing fossil fuel infrastructure. Countries like **Norway**, **Canada**, and **the U.S.** are investing in CCUS projects, with a combined capacity of 120 million tonnes of CO2 capture annually by 2030. (Source: IEA CCUS Report 2023).

Digitalization: The energy sector will increasingly rely on digital technologies to enhance efficiency, monitor energy use, and enable smart grids that integrate renewables and manage demand effectively. Digital technologies could reduce energy costs by 10-15% by 2030. (Source: IEA Digitalization and Energy 2023)

Demand and Supply Dynamics for 2030/2050

The global fuel or energy demand scenario is shown in figure 3 (Souce: McKinsey)

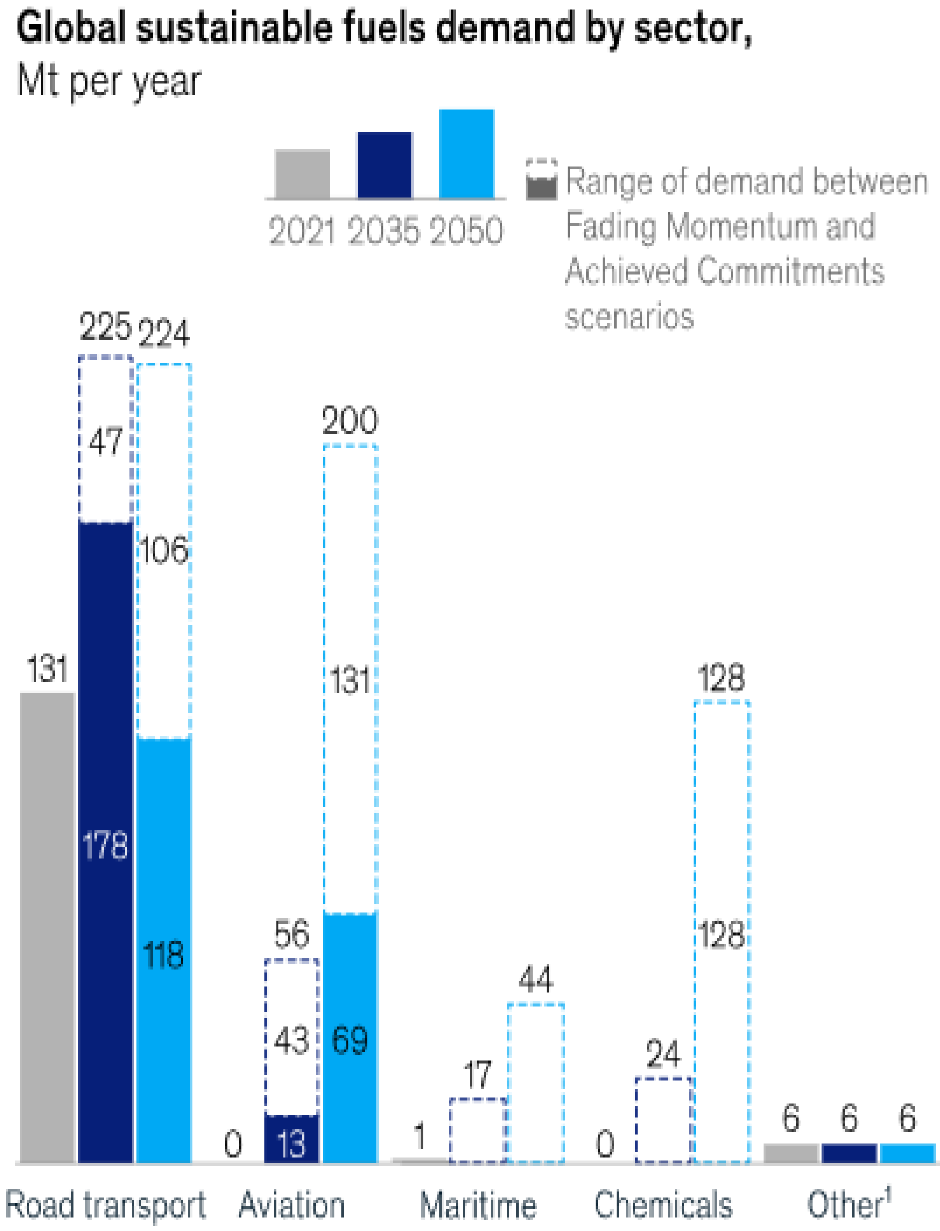


Figure 3: Global Fuel demands scenario for future (Mc Kinsey 2023)

As regards specific fuel demand scenarios, McKinsey further provide their projection for the future as shown in Figure 4.

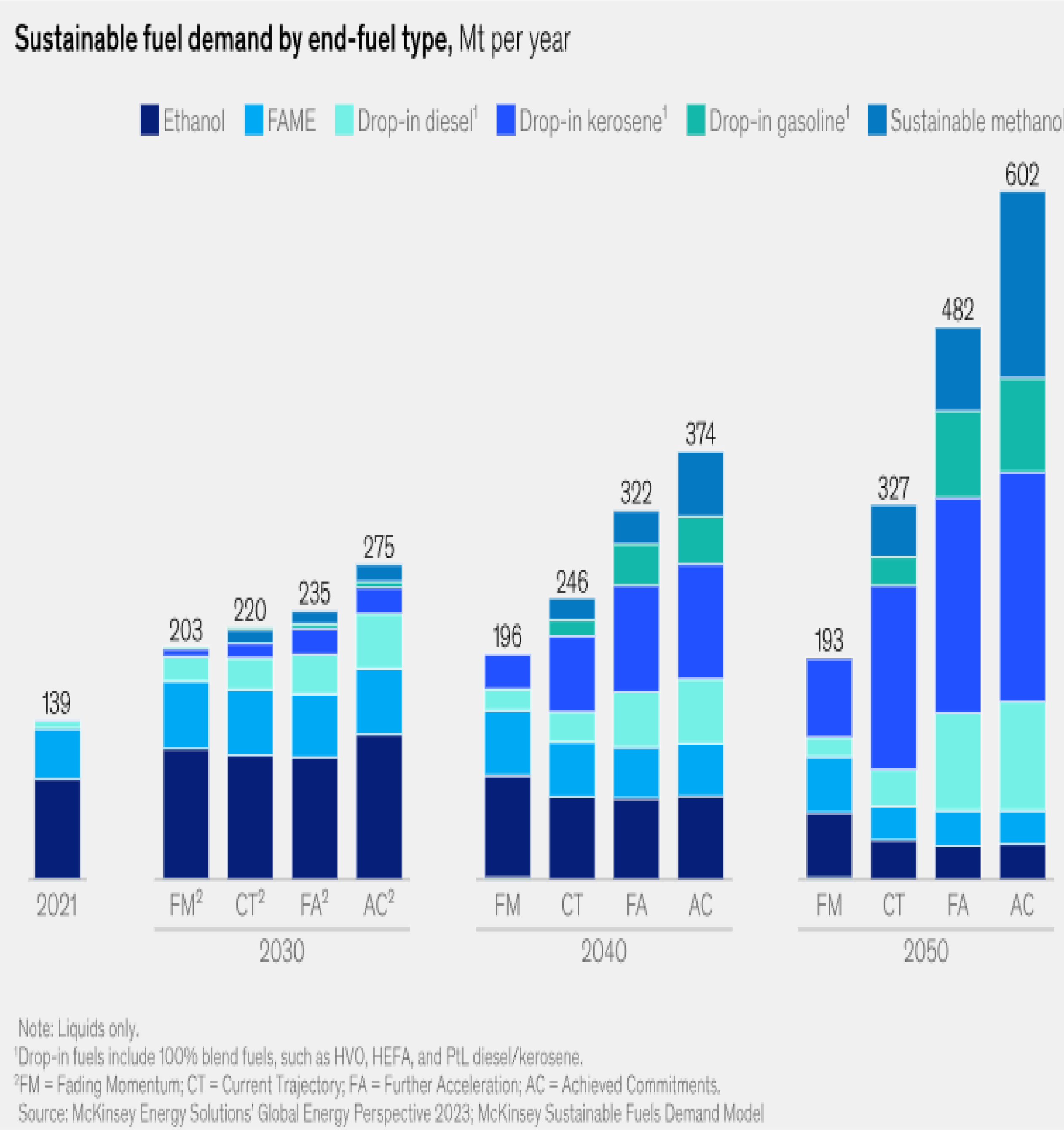


Figure 4: Sustainable Demand Projection for different Fuels (Source: McKinsey 2023)

Against this demand in the backdrop, investments have been planned to achieve the targets. This is shown in Figure 5.

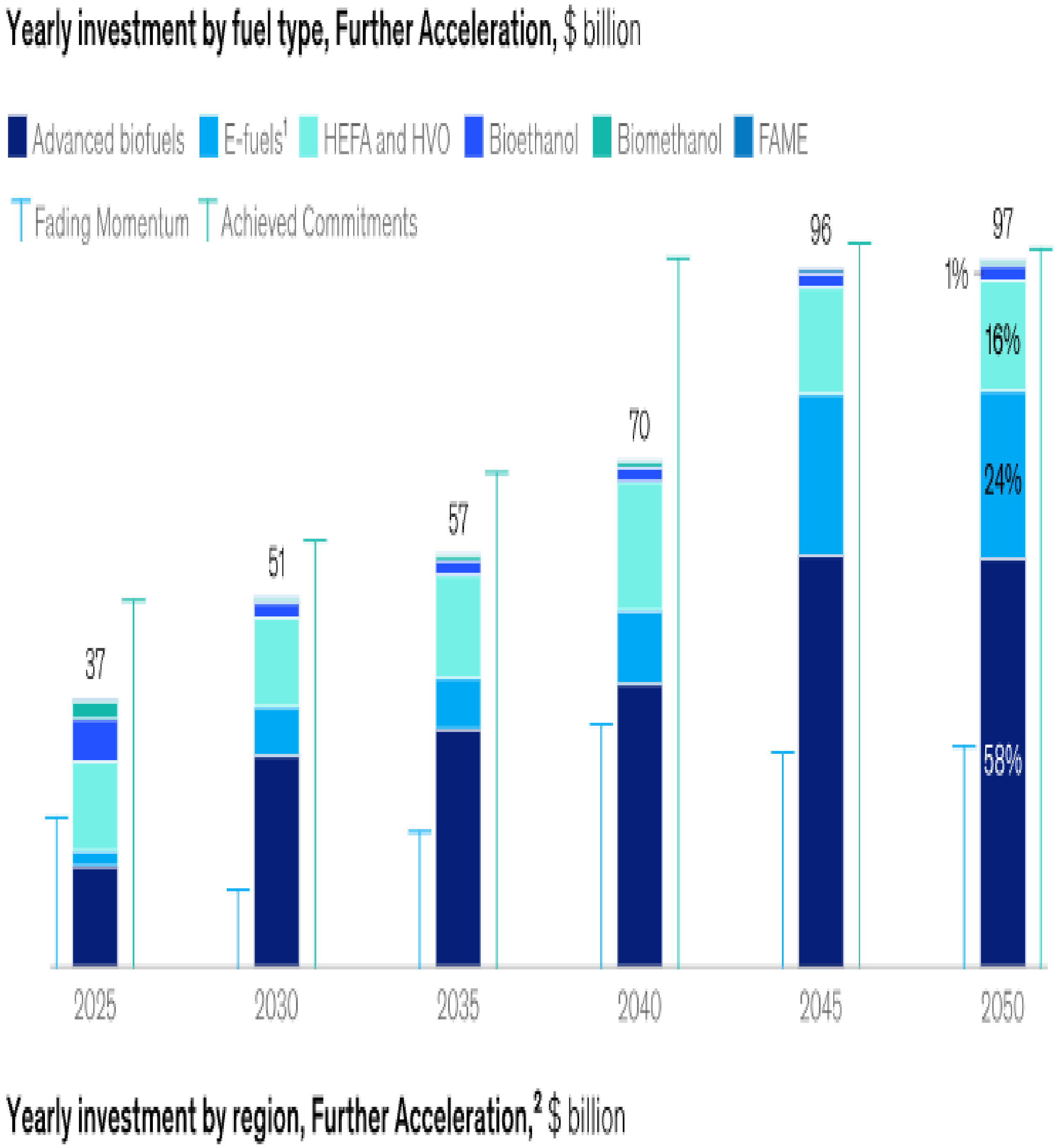


Figure 5: Investments to achieve sustainable fuel production (Mc Kinsey, 2023)

Summary (I)

Global Energy Landscape

The current energy landscape is still dominated by fossil fuels, with countries like the United States, China, India, Russia, and Qatar leading in production and consumption.

Renewable Energy Progress: Renewable energy is expanding rapidly, with major advancements in solar, wind, and hydropower. China leads in solar energy capacity, followed by the United States and India. Wind energy has seen similar growth, with China, the United States, and Germany. Hydropower also remains significant, with China, Brazil and Canada being the top three producers. Germany leads in renewable energy share, with 56.3% of its total generation capacity from renewables.

Green Fuels for the Future: Green fuels like hydrogen, ammonia, and biofuels are key to achieving a zero-carbon future. However, it needs to be ensured that such fuels are sustainably produced considering a total lifecycle analysis from well to wake. Renewable energy in terms of nuclear energy would also be helpful for production of green fuels.

Cost Comparisons and Projections: The cost of green fuels is expected to become competitive with fossil fuels by 2030. Technological advancements and economies of scale will be crucial in reducing these costs, making green fuels viable alternatives.

Future Outlook (2050): By 2050, renewable energy will dominate the energy mix, with a major shift towards green hydrogen, green ammonia, biofuels, and synthetic fuels. Green ammonia will also play a key role in decarbonizing agriculture and heavy industries. The transition to green fuels will require international collaboration, substantial investments, and supportive policies to create a sustainable energy future.

Chapter – II

The Evolving Global Maritime Fuel Landscape For 2030 and 2050

The Evolving Global Maritime Fuel Landscape - 2030/2050

The maritime industry is responsible for transporting more than **80% of global trade by volume**, making it a critical component of the global economy. However, it also contributes significantly to greenhouse gas (GHG) emissions, with shipping accounting for approximately **2% of global CO_2 emissions** in 2018. With growing global concerns about climate change, the maritime industry faces increasing pressure to reduce its carbon footprint and transition to low-carbon fuels. In response, **International Maritime Organization (IMO)** strategies and market-based measures are being formulated to achieve net-zero emissions by 2050, fostering the development of alternative fuels like **green ammonia**.

Deciding Factors of the Evolving Global Maritime Fuel Landscape

The maritime industry is at a crucial crossroads, facing the need to significantly reduce greenhouse gas (GHG) emissions and shift towards sustainable energy sources. The adoption of green fuels is driven by international as well as regional regulatory frameworks, technological innovations, infrastructure development, cost competitiveness, and stakeholder collaboration. This summary provides a comprehensive overview of the factors influencing the future trends in maritime fuels, outlining the role of global regulations, technological advancements, infrastructure readiness, and investment dynamics in shaping a sustainable future for the shipping sector.

Regulatory Frameworks and Decarbonization Targets

The drive towards decarbonization in the maritime industry is shaped by a combination of international, regional, and national regulations.

The United Nations Framework Convention on Climate Change (UNFCCC) and the International Maritime Organization (IMO) play critical roles in this transition. The IMO's Revised GHG Strategy 2023 targets net-zero GHG emissions by 2050, with interim goals for 2030 and 2040. Market-Based Measures (MBMs) for example carbon levies, are also being considered to promote cleaner technologies by making conventional fuels less economically viable.

Technological Readiness and Compatibility

The adoption of alternative fuels depends on the technological readiness of the maritime sector. Dual-fuel engines that can operate on both conventional and alternative fuels are gaining traction, offering a flexible solution during the transition phase. Engine manufacturers have developed engines compatible with methanol and LPG. Efforts are ongoing to develop internal combustion engines suitable for use with hydrogen, and ammonia fuels.

Hydrogen fuel cells and hybrid electric propulsion systems are also being developed for maritime use, particularly for smaller vessels and short-sea shipping. Onboard Carbon Capture and Nuclear Propulsion are other technologies being considered for use in maritime. There is also impetus to improve the energy efficiency of shipping so as to reduce fuel consumption.

Infrastructure and Bunkering Network Development

The development of alternative fuel infrastructure is crucial for the adoption of green fuels in the maritime industry. Major ports are investing in hydrogen and ammonia bunkering facilities to become key green fuel hubs by 2030. The establishment of green shipping corridors is also useful for supporting the global uptake of green fuels by providing consistent access along major shipping routes.

Standardization of bunkering procedures for alternative fuels, such as those being developed by the International Association of Ports and Harbors (IAPH), is necessary to ensure safety and efficiency of bunkering operations. Public-private partnerships are considered to playing a significant role in developing bunkering infrastructure and accelerating the green transition.

Cost Competitiveness and Commercial Viability

The commercial viability of alternative fuels is a key factor influencing their adoption. The production costs of green fuels, such as hydrogen and ammonia, remain high presently but are expected to decrease significantly with technological advancements, economies of scale as well as enabling policy frameworks supported by regulations.

Government subsidies, policies such as carbon pricing, and incentives are expected to narrow the cost gap between green and conventional fuels. The cost of retrofitting vessels to use alternative fuels, such as LNG, ammonia, or hydrogen, also plays a role in determining their commercial feasibility.

Safety and Regulatory Standards

Ensuring the safe adoption of new fuels requires comprehensive safety standards and regulations. The IMO's International Code of Safety for Ships using Gases or other Low-flashpoint Fuels (IGF Code) provides specific requirements for alternative fuels like LNG. The IMO has approved interim guidelines for use of fuels or technologies such as LPG, Methanol, Ammonia and Fuel Cell Installations etc. Major Classification Societies have also developed their rules/guidelines for safe use of these fuels/technologies onboard

Availability of Renewable Energy for Fuel Production

The production of green fuels depends on the availability of renewable energy. Countries like Australia, Saudi Arabia, and Chile are emerging as potential candidates to be major producers of green hydrogen and ammonia due to their vast renewable energy resources.

The Asian Renewable Energy Hub (AREH) in Australia, Saudi Arabia's NEOM project, and Chile's National Green Hydrogen Strategy are examples of large-scale initiatives that aim to produce green hydrogen at a competitive cost for global export.
The European Union's "hydrogen valleys" initiative, which integrates hydrogen production, storage, and use within a regional ecosystem, is another example of how renewable energy availability is driving the adoption of green fuels. Projects like the Northern Netherlands

Hydrogen Valley are demonstrating how renewable energy can be used to produce green hydrogen for maritime applications

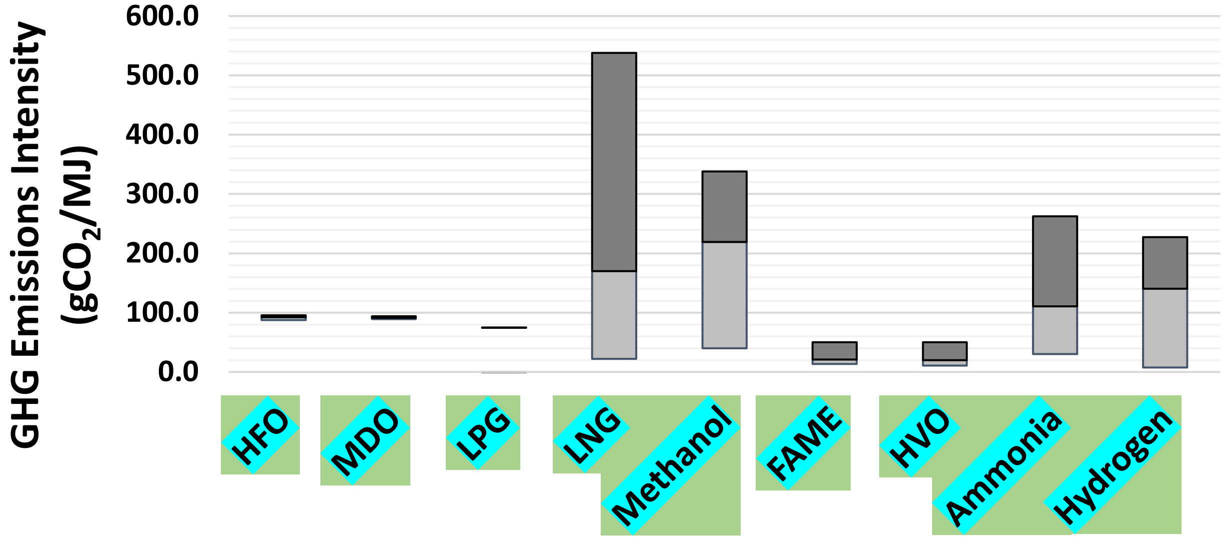


Figure 6: Lifecycle analysis depicting GHG Intensity ranges for select marine alternative fuel candidates (Source: MEPC 80/7/4)

Trends in Green Ship Construction and Future Outlook

The transition to alternative fuels is also reflected in the construction orders for new ships. Recent trends indicate a growing interest in vessels designed to operate on alternative fuels. Methanol and LNG appear to be the frontrunners in terms of fuel transition. However, it may also be observed ships are being fitted with technologies such as onboard carbon capture, nuclear propulsion and wind assisted propulsion. Battery powered ships and Battery assisted propulsion are also quite popular as on date with newbuilding orders covering a wide range of ship types including cargo ships as well as passenger ships and gross tonnages ranging from 50 to 125000.

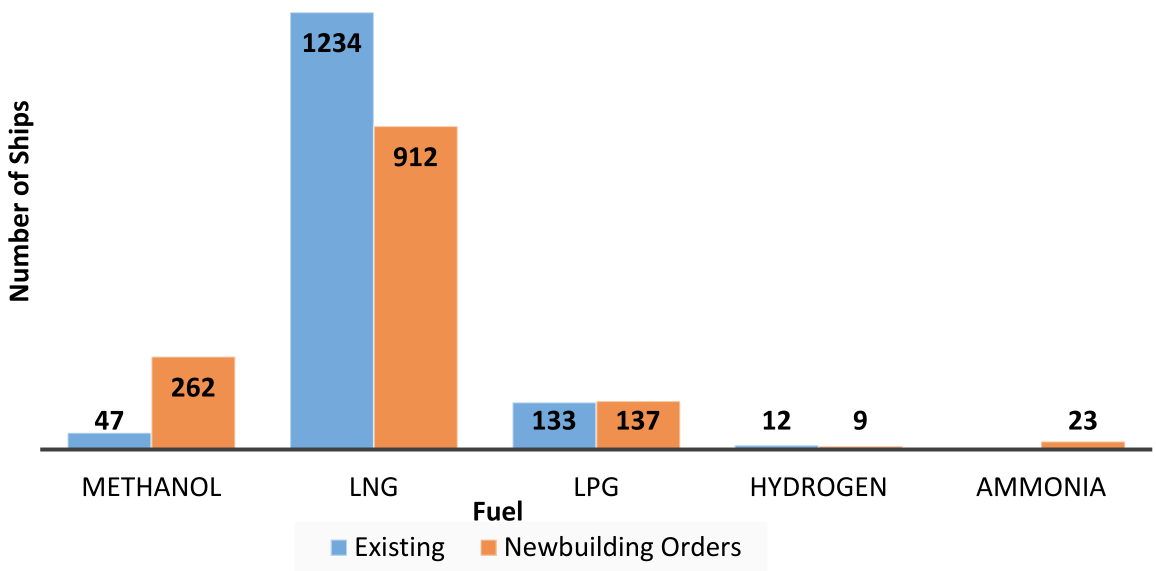


Figure 7: Present Statistics of the Ships operating on Alternative Fuels (in January 2025)

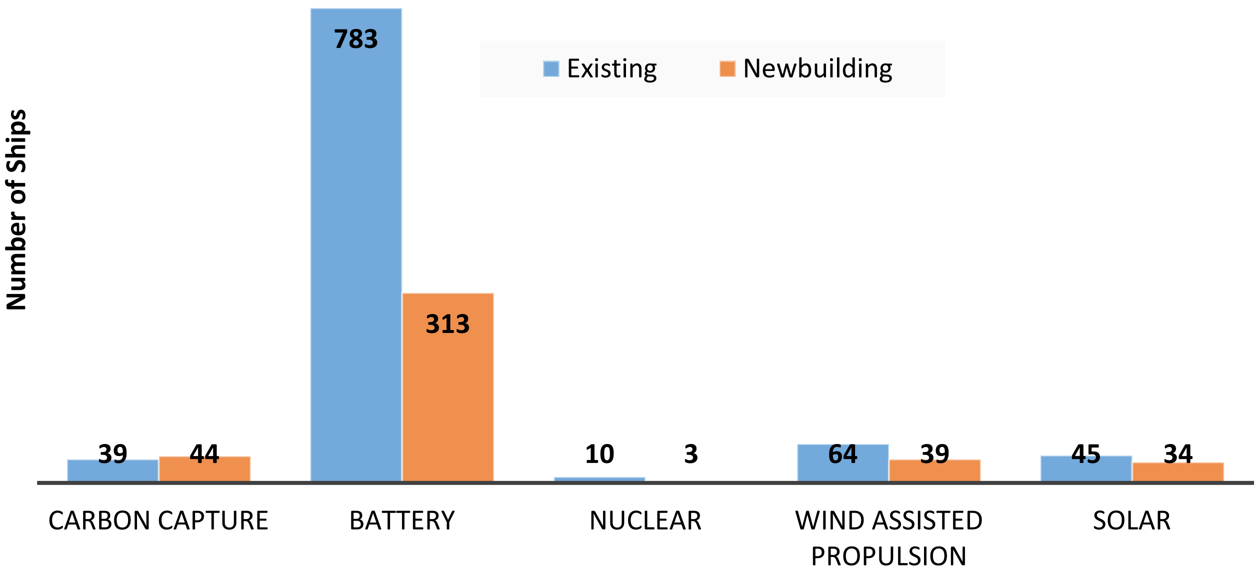


Figure 8: Present Statistics of the Ships installed with New Technologies (in January 2025)

Global Maritime Fuel Mix Scenario for 2030/2050

The International Energy Agency has forecast scenario for fuel mix for shipping as shown in the figure below:

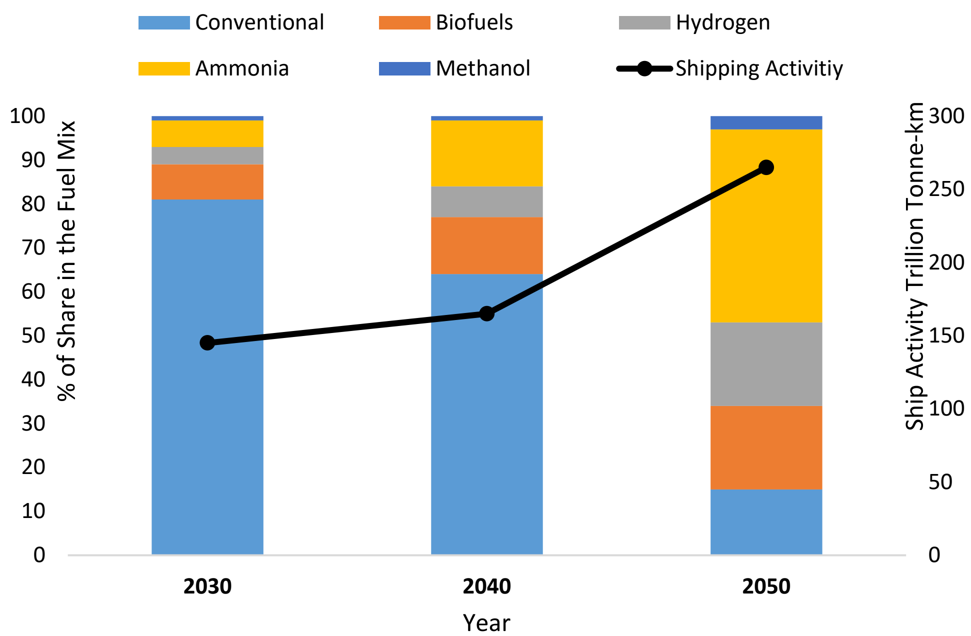


Figure 9: IEA net-zero forecast for future fuels from 2030 to 2050 (Source: IEA, 2024)

Additionally, the IRENA fuel mix forecast also provides similar observations forecasting ammonia as the major future fuel by 2050.

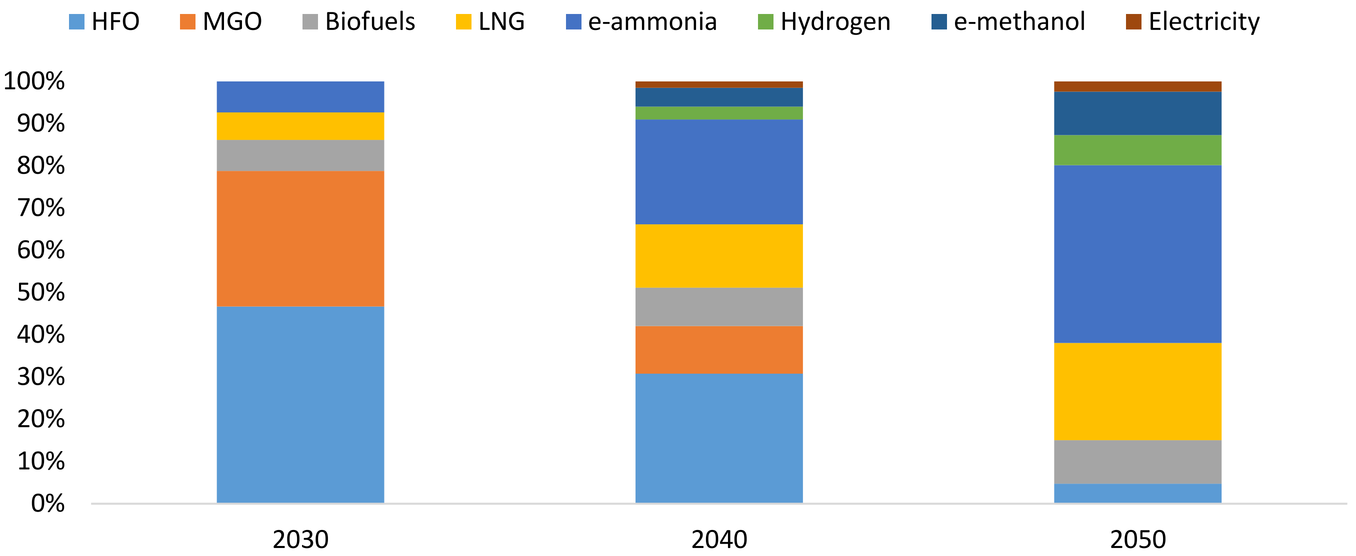


Figure 10: IRENA net-zero forecast for future fuels from 2030 to 2050 (Source: IRENA, 2021)

(Note: It is considered that the IEA data as presented in Figure 6 is more recent since it was updated in November 2024. Hence this data is taken further to predict the future global maritime fuel mix scenarios in 2030 and 2050.)

Table 1 Projected Global Maritime Fuel-mix Scenario 2030

Fuel Type	Share (%)	Reasons	Dominant Sectors
HFO/ VLSFO	81	Existing dominance, low cost, established infrastructure	Long-haul shipping, older vessels, regions with established bunkering
MGO		Compliance with sulphur regulations, cleaner alternative to HFO	Short-sea shipping, vessels operating in Emission Control Areas
LNG/LPG		Lower emissions, transitional fuel with growing infrastructure	Newer vessels, regions with developed LNG infrastructure, transitional fuel
Biofuels	8	Lower carbon footprint, can be used in modified engines, drop-in capability for biofuels	Coastal shipping, regional services, smaller vessels, areas with biofuel incentives
Methanol	1	Lower carbon footprint especially when derived from biogenic sources or green methanol. Marine Engines commercially available	Long-haul shipping
Ammonia	6	Zero-carbon potential, early adoption phase with ongoing pilot projects	Future-focused projects, research vessels, early adopters of alternative fuels
Hydrogen	4	Emerging zero-carbon fuel, limited to niche	Small vessels, pilot projects, hybrid systems

		applications due to storage and cost challenges	
Electric/ Battery/ Wind-assisted		Suitable for short-sea shipping, hybrid systems, and energy efficiency improvements	Ferries, short-sea shipping, vessels using hybrid propulsion

By 2050, the maritime sector aims to achieve net-zero GHG emissions, leading to a significant transformation of the fuel mix. The projected fuel mix for 2050 is expected to be dominated by zero-carbon fuels, including ammonia and hydrogen, with the complete phasing out of traditional fossil fuels such as HFO and VLSFO. The key factors driving this shift include stringent regulatory environments, technological advancements, infrastructure development, and economic incentives for low-carbon solutions.

Table 2 Projected Global Maritime Fuel-mix Scenario-2050

Fuel Type	Share (%)	Reasons	Dominant Sectors
Ammonia	44	Zero-carbon potential, high energy density, technological advancements in combustion and safety	Long-haul shipping, large vessels, global bunkering network
Hydrogen	19	Zero-carbon fuel, direct use in fuel cells, emerging storage technologies	Coastal shipping, short-sea voyages, hybrid propulsion systems
Biofuels	19	Transition to green methanol, compatibility with existing engines, drop-in capabilities for biofuels	Regional routes, ferries, smaller vessels, transitional applications
Methanol	3	Lower carbon footprint especially when derived from biogenic sources or green methanol. Marine Engines commercially available	Long-haul shipping
Electric/ Battery Solutions	12.5	Suitable for short-sea shipping and hybrid systems, improvements in battery technology and charging infrastructure	Short-sea shipping, ferries, auxiliary systems on large vessels
LNG/LPG	15	Transitional role, existing infrastructure, declining due to methane slip concerns	Regions with established LNG infrastructure, older LNG-capable vessels
HFO/VLSFO		Phasing out due to decarbonization goals, limited use in legacy vessels or niche applications	Niche use cases, legacy systems, emergency backup power

Ammonia is expected to be the leading fuel for the maritime sector by 2050, followed by Hydrogen and Biofuels.

The above forecast does not consider uptake of carbon capture technologies and nuclear technologies in the maritime field. It is anticipated that their utilization onboard ships may pick-up in the next decade which can influence the future fuel mix as predicted above. If bio-LPG and bio-LNG are produced in scalable quantities then these could also occupy a larger proportion of the fuel mix. Carbon capture plant onboard as well as reception facilities onshore coupled with renewable energy availability may also spur production of synthetic fuels which would again be advantageous in transitioning towards a greener future.

Summary (II)
The Evolving Global Maritime Fuel Landscape

The maritime industry, responsible for transporting over 80% of global trade by volume, significantly contributes to greenhouse gas (GHG) emissions, accounting for approximately 2.89% of global CO_2 emissions in 2018. With the International Maritime Organization (IMO) aiming for net-zero emissions by 2050, the maritime sector is undergoing a substantial transformation in its fuel mix to reduce its carbon footprint and adopt alternative fuels like green ammonia, methanol, and hydrogen.

Fuel Mix Scenario for 2030: The global maritime fuel mix by 2030 is expected to remain diverse, incorporating a combination of conventional and alternative fuels. The estimated shares are:

- **Conventional Fuels such as Heavy Fuel Oil (HFO) & Very Low Sulfur Fuel Oil (VLSFO), Marine Gas Oil (MGO), Liquefied Natural Gas (LNG): 81%** Despite increased environmental regulations, HFO and VLSFO will still dominate due to their cost-effectiveness and established infrastructure. MGO, a cleaner alternative to HFO, is suitable for short-sea shipping and vessels operating in Emission Control Areas (ECAs). LNG is viewed as a transitional fuel, providing lower CO_2 emissions compared to traditional fuels. However, methane slip remains a concern.
- **Methanol: 1%,** Methanol is gaining traction due to its lower carbon footprint and availability of commercial engines.
- **Biofuels: 8%**, Biofuels offer a drop-in solution for existing vessels.
- **Ammonia: 6%** Ammonia, a promising zero-carbon fuel, will see early adoption through pilot projects.
- **Hydrogen: 4%** Hydrogen, particularly for niche applications, is limited by storage and cost challenges.
- **Electric/Battery Solutions & Wind-Assisted Technologies:** Electric propulsion and wind-assisted technologies are primarily suited for short-sea shipping and energy efficiency improvements.

Fuel Mix Scenario for 2050: By 2050, the maritime sector aims to achieve net-zero GHG emissions, leading to a significant shift towards zero-carbon fuels. The projected fuel mix is as follows:

- **Ammonia: 44%** Ammonia will become a leading fuel for deep-sea shipping due to its zero-carbon potential and high energy density.
- **Hydrogen: 19%** Hydrogen, either directly or as a derivative like ammonia, will play a major role in hybrid systems and short-sea shipping.
- **Methanol: 3%,** Methanol is gaining traction due to its lower carbon footprint and availability of commercial engines.
- **Biofuels: 19%**, Biofuels offer a drop-in solution for existing vessels.
- **Electric/Battery Solutions:** Battery-electric propulsion will be feasible for short-sea and hybrid systems, improving energy efficiency.
- **Conventional Fuels such as Heavy Fuel Oil (HFO) & Very Low Sulfur Fuel Oil (VLSFO), Marine Gas Oil (MGO), Liquefied Natural Gas (LNG): 15%** Traditional fossil fuels will have limited use in legacy vessels.

Trends in Green Ship Construction

The maritime sector is witnessing a shift towards green ship technologies, driven by the IMO's Revised GHG Strategy 2023. Methanol fuelled ships and Battery Fuelled Ships are being constructed.

Ships using carbon capture technology and nuclear propulsion may also gain popularity in the next decade

Chapter – III

Exploring Green Fuel And Technology Options For The Global Maritime Future

Exploring Options or Global Future Maritime Fuel / Technology

The maritime sector is at an important juncture, as it seeks to significantly reduce greenhouse gas emissions in line with international climate targets. Zero Carbon fuels such as green hydrogen, green ammonia or biofuels, green methanol, green LNG, fuel cells, and Battery Technology (using renewable electricity) are being considered as promising solutions for decarbonizing maritime operations. Each of these fuels presents unique opportunities and challenges, requiring a careful assessment of their viability, infrastructure needs, and long-term environmental benefits to determine their role in shaping the future of maritime energy.

Green Hydrogen as Future Maritime Fuel

Green hydrogen, produced via electrolysis using renewable energy, is gaining traction as a key alternative fuel for maritime decarbonization. The International Maritime Organization (IMO) aims for net-zero emissions by 2050, with green hydrogen expected to play a crucial role.

Table 3 Typical and Relevant Attributes of Green Hydrogen as a Marine Fuel

Specification	Details
Production Method	Electrolysis using renewable energy
Energy Density	120-142 MJ/kg (lower than fossil fuels)
Storage Options	Pressurized (350-700 bar) or cryogenic (-253°C)
Fuel Supply System	Requires specialized piping and insulation, compressors, pumps, and cryogenic tanks
Engine Compatibility	Hydrogen Internal Combustion Engines (H-ICE), Hydrogen Fuel Cells
Safety Considerations	High flammability; liquefied hydrogen stored at very low cryogenic temperatures; hydrogen has low energy of ignition. Hydrogen is also permeable through some metallic materials. Oxygen freezing or condensation can occur upon leakage of liquefied hydrogen. Only helium as inert gas can be used with Liquefied Hydrogen and it is less available as compared to other commonly used inert gases.
Global Warming Potential (GWP)	Zero emissions at point of use; lifecycle emissions depend on renewable energy availability (Hydrogen is considered to be an in-direct GHG)
Lifecycle Assessment (LCA)	Emissions depend upon the mode of production. E.g. green hydrogen has minimal GHG emissions if produced from renewable energy
Flammability	Highly flammable; flammability range between 4-75%
Autoignition Temperature	585°C
Color, Odor, Toxicity	Colourless, odourless, non-toxic

Storage Temperature	Cryogenic storage below -253°C for liquid hydrogen; ambient temperature for compressed hydrogen.
Infrastructure Requirements	Bunkering stations, cryogenic storage, specialized port facilities
Green Fuel Index (GFI)	High GFI due to renewable energy production and zero emissions at point of use
Current Technological Maturity	Can be used in fuel cells. Hydrogen internal combustion engines are under development.
Challenges	Storage space, safety, cost of production, bunkering infrastructure

Technical Feasibility and Challenges

Green hydrogen can be used through hydrogen internal combustion engines (H-ICE) and hydrogen fuel cells (marine internal combustion engines are still under development and will require pilot fuel to be used). However, hydrogen's low energy density (120 MJ/kg) requires high-pressure (350-700 bar) or cryogenic storage at -253°C, posing challenges for vessel design and reducing cargo capacity by up to 20-25%. Ships have been built with fuel cell installations using hydrogen fuel.

Table 4 Technical Feasibility/challenges of Hydrogen as a Marine Fuel H-ICE Vs Hydrogen Fuel Cell

Feature	Hydrogen Internal Combustion Engines (H-ICE)	Hydrogen Fuel Cells
Emission Characteristics	Low emissions (with NOx control) (Hydrogen is however considered an indirect GHG hence Hydrogen slip may potentially affect the overall GHG emissions)	Zero emissions at point of use
Fuel Utilization	Lower due to combustion inefficiencies Pilot fuel would be required	Higher due to direct energy conversion
Application	Engines are under development	Preferred for new builds and electric propulsion
Complexity	Development of efficient I.C. Engines considering the combustion characteristics of Hydrogen	Requires advanced fuel cell technology and power electronics
Storage Requirements	Requires pressurized or cryogenic hydrogen	
Commercial Availability	Under development	Being used on Ships (i.e. commercially available)
Suitability for Large Vessels	Suited for short sea shipping	

Environmental Benefits

Green hydrogen produces zero GHG emissions at the point of use, emitting only water vapor. This eliminates CO2, SOx, and NOx emissions typical of traditional marine fuels like HFO. A lifecycle analysis indicates up to 90% lower emissions when hydrogen is produced using renewable energy.

Policy Drivers and Infrastructure Development

Ports such as Rotterdam, Singapore, and Los Angeles are investing in hydrogen bunkering infrastructure. Rotterdam alone plans to invest €1 billion in hydrogen facilities by 2030. However, hydrogen storage and bunkering require significant infrastructure development due to cryogenic requirements. By 2050, hydrogen bunkering facilities are expected to have grown significantly globally.

Green Ammonia as a Maritime Fuel

Green ammonia, produced from green hydrogen using renewable energy, is emerging as a key carbon-free fuel for maritime decarbonisation.

Carbon-free fuel for maritime decarbonisation.

Table 5 Typical and Relevant Attributes of Green Ammonia as Maritime Fuel

Specification	Details
Chemical Composition	Anhydrous Ammonia (NH_3)
Production Method	Produced from Green Hydrogen via electrolysis powered by renewable energy (e.g., wind, solar)
Boiling Point	−33.3°C
Energy Density	18.6 MJ/kg (lower than conventional marine fuels, but comparable to hydrogen)
Storage Requirements	Requires pressurized tanks or refrigerated tanks at −33.3°C
Toxicity	Highly toxic; requires specialized safety handling and storage procedures
Corrosiveness	Corrosive to copper, brass, and other materials; requires corrosion-resistant equipment
Engine Compatibility	Can be used in fuel cells. Internal Combustion Engines using Ammonia are under development
NOx Emissions	Produces nitrogen oxides (NOx) and nitrous oxides (N_2O) during combustion; requires Selective Catalytic Reduction (SCR) for compliance. Engines also may need to be accordingly designed or tuned to minimize the N_2O emissions (since this is also a GHG and nearly 300 times as potent as carbon dioxide).
GHG Emissions	Zero-carbon at point of use; carbon-neutral lifecycle when produced using renewable energy. Ammonia has been considered as an indirect GHG

Safety Considerations	High toxicity and corrosiveness require stringent safety protocols for bunkering and handling. Ammonia Release Management Systems (ARMS) need to be installed for safe handling and disposal of ammonia leakage and releases onboard.
LCA (Life Cycle Analysis)	zero carbon when produced using renewable energy; reduced GHG emissions compared to fossil fuels (please note that use of ammonia in internal combustion engines would require pilot fuel up to 15%, if this fuel is obtained from fossil sources, then there would be GHG emissions incurred)
GHG emission	Significantly lower compared to conventional fossil fuels when considering full lifecycle emissions
Colour	Colourless
Odour	Pungent, strong odour
Flammability	Lower flammability range (15% – 28%) compared to other fuels;
Toxicity Level	High toxicity; inhalation, ingestion or contact can cause health issues which may be severe depending upon the level of exposure

Technical Readiness and Challenges

Green ammonia is produced by electrolyzing water to generate hydrogen, followed by ammonia synthesis. Two stroke Ammonia-powered ICEs are expected by **2026**, Key challenges include ammonia's toxicity, requiring specialized handling and safety systems, and modifications to vessel design, which may lead to reduction for cargo capacity when fitted on existing ships. Ammonia Release Management Systems (ARMS) may need to be installed on ships to handle any leakage or release of ammonia.

Table 6 Technology Readiness of Ammonia- ICE Vs Fuel Cells

Feature	Internal Combustion Engines (ICE)	Fuel Cells
Technology Readiness	Under development and may be available commercially from 2026	Lower; ammonia-fed SOFCs are still in development
Emissions	Produces NOx and N_2O; requires SCR for reduction	Minimal emissions; almost zero NOx
Complexity	Moderate; retrofitting existing engines	High; requires complex fuel cell stack and reformer
Cost	Too early to state since engines are still under development	High initial cost for fuel cell systems
Scalability	Easier to scale due to existing infrastructure.	More challenging; requires development of new infrastructure
Maintenance	Regular maintenance; similar to conventional ICE engines	Lower maintenance due to fewer moving parts
Fuel Utilization	Lower utilization efficiency	Higher utilization efficiency
Power Output	Suitable for high-power applications	Better suited for medium-to-low power applications
Safety Requirements	Requires modifications for handling toxicity. ARMS also need to be installed	Requires advanced safety for ammonia handling. ARMS also need to be installed
GHG Reduction Potential	Significant if produced from renewable sources	Very high; nearly zero emissions at point of use
Commercial Availability	Expected by 2026	Expected post-2030

Adoption and Infrastructure Development

Ships using ammonia as fuel (anticipated to be dual fuel with LPG and Ammonia as the fuel options) are on order with anticipated delivery dates from 2026. These are liquefied gas carriers carrying ammonia cargo or LPG cargo. Europe is leading the way in bunkering infrastructure, followed by China, India, and the Middle East and by **2050**, green ammonia bunkering networks are expected to be fully established in major ports globally. But considering ammonia is a widely traded cargo and the availability of ammonia import terminals globally, this may not be an insurmountable hurdle.

Green Methanol as a Maritime Fuel

Green methanol, produced from renewable sources like biomass or synthesized using CO_2 and renewable hydrogen using renewable electricity, is emerging as a promising fuel for maritime decarbonisation. Methanol's comparatively easier handling compared to cryogenic fuels makes it attractive for maritime use also coupled with the fact that it has been extensively handled as cargo on chemical tankers.

Table 7 Typical and Relevant Attributes of Green Methanol as Marine Fuel

Parameter	Value
Boiling Point	64.7 °C
Density	791-792 kg/m^3 at 20 °C
Energy Content	19.7 MJ/kg
Flashpoint	11-12 °C
Storage Requirements	Standard liquid/product tanks
Life Cycle Analysis (LCA)	Up to 95% reduction in GHG emissions compared to fossil fuels (Source: IRENA)
Fitness for Combustion	Suitable for both two-stroke and four-stroke marine engines (Source: MAN Energy Solutions)
Self-Ignition Temperature	470 °C
Viscosity	0.59 mPa·s at 20 °C
Corrosiveness	Corrosive to certain metals; requires compatible materials (Source: ABS Methanol as Marine Fuel)
Emission Profile	Generally Low NOx, zero SOx, minimal particulate matter (Source: IMO Studies on Alternative Fuels)
Fire Safety	Fire invisible in daylight. Flammability limits between 6% – 36%. Alcohol Resistant Foam FireFighting systems required to be installed onboard.

Technical Feasibility and Environmental Benefits

Green methanol can be used in two- and four-stroke marine engines. Retrofitting involves modifying fuel supply system including fuel storage tanks and engine components, with methanol requiring typically **2.8 times** the storage capacity compared to conventional fuels in terms of the same energy content. Overall, the use of methanol as fuel is expected to lead to reduction in emission of NOx, SOx and Particulate Matter.

LNG as a Maritime Fuel

Methane, whether in the form of liquefied natural gas (LNG), bio-methane, or synthetic methane (e-methane), is gaining attention as a transitional fuel for maritime decarbonisation. While LNG is already well-established, bio-methane and e-methane offer carbon-neutral or net zero options, supporting the maritime industry's transition to meet international emissions reduction targets.

Table 8 Typical and Relevant Attributes of LNG as a Marine Fuel

Specification	LNG	Bio-Methane	Synthetic Methane (e-Methane)
Chemical Composition	CH4 (Methane)	CH4 (from organic sources)	CH4 (produced synthetically)
Energy Density	50-55 MJ/kg	Similar to LNG	Similar to LNG
Storage Temperature	-162°C	-162°C	-162°C
Carbon Content	Lower than traditional fuels	Carbon-neutral	Potentially carbon-neutral
Methane Slip Potential	High (depending on engine type)	Lower with improved technology	Lower with CCS integration
Production Method	Extraction and liquefaction	Anaerobic digestion	Power-to-gas
Bunkering Infrastructure	Established (150+ ports)	Limited	Limited
GHG Emission Reduction	Up to 20% (Tank to Wake) compared to HFO	Near-zero (depends on feedstock)	Near-zero (depends on electricity source)

Technical Feasibility

Methane can be used in dual-fuel engines. LNG bunkering infrastructure is well-developed, but bio-methane and e-methane availability requires further development. Technical complexity includes the need for cryogenic storage and reduction of methane slip, which refers to unburned methane released during combustion as well as fugitive methane emissions.

Environmental Benefits and Challenges

Methane as LNG can reduce CO_2 emissions by up to 20% (tank to wake), NOx, sulfur oxides (SOx) by 90%, and particulate matter (PM) by 99% compared to conventional marine fuels. Bio-methane and e-methane can achieve near-zero carbon dioxide emissions, if these are produced sustainably with renewable energy utilized in the production process. Methane slip is an issue as methane has a global warming potential approximately 25 times higher than CO_2 (considering a 100-year period), remains a significant challenge, but advancements in engine technology aim to address this issue. Further, Technological solutions, such as methane oxidation catalysts and high-pressure direct injection, are being developed to minimize methane slip.

Biofuel as a Future Maritime Fuel

Biofuels offer a transitional pathway for maritime decarbonisation, reducing emissions while progressing towards net-zero targets. Key types include **Fatty Acid Methyl Ester (FAME)**, **Hydro treated Vegetable Oil (HVO)**, and **algae-based biofuels.** HVO, with its high cetane number (70-90), can be used without engine modifications, making it a promising option.

Table 9 Typical and Relevant Attributes & Categorization of Biofuel

Generation	Biofuel Type	Feedstock	Cetane Number	Energy Density	Technical Challenges	Compatibility
First	Fatty Acid Methyl Ester (FAME) (Biodiesel)	Vegetable oils, animal fats	50-65	Lower than marine diesel	Hygroscopic, increased microbial growth risk	Blend with diesel (up to B20)
Second	Hydrotreated Vegetable Oil (HVO)	Vegetable oils, animal fats	70-90	Comparable to marine diesel	None; sulfur-free, requires no engine modifications	Direct replacement or blend with diesel
Third	Algae-Based Biofuels	Algae	50-70	Comparable to marine diesel	High production cost, scalability issues	Potential for direct use after processing
Fourth	Pyrolysis Oil	Forestry residues, organic waste	40-50	Lower than marine diesel	High acidity, requires upgrading	Co-processed in refineries

Table 10 Technical Feasibility Analysis of Biofuel as Marine Fuel

Technical Aspect	HVO	FAME (Biodiesl)	Algae-Based Biofuels	Pyrolysis Oil
Engine Compatibility	No modifications required	Blend with diesel up to B30 typically	Potential for direct use after processing	Requires upgrading or blending
Fuel Handling and Storage	Easy to handle, similar to diesel	Hygroscopic, requires tank maintenance	Requires stability standards	Requires upgraded handling
Combustion Characteristics	High cetane number, efficient combustion	Comparable to FAME	Similar to FAME	Lower cetane, requires upgrading

Energy Density	Comparable to MGO	Lower than MGO	Comparable to MGO	Lower than MGO
Engine Modifications	None	May require modifications at higher blend ratios (i.e. B30 and above)	Potential for direct use	Requires upgrading
Material Compatibility	Similar to diesel, fewer risks	Can react with rubber/metals	TBD, needs further assessment	TBD, needs further assessment
Operational Considerations	Excellent cold flow properties	Poor cold flow properties	Requires stability standards	Requires stability standards

Environmental Benefits and Challenges

Biofuels offer significant GHG reductions, with lifecycle emissions much lower than fossil fuels due to carbon absorption during feedstock growth. They produce negligible **SOx** and generally lower **NOx** compared to marine gas oil (however depending upon the biofuel blend, NOx compliance has to be verified – please refer MEPC./Circ.795/Rev.9) as well as negligible particulate matter emissions. **Third and fourth-generation biofuels** can achieve up to **90% GHG reduction**, particularly algae-based fuels that also capture CO_2 during cultivation.

However, other sustainability issues (e.g. land use change, food security, water resources etc.) need to be confirmed. Further, these fuels may also be in demand by the other transport sectors such as aviation and automotive which may lead to shipping competing with these sectors in terms of biofuel prices.

Table 11 Environmental Performance Analysis of Biofuels

Aspect	First-Generation Biofuels	Second-Generation Biofuels	Third-Generation Biofuels	Fourth-Generation Biofuels
GHG Emission Reduction	20-50%	70-80%	80-90%	80-90%, with CCS potential
LCA Impact	High impact due to land use and inputs	Moderate impact, uses residues	Low impact, minimal land competition	Very low impact, negative emissions possible
Land Use	Competes with food production	Uses non-food residues	Non-arable land, high efficiency	Carbon-negative potential
Water Use	High	Moderate	Utilizes wastewater	Moderate

LPG as Marine Fuel

LPG is used widely in domestic applications on shore. This is a mixture of the hydrocarbons, propane, and butane. This can be produced from fossil sources or from biomass. LPG is widely traded as marine cargo hence there are export and important terminals on the coastlines of major LPG producers and consumers to facilitate use of LPG as fuel.

Table 12: Typical and Relevant Attributes of LPG

Item	Value
Storage Temperature	-42 to -1 °C
Storage Pressure	1 bar
Density	525-580 kg/m^3
Lower Heating Value	44-46 MJ/kg
Flashpoint	-
Autoignition Temperature	410-580 °C
LFL – UFL	1.8%-9.5%
Cetane Number	40 – 55
Octane Number	-

Safety Aspects

Hazards to Persons – Exposure to lower temperature LPG can lead to frostbite. Other hazards include asphyxiation, irritation to skin, dizziness, drowsiness, respiratory irritation. Long term exposure can lead to damage of the central nervous system.

Hazards during Handling and Storage - There is extensive experience of handling LPG as cargo on ships. This is regulated by the IGC code. For use of LPG as fuel, IMO has developed interim guidance for use of LPG as fuel on non-gas carriers as well as use of LPG cargo as fuel.

Hazards during use in onboard power generation/propulsion systems - For use of LPG as fuel, requirements are provided within the interim guidance developed by IMO.

Environment Aspects

CO_2 emissions would be reduced marginally (unless the LPG is obtained from biomass). NOx, SOx, PM emissions would be significantly reduced as compared to conventional marine fuels.

Ships using LPG as fuel are mainly the LPG Carriers though other ship types are also envisaged to use LPG fuel. IMO has published Interim Guidelines for this purpose for facilitating safe use of LPG as fuel on Ships carrying LPG as cargo as well as ships using LPG as fuel.

Fuel Cells as a Maritime Technology

Fuel cells are emerging as a promising propulsion option (mainly for short distance shipping) for maritime use, offering higher efficiency and lower emissions compared to conventional marine engines. They work by converting chemical energy from hydrogen or other fuels into electricity, providing an efficient, low-emission solution for shipping.

Types of Fuel Cells

Different types of fuel cells are being explored for maritime applications, each with unique characteristics and operational requirements. Proton Exchange Membrane Fuel Cells (PEMFC) operate at temperatures between 50-80°C, use hydrogen as a fuel, and are ideal for small to medium vessels, although hydrogen storage remains a key challenge. Solid Oxide Fuel Cells (SOFC) operate at high temperatures (700-1000°C) and can use hydrogen, ammonia, or natural gas, making them suitable for larger vessels due to their high efficiency and fuel flexibility. Molten Carbonate Fuel Cells (MCFC) operate at 600-700°C and can utilize multiple fuels, making them promising for large vessels, although they require extensive heat management. Alkaline Fuel Cells (AFC) operate at 60-100°C, use hydrogen, and are highly efficient, but their sensitivity to CO_2 limits their applicability.

Table 13 Technical Categorization of Fuel Cells

Fuel Cell Type	Operating Temperature	Suitable Fuels	Efficiency	Suitable Vessel Type	Advantages	Challenges
Proton Exchange Membrane (PEMFC)	50-80°C	Hydrogen	High	Small to medium vessels	Rapid start-up, high efficiency	Hydrogen storage challenges, Hydrogen of high purity is necessary
Solid Oxide (SOFC)	700-1000°C	Hydrogen, natural gas, ammonia	Very high	Larger vessels	High efficiency, fuel flexibility	High temperature operation, complex integration
Molten Carbonate (MCFC)	600-700°C	Hydrogen, natural gas	High	Larger ships	Fuel flexibility, high efficiency	Requires significant waste heat recovery management
Alkaline (AFC)	60-100°C	Hydrogen, oxygen	Moderate	Small-scale applications	Efficient, simple design	Vulnerable to CO_2 contamination

Technical and Cost Feasibility

Fuel cells offer scalability across different vessel sizes, with PEMFCs and AFCs fitting well for small vessels, while SOFCs and MCFCs are more suited for larger vessels. Hydrogen storage remains complex, requiring high-pressure or cryogenic systems, while SOFCs provide more flexibility in terms of fuel options.

Table 14 Cost Feasibility Review of Fuel Cells

Fuel Cell Type	Capital Costs (per kW)	Fuel Costs (Hydrogen)	Maintenance Costs	Infrastructure Costs
Proton Exchange Membrane (PEMFC)	$3,000 - $5,000	$6 - $8 per kg (green hydrogen)	20-30% lower than traditional engines	High due to specialized hydrogen bunkering requirements ($50 million per port)
Solid Oxide (SOFC)	$4,000 - $6,000	$6 - $8 per kg (green hydrogen)	Moderate; high temperature components require specialized maintenance	High; requires additional thermal insulation and infrastructure investments
Molten Carbonate (MCFC)	$4,000 - $6,000	$6 - $8 per kg (green hydrogen)	Moderate; requires effective heat management systems	High; similar infrastructure costs as SOFCs due to high operating temperatures
Alkaline (AFC)	$2,500 - $4,000	$6 - $8 per kg (green hydrogen)	Lower compared to high-temperature fuel cells	Moderate; requires high-purity hydrogen storage and CO_2 management systems

Environmental Impact

Fuel cells offer a zero-emission propulsion option, emitting only water vapor and eliminating greenhouse gases during operation. They significantly reduce NOx emissions by up to **80%** compared to conventional fuels and completely eliminate SOx emissions. The use of green hydrogen further minimizes environmental impacts. Recycling potential varies among different types of fuel cells; PEMFCs, for instance, are highly recyclable due to their platinum content, while SOFCs are less recyclable due to their ceramic materials.

Global Scenario of Fuel Cell Adoption as Marine Fuel

Fuel Cell Technology has been installed on Ships as can be observed from Figure 5 (which shows the number of ships using hydrogen fuel). A technology demonstration vessel using hydrogen within fuel cells has also been commissioned in India in 2024 to operate on inland waterways and short coastal routes and it may be noted that more such vessels are on order in indian yards.

Green Electricity as a Marine Technology

Green electricity for maritime use can be implemented through fully electric, diesel-electric, and hybrid electric propulsion systems. **Fully Electric Propulsion** involves the use of energy stored in batteries to power electric motors, making it suitable for short-range vessels such as ferries and tugboats. Battery capacities range from **1 MWh to 5 MWh**, and they require high voltage levels (1000V or more). However, limited energy density necessitates frequent charging, restricting these systems to short-haul or short distance shipping applications.

Table 15 Green Electricity as Marine Fuel- Types & Applications

Type	Components	Applications	Technical Challenges
Fully Electric Propulsion	Battery banks, electric motors, power management systems, energy management systems	Short-range ferries, tugboats, inland vessels	Limited battery energy density, frequent charging, significant weight
Diesel-Electric Propulsion	Diesel generators, electric motors, power distribution units, variable frequency drives, switchboards, automation systems	Cruise ships, icebreakers, offshore support vessels	Dependence on fossil fuels, need for emission control technologies, complexity in power management
Hybrid Electric Propulsion	Internal combustion engines, electric motors, batteries, energy storage management systems, control algorithms	Ro-Ro ferries, offshore supply vessels, yachts	Complex power management, integration of multiple power sources, battery cycling and degradation

Technical and Environmental Feasibility

Electric and hybrid propulsion systems are technically feasible for short-haul operations. Advances in **lithium-ion battery technology** have led to improved energy density, making electric propulsion suitable for a range of maritime applications. Electric motors offer greater efficiency and reduced maintenance costs due to fewer moving parts, which make them economically attractive over the long term. However, electric propulsion systems require sophisticated power management and distribution systems, adding complexity.

Environmental Benefit	Details	Sources
Reduction in Greenhouse Gas Emissions	Fully electric ships produce zero direct emissions (provided that the grid electricity used to charge them is obtained from renewable sources); hybrid vessels reduce fuel consumption by up to 50%	IMO GHG Study 2020, Norwegian Ministry of Climate and Environment
Noise Reduction	Electric propulsion reduces noise levels by up to 20-30 dB, benefiting marine species	WWF Report on Underwater Noise Pollution
Particulate Matter and NOx Emissions	Hybrid systems can reduce NOx emissions by up to 30-50%; fully electric ships produce zero PM and NOx emissions	European Environmental Agency (EEA) Report, Norwegian Public Roads Administration
Reduction in Sulfur Oxide (SOx) Emissions	Electric and hybrid technologies can lead to up to 60% reduction in SOx emissions by 2030	European Commission on Clean Shipping
Energy Efficiency	Electric motors have an efficiency of 90-95%, leading to 30-40% reduction in energy consumption	Maritime Battery Forum Study 2022

Table 16 Environment Feasibility Review of Green Electricity as Marine Fuel

The environmental benefits of electric and hybrid propulsion are significant. Fully electric vessels produce zero direct emissions, while hybrid vessels can reduce CO_2 emissions by up to **50%.**

Cost Feasibility and Economic Considerations

The cost of electric and hybrid propulsion is influenced by both capital and operational expenses. **Fully electric systems** have high initial costs primarily due to battery expenses. Hybrid systems are generally less expensive and offer a shorter payback period, particularly for vessels with variable operational profiles. As the cost of batteries decreases, electric systems are expected to become more economically viable, especially for short distance shipping.

Table 17 Cost Analysis of Electric Propulsion Systems

Cost Factor	Electric Propulsion	Hybrid Propulsion	Diesel Propulsion
Capital Expenditure (CAPEX)	High initial battery cost ($300-$500 per kWh). For 4 MWh: $1.2-$2 million [Source: BloombergNEF]	High due to combination of power sources and power management systems	Moderate cost; conventional engine and auxiliary systems ($2-$4 million depending on vessel size) [Source: Clarkson Research]
Operational Expenditure (OPEX)	Maintenance cost reduction of up to 30% due to fewer moving parts [Source: DNV GL]	Fuel savings of 20-30% depending on operational profile [Source: IMO Report]	Higher maintenance costs due to complex machinery and fuel systems; maintenance costs can be 15-25% higher compared to hybrid systems [Source: Lloyd's Register]
Fuel Savings	40-60% fuel cost savings for short-range ferries [Source: EMSA]	15-25% reduction in fuel consumption depending on vessel type [Source: ABS Report]	No fuel savings; high fuel consumption, typically $200-$500 per metric ton of marine diesel oil, with annual fuel expenses ranging from $1.5 to $3 million depending on vessel type [Source: IEA]
Charging Infrastructure Cost	Shore-side charging: $500,000 to $2 million [Source: Port Technology International]	Lower infrastructure costs due to dual power capability	None required for conventional fuel bunkering; average bunkering costs range from $10,000 to $30,000 per session depending on port [Source: BIMCO]
Incentives and Regulatory Support	EU's Horizon 2020 allocated over €100 million for green maritime technologies [Source: European Commission]	Similar support available for hybrid systems from various international bodies	Limited incentives; increased regulatory pressure to reduce emissions, including carbon tax considerations [Source: IMO]
Break-Even Analysis	Break-even in 5-10 years for short-range vessels [Source: Maritime Battery Forum]	Payback period of 3-8 years depending on extent of hybridization [Source: Lloyd's Register]	No break-even benefits; subject to rising fuel costs and emission penalties, making it less economically viable long

			term [Source: Clarkson Research]
Lifecycle Cost	10-20% reduction in lifecycle costs due to fuel and maintenance savings [Source: DNV GL Report]	Lifecycle savings similar due to combined efficiency gains	Higher lifecycle costs due to ongoing fuel expenses and maintenance, typically 25-40% more compared to hybrid systems [Source: Clarkson Research]
Payback Period	Longer payback due to high initial battery and infrastructure cost	Shorter payback with flexible operational modes	No significant payback; ongoing fuel expenses dominate, with potential cost increases due to stricter environmental regulations [Source: IEA]

Operational savings are also significant, with **30%** lower maintenance costs compared to traditional engines. Fuel savings for electric systems can reach **40-60%** for short-range vessels, while hybrid systems provide fuel savings of **15-25%** depending on the vessel type. Despite these benefits, infrastructure costs, such as the development of charging facilities, remain a major barrier to widespread adoption.

Cost Trend Analysis and Roadmap

The cost of **green electricity** is expected to decrease significantly from **$50-$70 per MWh** in 2025 to **$20-$30 per MWh** by 2050, driven by advances in renewable energy technologies and increased economies of scale.

The roadmap for adopting green electricity in the maritime sector includes establishing pilot projects, expanding **shore-to-ship power** infrastructure, and introducing international mandates for zero-emission maritime operations. By 2050, fully electric systems are expected to dominate **short-haul operations**, while hybrid systems will be common for longer routes.

The Challenges and Future Prospects of Green Electricity

The adoption of electric propulsion faces challenges such as limited charging infrastructure at ports, range limitations due to current battery technologies, and regulatory barriers. Battery production depends on raw materials like lithium and cobalt, which are subject to supply chain constraints and environmental concerns regarding extraction as well as sustainable mining practices. Additionally, the recycling of batteries is complex and costly, presenting a potential environmental challenge in the future.

Despite these challenges, green electricity has substantial potential for decarbonizing the maritime industry. With advancements in battery technology, infrastructure development, and supportive regulatory frameworks, electric and hybrid propulsion systems are expected to play a major role in achieving a sustainable maritime industry by **2050**.

On-board Carbon Capture Systems

Onboard Carbon Capture Systems enable the removal of carbon dioxide from the engine exhaust thus contributing to reduction of the GHG emissions onboard. Such systems have been installed on ships. The technology for this purpose has been inspired from application on land typically in industrial plants.

Key Advantages

- Carbon Capture Systems can facilitate operation of ships on conventional marine fuels while serving the original intent of reduction of GHG.
- Carbon dioxide captured from the process can be stored in form of liquid within independent tanks onboard. Though this involves low temperature applications, such application does not involve storage at cryogenic temperatures
- Carbon dioxide captured can be discharged onshore at Port Reception Facilities or at Offshore Sites.
- Carbon dioxide can be used further as feedstock to develop synthetic or electro fuels which can be further utilized on ships or land-based applications. Carbon dioxide also forms feedstock for several industrial applications and hence has the potential to be reused in shore-based industries.

Key Challenges

- The use of some carbon capture technologies requires active substances such as monoethanolamide. Such substances are toxic to humans as well as classified as dangerous goods under the IMDG Code. The hazards posed by use of such substances should be addressed.
- For retrofitting of existing ships, there may be space constraints in the engine room as well as constraints regarding installed power onboard to operate the carbon capture plant.
- Storage tanks as well as tanks for the active substance used for carbon capture need to be installed which can further lead to sacrifice of cargo space on existing ships.
- Carbon Dioxide tanks will need to be provided along with dedicated piping systems and discharging equipment. A release of carbon dioxide from the tanks or piping system (for example due to accident) should be considered potential scenario for risk assessment.

The Global Centre for Maritime Decarbonization (GCMD) and the Boston Consulting Group (BCG) estimated in 2024 in their report that totally 170 million metric tonnes of carbon dioxide would be transported globally in 2050. This would typically correspond to 54 million tonnes of conventional marine diesels. The report by GCMD and BCG highlights actions would have to be taken to promote carbon capture and transportation to offshore sites. However, prima-facie this option cannot be ignored as it enables operation with cleaner fuels such as LNG and LPG provided these are produced so as not to incur significant emissions in terms of well to tank as well as considering that carbon capture technology installation on ships will further mature significantly with time.

Nuclear Technology

Key Advantages

- Nuclear Technology provides a zero-carbon pathway to generate power onboard for ship propulsion and auxiliary purposes.

- Nuclear Technology has been in use on Naval Ships and Submarines. It has also been utilized on Ships operating in Russian waters.
- Small Modular Reactors and Molten Salt Reactor technology being discussed in place of the conventional Pressurized Water Reactors (PWR)
- Potential to generate large magnitude of onboard power (up to 300,000 kW).
- Nuclear Fuel may not require large storage capacity as compared to conventional marine fuels.
- Bunkering frequency may also be significantly reduced. It is envisaged that bunkering may be at each special survey or may not be required at all during the operational life of the ship once the nuclear fuel is provided at the initial stage.
- With exception of a few accidents, nuclear technology on shore has been operating smoothly. This demonstrates that if safety protocols are properly met, then accidents may be significantly reduced.
- IMO has already published a Code for Safety for Nuclear Powered Ships as well as SOLAS Chapter VIII. This may be updated given the new developments in reactor technology.

Key Challenges

- Safety of operation of the nuclear reactor plant onboard is a key concern especially when applying to merchant ships.
- Security issues also may need evaluation
- The performance of the new reactor technologies in marine environment will need to be demonstrated with experience
- Special Training would be required for crew as well as technicians who would need to operate equipment
- Disposal of nuclear fuel at the end of the fuel life as well as the safe recycling of such ships may also pose challenges.
- Tariffs and costs may need to be assessed in order to demonstrate the feasibility of operation.

Nuclear Powered Propulsion may prove to be a very useful technology for maritime needs. If the challenges listed for this technology are resolved, then this has potential to be used for international seagoing cargo ships such as bulk carriers, tankers, container ships etc. provided that the safety aspects are complied with. The potential of this technology for power generation on shore and using this power to produce green fuels may be considered. The uptake of small reactors for maritime use has to be facilitated by development of a national framework.

It is therefore anticipated that the necessary ecosystem and framework for wide spread use of nuclear propulsion for cargo ships may be set by 2040 and by 2050 a small but definite proportion of vessels may be able to use this technology onboard.

Synthetic Fuels

Synthetic fuels or electro fuels are produced using carbon dioxide feedstock and combining it with hydrogen to obtain fuels such as methanol, methane, propane & butane. The electricity used in the process needs to be produced from renewable sources so as to ensure reduction of the GHG emissions on a well to wake basis. This is envisaged to work in tandem where carbon dioxide captured onshore or captured onboard and discharged from ships to shore facilities, is available in steady supply.

Key Advantages

- Synthetic or electrofuels can help enable use of fuels such as methane, methanol, LPG with the existing technology since the chemical composition of these fuels is not changed, rather only the mode of production. Therefore, no specific engine technology will be required for operation with e-methanol, e-methane, or e-LPG.
- These could complement the carbon capture process onboard or the onshore industries as these could utilize the carbon dioxide generated from these processes.

Key Challenges

- The availability of renewable electricity as well as the carbon dioxide needs to be scaled up in order to produce a significant quantity of these fuels
- The costs of the fuels would be directly dependent on the costs of the renewable electricity
- These fuels may also be in demand from road and rail transportation industries as well as domestic land-based applications.

These fuels would be amenable to both short distance as well as long distance ships. The availability and the cost of these fuels is an important factor in their uptake. Their production depends upon the installed electrolyser capacity and the renewable energy generation in India. Therefore, in the short timeframe (i.e. 2030), these may not be produced in significant quantities, however by 2050, it may be possible to upscale the electrolyser capacity and renewable energy generation in India to produce and utilize these fuels.

Summary of Comparison of Green Fuel Options as Marine Fuels with respect to cost analysis, investment scenario, demand/supply scenario and areas of applicability

The maritime industry is at the forefront of transitioning towards sustainable energy solutions to reduce greenhouse gas emissions and achieve global climate targets. As the industry aims to decarbonize, several green fuels are being explored for their viability, efficiency, and applicability to different types of vessel operations. This comparative analysis provides an overview of key green fuel options, including their technical features, environmental impact, cost analysis, investment requirements, demand-supply outlook, and specific areas of applicability in the maritime sector. By evaluating these fuels, stakeholders can better understand their potential for decarbonizing maritime transportation and make informed decisions for future energy transitions.

Table 18 Comparative Review of Green Fuel Options as Marine Fuel

Fuel Type	Cost Analysis	Investment Scenario	Demand-Supply Scenario (2030/2050)	Areas of Applicability (Type or Sector of Ship Operations)
Green Hydrogen	\$10-15 per GJ by 2030, \$1-1.5/kg by 2050	Significant R&D needed for electrolysers; \$50 billion by 2040	High demand in Europe, Australia, India; significant export focus by Middle East	Suitable for large vessels and deep-sea operations requiring high energy density, but less ideal for long-haul shipping due to storage limitations and high energy requirements
Green Ammonia	\$12-16 per GJ by 2030, \$450-650/ton by 2050	Investment in bunkering infrastructure required at ports	Primarily for maritime fuel in Asia; high export from Australia and Middle East	Ideal for long-haul shipping and large container vessels due to its high energy density and suitability for existing bunkering infrastructure modifications
Green Methanol	\$800/ton in 2024, expected to decline to \$400-600/ton by 2050	Requires CO_2 capture technology, focus in Northern Europe	Key fuel for decarbonizing short-to-medium-range shipping; growth driven by Europe	Suitable for coastal shipping, short-to-medium range vessels due to easier storage and compatibility with existing engine technologies
LNG (Methane)	\$5-8 per MMBtu by 2050	Expansion of LNG bunkering terminals needed	Decline expected as other green alternatives gain traction	Primarily used for existing LNG-powered vessels as a transitional solution while more sustainable fuels are developed
Biofuels	\$15-18 per GJ by 2030; potential to lower to \$1.0-1.5/litre by 2050	Moderate investment in bio-refineries; agricultural dependency	Primarily targeted at smaller vessels; high domestic production focus in Brazil, India, US	Suitable for smaller vessels, inland waterways, and regional ferries due to its availability and lower infrastructure modification requirements
Fuel Cells	High initial capital cost for technology	Major R&D in technology; focus on reducing costs	Limited to niche maritime applications initially	Suitable for ferries, small vessels, and specialized vessels requiring zero emissions due to their lower energy demand and the ability to use renewable hydrogen
Green Electricity	Decline in cost due to renewables (\$8-12 per GJ by 2030)	Requires grid upgrade and SPS infrastructure (\$10 billion by 2035)	High SPS coverage at major ports by 2035	Suitable for port operations, auxiliary power during docking, reducing emissions during stationary periods

Onboard Carbon Capture	Cost estimated between \$150 - \$200 per tonne of carbon dioxide extracted and stored onboard	Projects have been planned abroad. The Northern Lights project is an instance where the captured carbon dioxide is discharged to the Norwegian Continental Shelf	Envisaged in North America, Europe, Middle East Asia, and Far East Asia	Can enable the ship to operate on conventional marine fuel while not emitting significant quantities of carbon dioxide in the process.
Nuclear Propulsion	The CAPEX required may be significant. Fuel Cost may range from 480 EUR per tonne to 1100 EUR per tonne in 2030 and from 784 EUR per tonne to 1464 EUR per tonne in 2050. OPEX costs may not be mature to quote at present. Costs for decommissioning and disposal of waste nuclear fuel need to be taken into account	R&D is ongoing but may be stimulated by a positive consideration by the marine industry for nuclear propulsion	Will be suited for deep sea shipping and large vessels	Suitable for large cargo vessels

The comparative analysis of green fuels for maritime use highlights that there is no one-size-fits-all solution. Each fuel type has distinct advantages and challenges, making it suitable for different vessel types, operational ranges, and infrastructure contexts Green Ammonia, Green LNG and Green Methanol are promising for larger vessels and long-haul operations considering the long-term IMO targets and their zero carbon or net zero nature, while Biofuels may cater to short-to-medium-range shipping needs (if available and produced in a sustainable manner). LNG and Methanol may also serve as a transition fuel (until green versions of these fuels are widely available), whereas Fuel Cells and Green Electricity appear to be suitable for short distance shipping and port operations. The transition to green fuels will require significant investments, technological advancements, and coordinated efforts across the maritime industry to achieve decarbonisation targets by 2050.

Chapter – (IV)

Mapping Future Fuel Landscape for Maritime India

Mapping Future Fuel Landscape for Maritime India

India's maritime sector is at the forefront of the nation's economic growth, playing a critical role in international trade while simultaneously contributing to greenhouse gas emissions. The future fuel landscape of India's maritime sector is shaped by various initiatives aimed at reducing emissions, increasing the use of alternative fuels, and enhancing energy efficiency. This comprehensive summary provides an in-depth analysis of India's current energy demand from maritime and projected energy demand for the future. The key challenges and strategies required to achieve a sustainable maritime future are also discussed, with a focus on bridging the gap between demand and supply for green fuels.

Overview of India's Emission Landscape

India's greenhouse gas emissions are primarily contributed by the power generation, industry, agriculture, and transport sectors. The transport sector contributes 13%, encompassing road vehicles, maritime shipping, aviation, and railways. The reliance on fossil fuels, such as diesel and petrol, is a major factor in emissions from this sector.

Projecting India’s Maritime Trade Trajectory

The maritime sector plays a crucial role in India's economic growth, handling approximately 819 million metric tons (MT) of seaborne trade as of 2024, representing 7.9% of global seaborne trade, which totals 12.3 billion MT. By 2030, India aims to handle 1.8 billion MT of trade, and by 2050, this volume is expected to rise to 2.2 billion MT, representing a 12.2% share of global trade. This growth is driven by several key factors, including economic expansion, infrastructure improvements, policy reforms, and green initiatives. India's annual growth rate is projected at 6.7%, which will drive increased trade volumes. Maritime India Vision 2030 aims to increase port capacity to accommodate this growing trade by developing new deep-water ports, expanding existing ports, and enhancing container-handling capabilities. Efforts are also underway to improve logistics efficiency through digitalization, automation, and streamlined customs procedures, which will further boost trade volume. Additionally, India's focus on sustainable practices in shipping, such as adopting cleaner fuels and reducing emissions, is attracting global trade partners seeking environmentally responsible options, thereby enhancing India's competitiveness in international trade.

Table 19 Projection of India's Seaborne Trade 2030/2050

Year	Seaborne Exim Trade (in MT)	Global Seaborne Trade (in MT)	India's Share in Global Seaborne Trade (%)
Current	1.4 billion	11.5 billion	12.2%
2030	1.8 billion	15 billion	12.0%
2050	2.2 billion	18 billion	12.2%

India's Ship Fleet (International and Domestic)

It is imperative to understand India's present ship fleet as well the future fleet when formulating a scenario of how the future transition to green fuels and technologies could pan out.

India's ship fleet can be further categorized into:
1. Seagoing Fleet
2. Inland Waterways Fleet (i.e. ships operating on rivers and water bodies located within the mainland of India)

The seagoing fleet can be further categorized as:

1. International Seagoing Fleet
2. Indian seagoing and coastal Fleet (i.e. operating on the coastal waters or engaged on domestic seagoing voyages (e.g. Ship operating between Chennai and the Andaman and Nicobar Islands), river sea vessels)

Seagoing Fleet

The below figures illustrate the characteristics of the seagoing ship fleet of India as recorded on 31 December 2023.

Figure 11 highlights the distribution of the number of ships for the various categories.

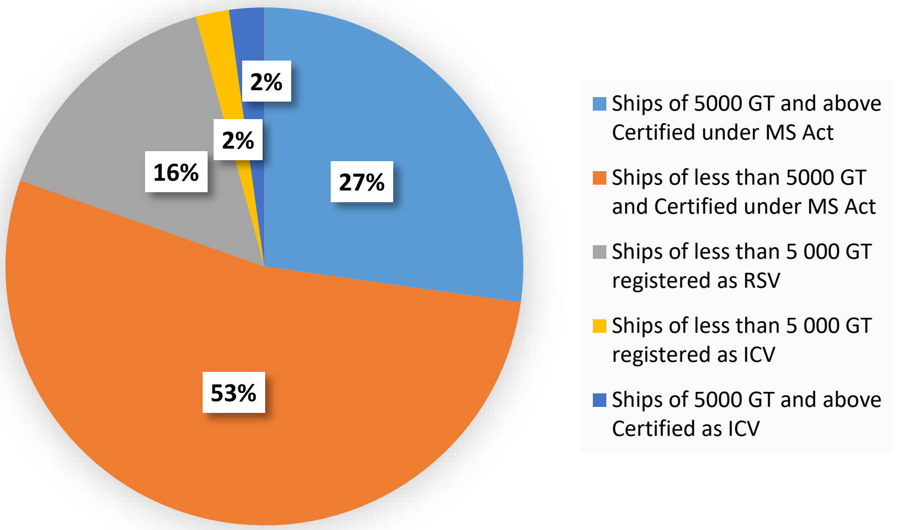


Figure 11: Distribution of the Indian Seagoing Fleet in terms of number of ships

From Figure 11, it can be observed the ship fleet is dominated by ships (in terms of number of ships) which are less than 5000 GT in size and engaged on Indian seagoing or coastal sea voyages.

It is also important to gauge the cargo carrying capacity of the various categories rather than the absolute numbers. This is depicted in Figure 12.

Figure 12: Cargo carrying capacity of the ships depicted in terms of total gross tonnage and deadweight tonnage.

From Figure 12 it can be observed that the international seagoing fleet accounts for a lion's share of the deadweight and the gross tonnage. Even though the Ships under 5000 GT and registered under MS act account for 53% of the fleet in terms of absolute number of ships, their contribution to the gross tonnage and deadweight capacities is negligible. This demonstrates that India's domestic seagoing shipping trade is much smaller as compared to the international seagoing trade.

Additionally, Figure 12 (please see the secondary axis on the right of the chart) demonstrates that the average gross tonnage and deadweight capacities are very low except for the international seagoing ships. For the domestic shipping the average gross tonnage is below 1000 in general. This brings out the fact that our domestic ship size is relatively much smaller compared to the average seagoing ships.

Figure 13 presents the average age of the various categories of seagoing ships.

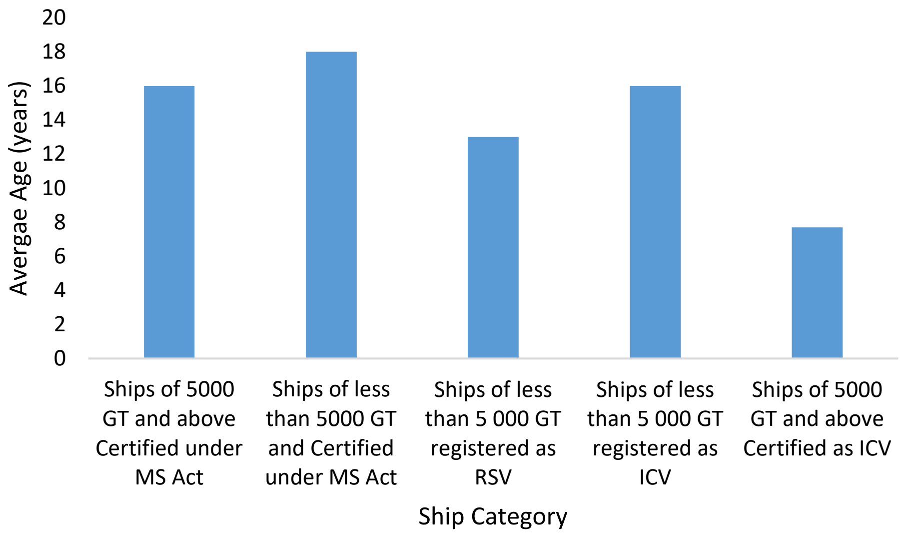


Figure 13: Average age of the ship categories (years)

From the Figure 10, it can be observed that the Indian fleet is growing old with the average age of most categories more than 15 years.

It will be of advantage to further explore the various ship categories as contained in the above figures and these are studied and represented as below:

Ships of 5000 GT and above certified under the Merchant Shipping (MS) act:

The key characteristics of the Ship Types, their numbers, cumulative gross and deadweight tonnage for Ships of 5000 GT and above as well as engaged on international voyages is shown in Figure 14.

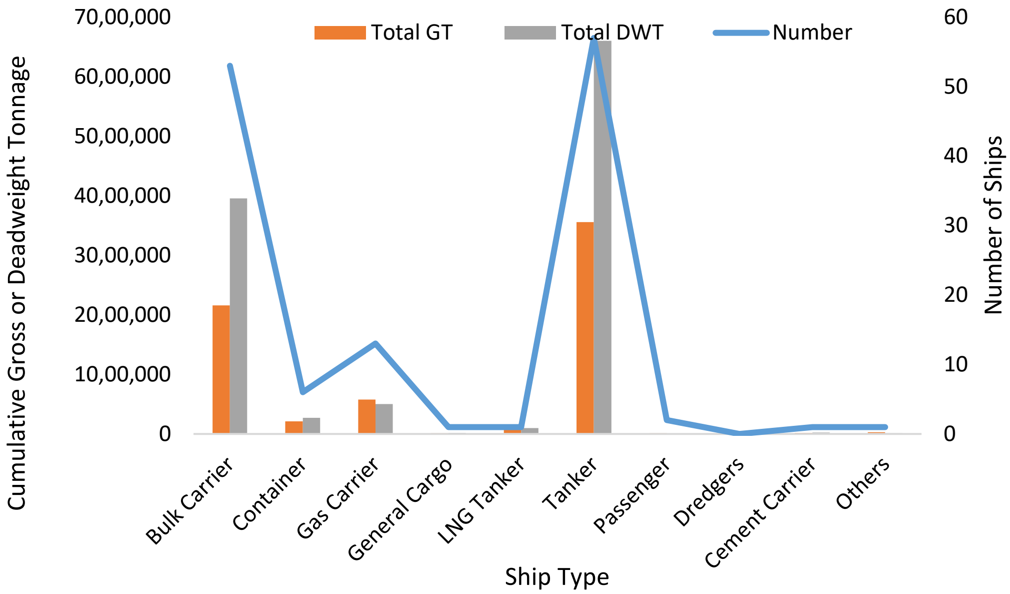


Figure 14: Ships of 5000 GT and above – International Voyages

From Figure 14, it can be observed that the Bulk Carriers and Tankers form a major chunk of the ships which come within the category of 5000 GT and/or above. This is applicable for the number of ships as well as the cumulative gross and deadweight tonnages as well.

With regards to Ships of 5000 GT and/or above as well as engaged on coastal voyages, the data is depicted in Figure 15.

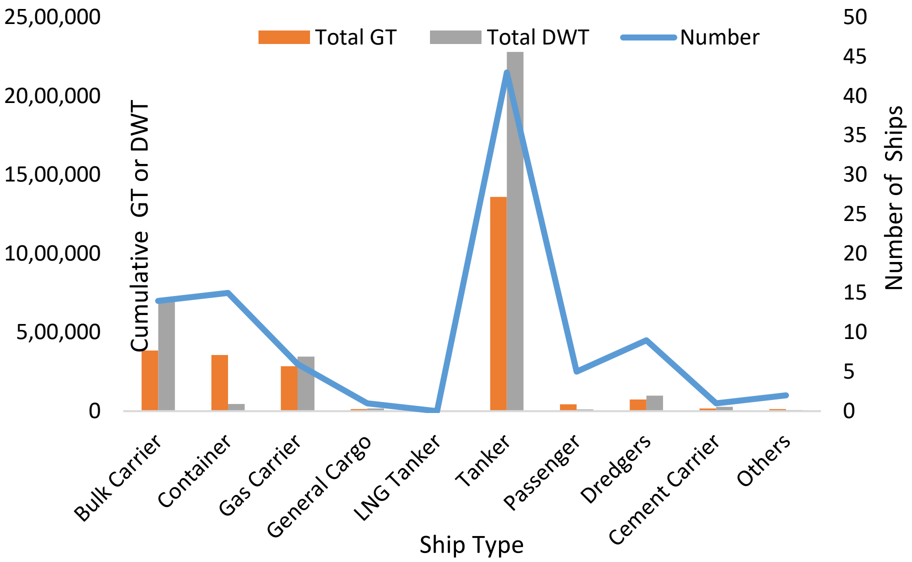


Figure 15: Ships of 5000 GT and above – Coastal Voyages

It can be observed from Figure 15 that ships of 5000 GT and above engaged on coastal voyages follow similar trends as shown in figure 14. Bulk Carriers and Tankers account for a major portion of these ships.
The average age profile of these ships is presented in Figure 16.

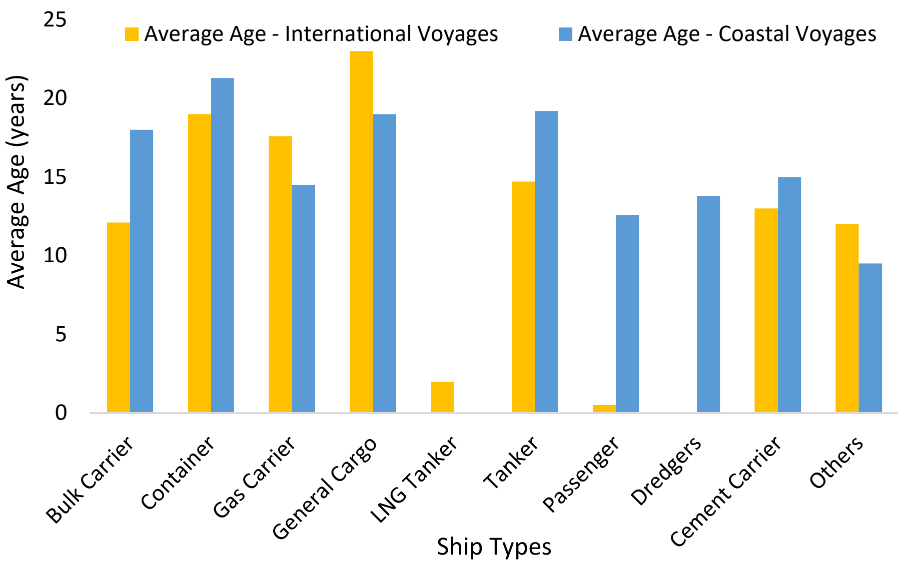


Figure 16: Average Age for Ships of 5000 GT and/or above engaged on international or coastal voyages

It can be observed that in general the average age of ships engaged on coastal voyages are higher as compared to those engaged on international voyages. The coastal fleets of bulk carriers and tankers are aging since they have an average age above 15 years. It may also be recalled that these two categories account for the bulk of the shipping trade.

Ships of size less than 5000 GT:

The profile of the fleet with gross tonnage less than 5000 is shown in Figure 17 below.

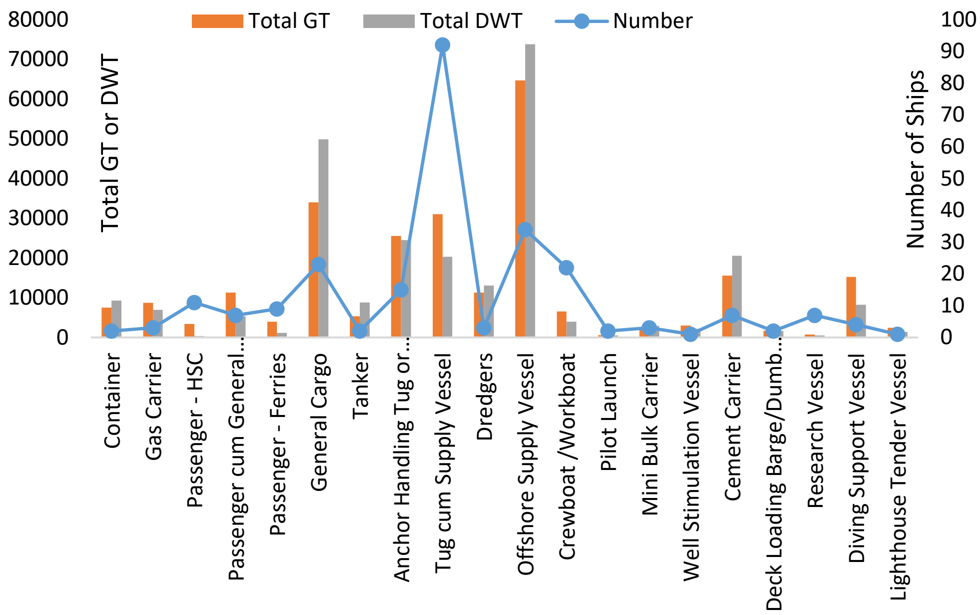


Figure 17: Ship Fleet with size below 5000 GT

It can be observed from Figure 17 that in terms of number of ships, the tugs form a large proportion. Whereas in terms of the cumulative gross and deadweight tonnage the general cargo ships and the offshore supply vessels are dominant.

The average age profile of these ships is presented in Figure 18. It can be observed that in general the average of all these ship types is above 15 years. For several of the ship types, the average age is more than 25 years which represents an aging fleet.

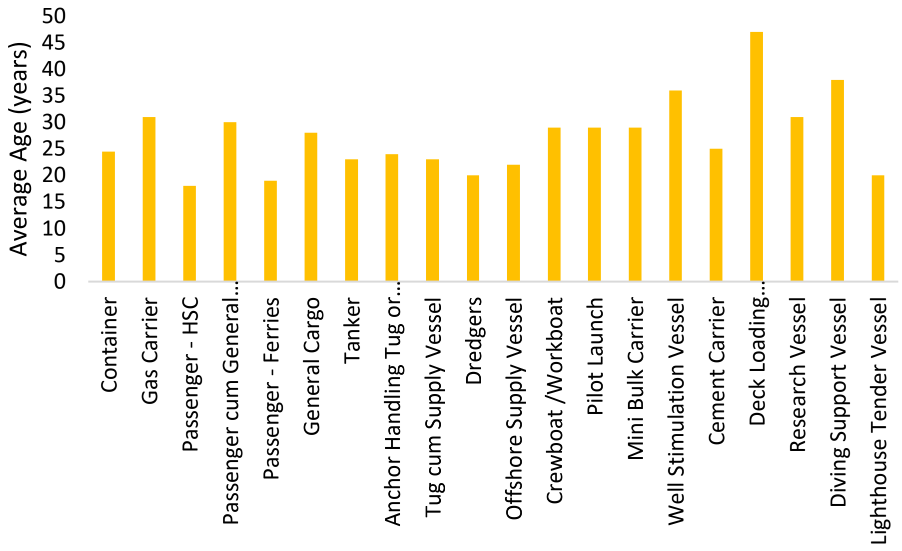


Figure 18: Average age profile of Ships < 5000 GT

Ships with Indian Coastal Vessel (ICV) Operation Notation:

As regards the ships with Indian Coastal Operation, Figure 19 depicts the present statistics for ships less than 5000 GT and certified as ICV. It can be observed that general cargo ships dominate this category in terms of the gross tonnage and deadweight. However, in terms of number of ships, the tugs constitute the dominant category. The ship fleet in this category is also very old with average age for all ship types above 25 years.

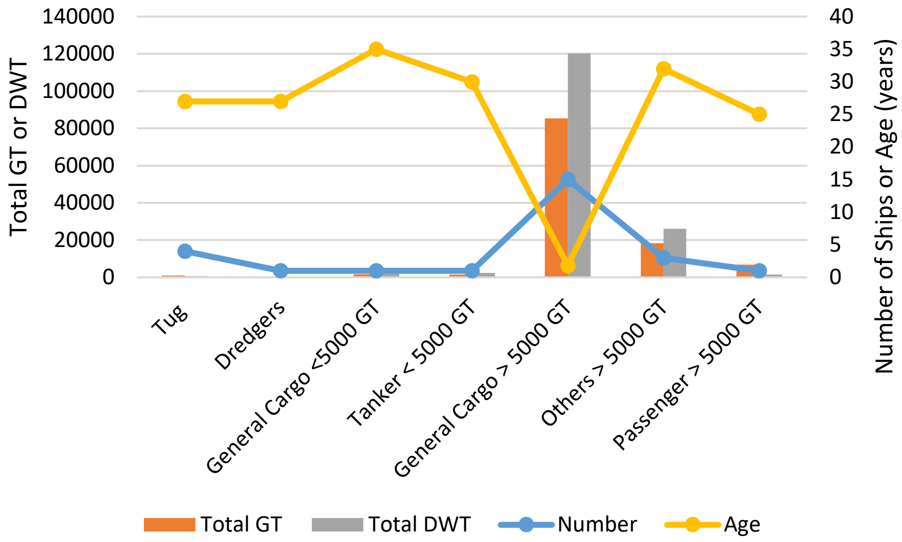


Figure 19: Ships < 5000 GT and certified as ICV

Figure 20 depicts the Indian Coastal Vessels which are River-Sea Vessel (RSV) and less than 5000 GT.

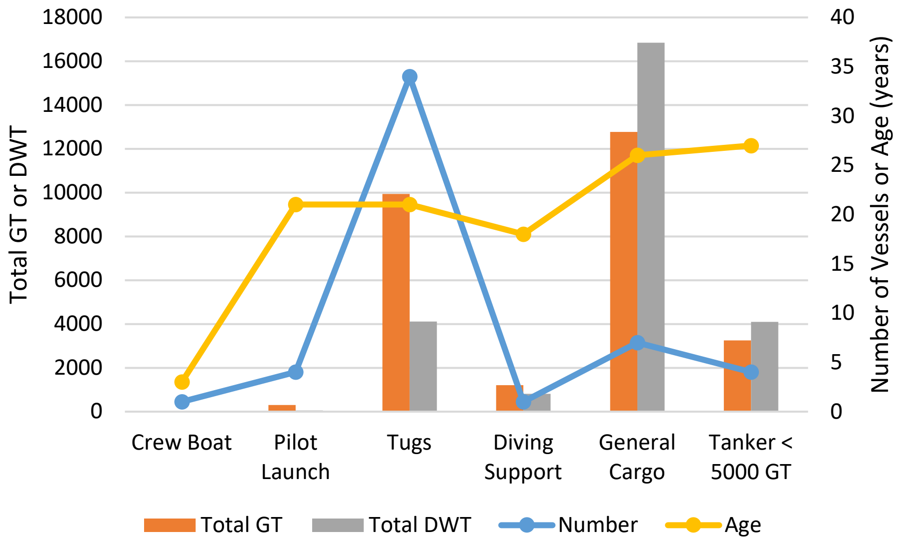


Figure 20: Ships (RSV) < 5000 GT and certified as ICV

From Figure 20, it can be observed that for Ships less than 5000 GT, this segment is mainly dominated by General Cargo Ships and Tugs.

Inference and Summary from study of the ship fleet:

The following inferences can be drawn from the study of India's ship fleet:

Ships of gross tonnage 5000 and above

- In terms of gross tonnage and deadweight tonnage, the category of 5000 GT and above is overwhelmingly dominant, the category of ships with gross tonnage 5000 and above represents the international fleet and is regulated by the MARPOL Annex VI as regards the energy efficiency requirements.

- In terms of number of ships, the dominant ship category within India's ship fleet is the category with less than gross tonnage 5000 which may be mainly considered to represent domestic shipping. The average age of all ship types in this segment is more than 15 years. The four ship types i.e. Tugs, Offshore Supply Vessels, General Cargo Ships and Crew boats represent 68% of the total number of ships in this segment.

Ships of gross tonnage below 5000

- For the Ship fleet with size less than 5000 GT, the average gross tonnage was computed for the various ship types. The ship types with average gross tonnage less than 500 GT were identified as Tug, Supply Vessels, Research Vessels, Pilot Launches, Crew boats and Passenger Ferries. These can be said to be small ships and their number represent 53% of the ships in this segment. This segment also represents an aging fleet.

Ships of gross tonnage below 5000 and certified for Indian Coastal Operation (ICV)

- For ships less than 5000 GT and certified for Indian Coastal Operation (ICV), it can be noted that Tugs, Crew Boats, Pilot Launches and Dredgers have an average size of less than 500 GT indicating that these are small size ships. It can be observed that in terms of number of ships these ship types account for 57% of the total number of ships certified for Indian Coastal Operation. In general, these ship types also shown an average age above 20 years.

Energy Demand of India's Ship Fleet

It is imperative to understand India's fuel consumption trends to gain an understanding of how the future potential for green fuels and technologies would take shape.

Fuel Consumption by Indian Ships

The data available in the Marine Environmental Performance Report indicates that the total fuel consumption in 2022 for Indian Ships was 1.24 million tonnes, which includes Heavy Fuel Oil, Diesel Oil and Light Fuel Oil for Ships which are of size 5000 GT and above and excluding River-Sea Vessels and Indian Coastal Vessels. This corresponds to the total annual energy consumption (assuming the average energy content of the above-mentioned fuels to be 45 MJ/kg) of 55.8 QJ (Quadrillion Joules). This value represents a 3% reduction from the fuel consumption recorded for 2021.

The global marine industry is reported to have consumed 9.5 EJ of energy in 2023. Therefore, in terms of energy consumption, the above values represent approximately 0.59% of the total global marine energy consumption.

For Indian ships of size below 5000 GT, the total fuel consumption in 2022 was reported to be 0.285 million tonnes of conventional marine fuel. This represents an energy consumption annually of 12.8 QJ.

For the category of Indian ships which are RSV and ICV and above 5000 or more GT in size, the annual fuel consumption for 2022 was 14231 tonnes. This represents an energy consumption of 0.64 QJ.

It should however be also noted that the fuel consumption figures for the latter two categories addressed above do not come under the jurisdiction of the IMO Data Collection System (DCS) and are therefore reported numbers.

Ships of gross tonnage 5000 and above

For the Ship Category 5000 GT and above (except RSV and ICV), the fuel consumption recorded for the year 2022 for various ship types in India is presented in Figure 21.

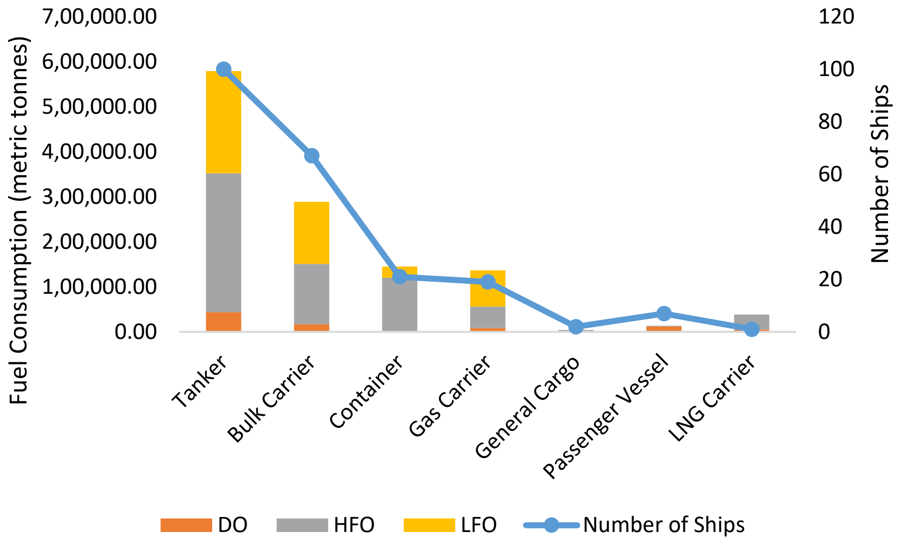


Figure 21: Fuel Consumption Share between various ship types for Ships of 5000 GT and above

From Figure 21, it can be observed that the Tanker and the Bulk Carrier Ship Types account for the major chunk of fuel consumption amongst all ship types. As mentioned previously in this report, these categories of ships represent the international Indian fleet and are regulated by MARPOL Annex VI.

It can be inferred that to move to a greener economy, the ship types Tanker, Bulk Carrier, Containers and Gas Carriers should be preliminarily targeted for use of alternative fuels. These could typically be LNG and Methanol for the short to medium term, while ammonia and hydrogen could be envisaged for the long term. Alternatively, use of technology such as carbon capture or nuclear power may be futuristically considered.

With regards to the fuel consumption of the Ships with gross tonnage less than 5000, the data is presented in Figure 22. It can be observed that the Tugs and the Offshore Supply Ship types account for the major fuel consumption in this segment.

For the ship types mentioned above and having gross tonnage less than 500 (i.e. smaller ships), fuel options or technology options such as Battery Assisted Propulsion, Hydrogen (within fuel cells) or LNG/CNG may be worth consideration. For the ships which are relatively larger in size (i.e. >500 GT), fuel such as methanol and LNG may be considered at least for the transition period, whereas for the long-term green hydrogen and green ammonia fuel may be more suitable. The above considerations would undoubtedly depend upon several other factors such availability of future fuels (which are sustainably produced) and technologies, the operating costs associated as well as the availability of infrastructure to support their application to the maritime industry.

Ships of gross tonnage below 5000

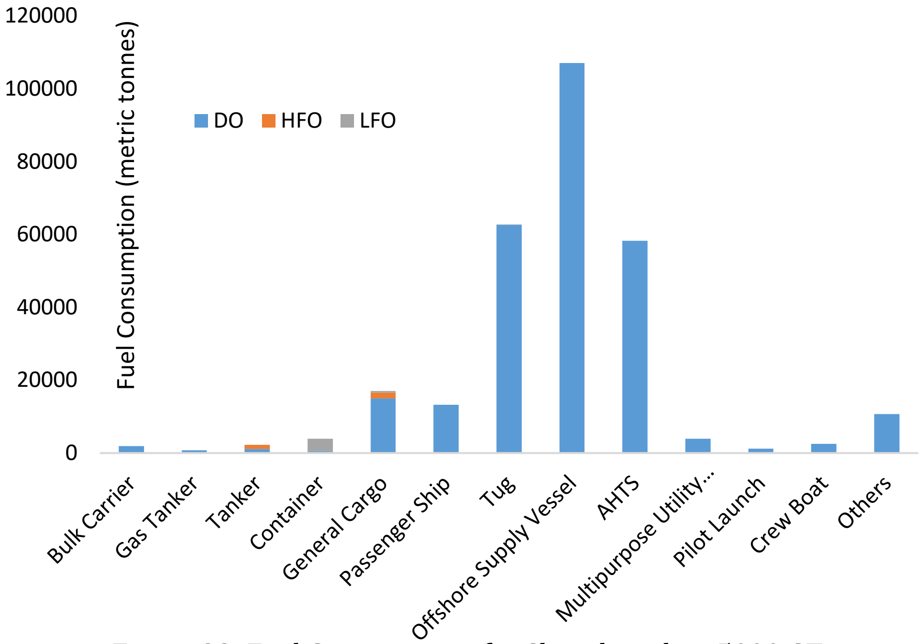


Figure 22: Fuel Consumption for Ships less than 5000 GT

The data for fuel consumption of ships having gross tonnage less than 5000 is shown in figure 22. It can be observed that Tugs, Offshore Supply Vessels and AHTS are the top three ship types in terms of fuel consumption.

New build ships capable of operation on Alternative Fuels/technologies will be beneficial to move towards the green transition.

For the other ship types which have an average size of 500 GT or above, green methanol and LNG could be considered as the possible fuel options in the medium term with Green Hydrogen and Green Ammonia fuel for the long term. As mentioned above, these considerations would be subject to factors such as availability of these fuels (sustainably produced) or technologies, operating costs as well as availability of infrastructure.

In reference to the foregoing discussion, it may also be noted that there are no specific regulations for domestic shipping requiring ships less than 5000 GT or Ships certified for ICV operation to improve their performance as regards GHG emissions. To complement India's targets and vision for a green transition, it is inevitable that relevant regulations be promulgated to ensure efficient design and operation of ships in this category.

Bunker Sales from Indian Ports/Terminals to Ships

The Indian Shipping Statistics Report 2023 indicates that the total bunker sales from India for 2021 were 1.59 million metric tonnes. The provision figures for 2022 – 2023 indicate that 2.06 million metric tonnes of fuel oil were delivered. This would include all ships including the non-Indian ships which would have purchased bunkers at Indian Ports. 56% of the bunker sales were to ships involved in Indian Coastal Trade.

Green Fuel Production Initiative and Scenarios

To mitigate emissions, India is focusing on adopting green fuels, such as LNG, green ammonia, hydrogen, and biofuels. Under the National Hydrogen Mission, India aims to produce 5 million tons of green hydrogen annually by 2030, scaling up to 20 million tons by 2050. Green hydrogen is critical for decarbonizing energy-intensive sectors like shipping, steel, and fertilizers. Plans for green ammonia include producing 7.5 million tons annually with applications in both maritime and fertilizer industries. Green ammonia, derived from green hydrogen, is being promoted as a promising alternative marine fuel due to its zero-carbon emissions and suitability for long-distance shipping.

Table 20 Projecting Green Fuel Production Scenario

Year	Green Fuel Type	Projected Production Capacity	Justification
2030	Ethanol	15 billion liters annually	Achieving 20% ethanol blending by 2030 through the expansion of 2G ethanol plants and EBP program.
2030	Green Hydrogen	5 million tons annually	Investments under the National Hydrogen Mission and ₹19,700 crore allocated in the 2023-24 budget.
2030	Compressed Biogas (CBG)	15 million tons annually	Establishment of 5,000 CBG plants under the SATAT initiative by 2025.
2030	Green Ammonia	7.5 million tons annually	Establishment of three ammonia production hubs and promotion of its use in maritime and fertilizers.
2050	Ethanol	20 billion liters annually	Continued expansion of biofuel programs and improved production technology for lignocellulosic feedstock.
2050	Green Hydrogen	20 million tons annually	Scaling up hydrogen production facilities in line with increased renewable energy generation capacity.
2050	Compressed Biogas (CBG)	30 million tons annually	Expansion of CBG production capabilities and increased demand for biogas as a transport fuel.
2050	Green Ammonia	10 million tons annually	Increased use in maritime and fertilizer sectors as green ammonia becomes the primary fuel alternative.

Projection of Energy Demand for Indian Ships for 2030/2050

Projection for overall fuel consumption/energy consumption by Indian Ships

Using the Energy Consumption figures for 2022 as depicted in Section 3.1, analysis is performed. Based upon these rates, Figure 23 provides the forecast of the fuel consumption up to 2050. A compounded annual growth rate of 4.5% is assumed for the increase in energy consumption.

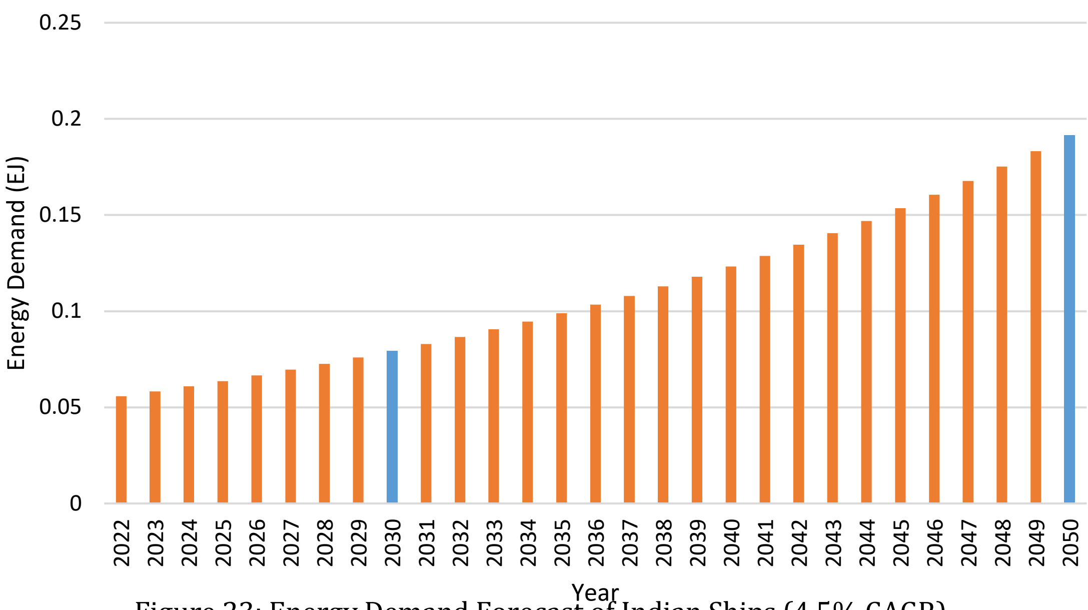


Figure 23: Energy Demand Forecast of Indian Ships (4.5% CAGR)

It can be therefore observed from Figure 23 that the energy consumption from Indian Ships by 2030, will show an increase of approximately 50% and will increase by four-fold in 2050. This analysis is of course subject to a normal course of growth of 4.5%.

Future fuel mix and Energy Demand Scenario

Taking into account the discussions in Chapter II in regard to Figure 10, 11 and Table 1 which provide the global forecast scenarios for the possible fuels in maritime for 2030 – 2050, it is endeavoured to develop maritime fuel/technology scenarios for India. The multiple scenarios provide flexibility and potential variation in the future fuel/technology mix and also urge pragmatism to be adopted while developing India's roadmap for the future fuels/technology.

Scenario 1

Scenario 1 for India's future fuel mix is inspired from the IEA global scenario presented in Figure 10. This is because of the fact that it is developed and updated in 2024 using the latest data and also is considered more realistic for Indian scenarios. Considering the fuel mix and the energy demand forecast for Indian ships as obtained in Figure 23, the fuel consumption for Indian Ships could appear for 2030 and 2050 as shown in Figure 24. It may be noted that fuels such as LNG and LPG are not indicated separately but are considered to be incorporated with the "conventional fuels" basket.

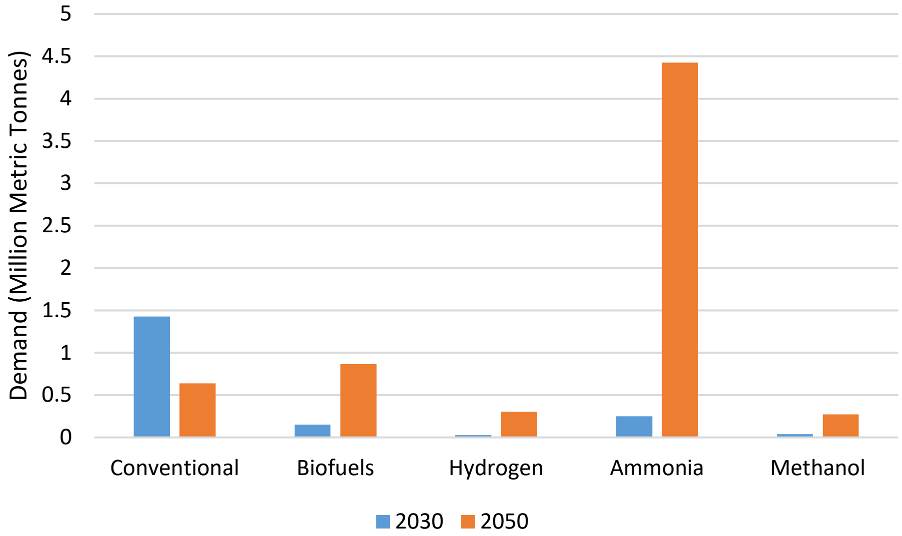


Figure 24: Future Fuels mix in accordance with Scenario 1

It is clarified here that for the 2050 scenario, all fuels utilized should have been produced as their green versions. It should also be kept in view that the present scenario is only a forecast prediction and may need to be tweaked to meet the 2030 target in case the ammonia fuel engines are not easily available to be installed or yard capacity may not be enough.

Scenario 2

Scenario 2 for India's future fuel mix is an extension of Scenario 1. The conventional fuels which are HFO, MGO, MDO and LNG may be replaced with exclusively LNG and LPG. This scenario assumes a 50-50 distribution of the LNG and LPG in the conventional fuels in terms of the energy. Figure 25 depicts this scenario.

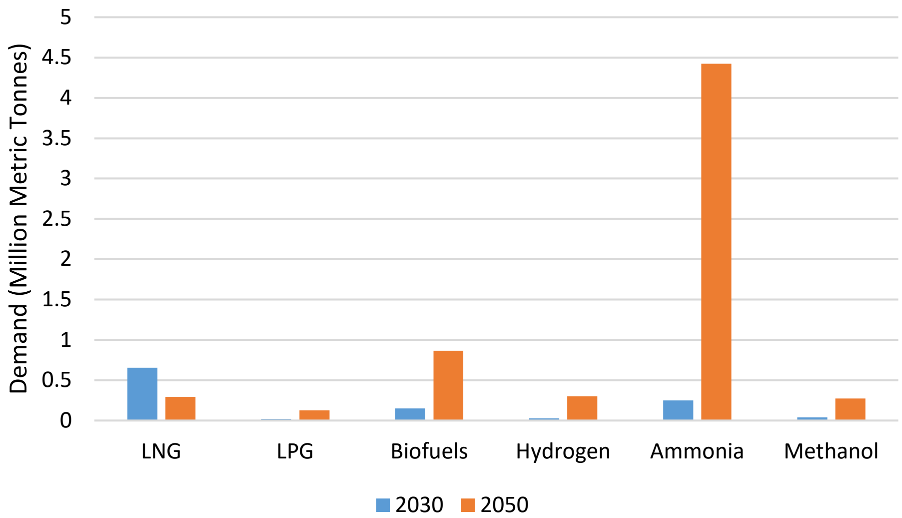


Figure 25: Future Fuels mix in accordance with Scenario 2

It is clarified here that for the 2050 scenario, all fuels utilized should be obtained as their green versions.

Scenario 3

This scenario considers scenario 1 for 2030 along with use of carbon capture technology in 2050 thereby eliminating the need for use of zero carbon fuels or alternative such as Hydrogen, Biofuels, Methanol or Ammonia. Figure 26 shows this scenario.

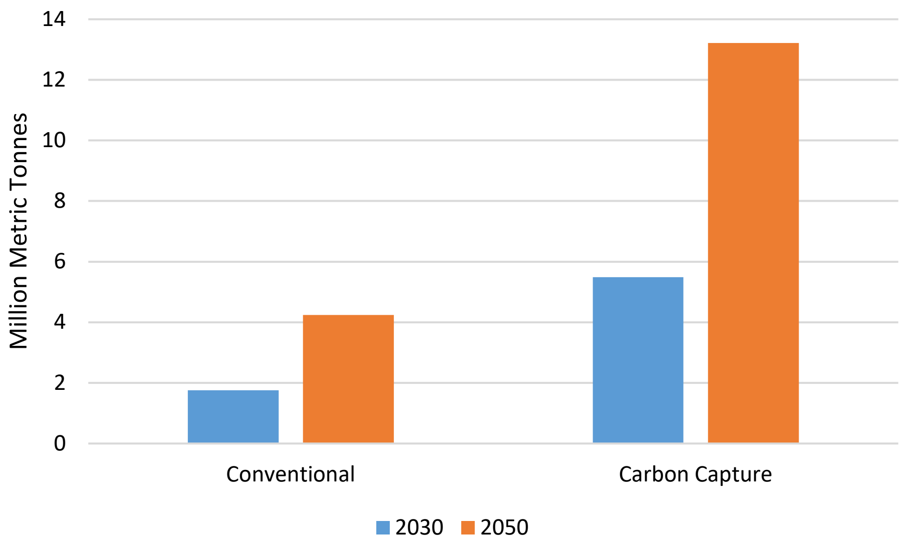


Figure 26: Future Fuels mix in accordance with Scenario 3

Scenario 3 indicates business as usual while ensuring carbon capture and storage facilities onshore as well as installation of carbon capture plant onboard. It can be inferred that 15 million tonnes annual facility of carbon capture reception facilities will need to be ready in 2050 to meet the demand.

The carbon dioxide captured and received on shore may be further used to produce synthetic fuels which can be resupplied to the shipping industry. This cycle may lead to reduction of conventional fuel consumption as well as the size of the facility needed for annual carbon capture storage, however this is not studied further in this section.

Nuclear Energy is not taken into account in this scenario because of the relatively uncertain environment regarding its adoption in maritime and especially for domestic maritime utilization in India. However, this could be a useful option and needs further detailed study.

India Electric Power Generation Scenario

Electric Power Generation is important to be considered since it is crucial in ensuring India remains on track for green transition of the Ports as well as inland waterways. It is estimated that 5000 TWh of electric power will be necessary by 2050 for India's consumption. It is further suggested that this should be from Renewable sources alone such as Wind and Solar. It is remarked that nuclear power plants (and carbon capture onshore) hold the key to India meeting this target. If there is increasing use of nuclear technology on shore, it may provide a positive environment to be also considered for use on Ships.

Cost of Alternative Fuels

The costs of purchase of alternative fuels and future scenarios have been discussed within MEPC 80/INF.10. This is also reproduced in Figure 27.

Figure 7-1: Forecast of fuel costs relative to VLSFO after accounting for the impact of additional energy efficiency measures, without a €100/t carbon price (left), and with a €100/t carbon price (right).

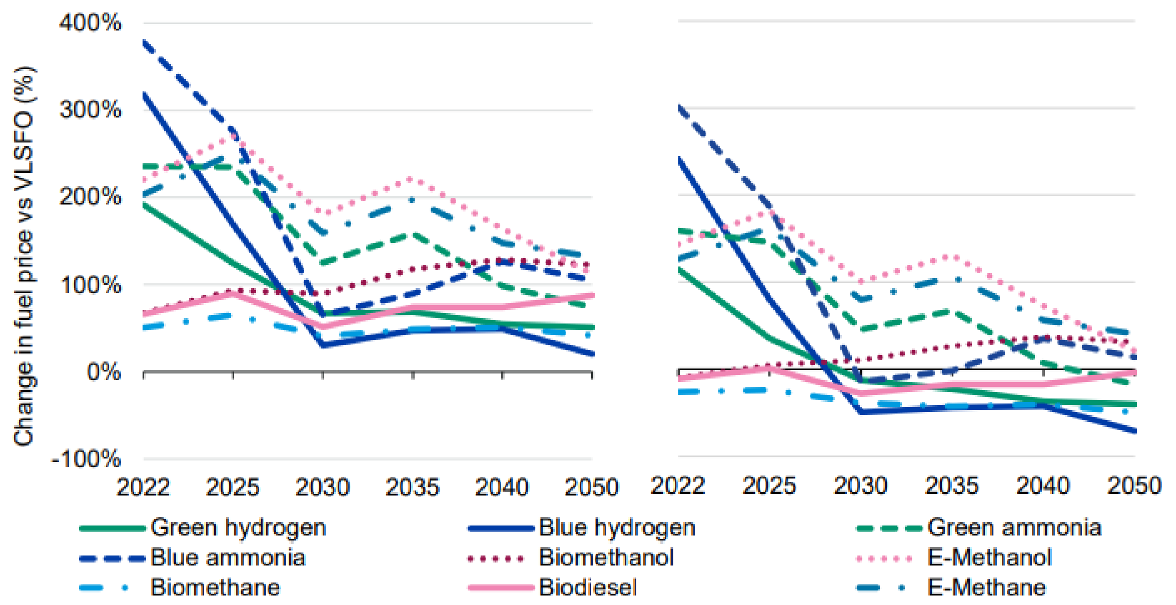


Figure 27: Price forecast for alternative fuels (MEPC 80/INF.10)

The price forecast for alternative fuels is shown in Figure 27. The application of a potential carbon penalty price is also depicted in Figure 31 which enables the alternative fuels to become more competitive over the conventional fossil fuels. It can be observed that the price of Blue Hydrogen, Bio methane, Biodiesel, Green Ammonia and Blue Ammonia appear to be competitive after 2035.

Summary

The foregoing discussion can help us understand the estimation for quantities of alternative fuels necessary for spearheading India's green transition. It is anticipated that the following will be annual requirements for fuels from the Indian maritime sector for 2030 and 2050. Therefore, capacity building needs to be explored to ensure these metrics are present for Indian ships. It is also anticipated that with increased uptake and facilities for production of alternative fuels coupled with a carbon penalty tax, costs will come down for these fuels to make them more competitive. Table 21 provides an estimate of the fuel demand scenario in 2030 and 2050. This discussion considers only the Indian Ship Fleet.

Table 21: Annual Fuel Supply Requirements for Indian Maritime Sector (million metric tonnes)

Fuel	2030	2050
HFO/MDO/MGO	1.43	0.64
LNG	0.66	0.30
LPG	0.017	0.124

Biofuel	0.15	0.864
Ammonia	0.25	4.4
Hydrogen	0.026	0.30
Methanol	0.037	0.272

Carbon Capture Facilities to receive onboard captured carbon dioxide onshore are estimated to be 13 million tons in 2050.

Fuel Supply & Port Infrastructure

Status of Port Infrastructure

India has a lengthy coastline which is more than 7500 km. The mainland coastline accounts for more than 5400 km within the above-mentioned figure. India has 13 major ports and 217 major ports. It is reported that 95% of India's trade in terms of volume and 70% in terms of financial value is carried out through the Indian Ports. It is reported that Indian Ports handled 818 million tonnes of cargo for the financial year 2023-2024.

India's major ports (government and private) are shown as mapped in Figure 28.

Figure 28: Scheme of India's Major Ports (private and government)

The cargo combined handling capacity of all major ports in India is 1617 million tonnes per annum. This demonstrates that there is ample scope for expansion of maritime trade and operations.

The cargo handled by major ports in India (government) for the fiscal year 2024 is shown in Figure 29.

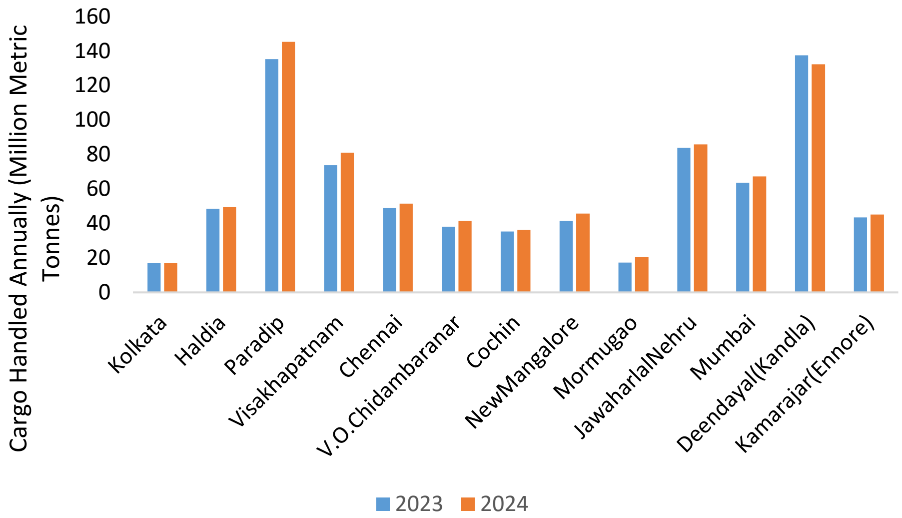


Figure 29: Cargo Handled at Major Indian Ports for the past two years

It can be observed that Deendayal Port (Kandla), Paradip Port and Jawaharlal Nehru Port account for a major chunk of the cargo handled across Indian Ports. These statistics may also convey the potential of bunkering at these ports especially for new fuels and technologies in the future.

Present Status of Bunkering in India

In terms of bunkers supply facilities in India, It can be observed from Figure 34 that Kakinada, Nhava Sheva Supply (JNPT), Vishakhapatnam were the top three locations for bunkers supply for 2022. These three locations account for nearly 63% of the bunker supply in India. It may however be noted that these locations provide conventional marine fuel bunkers. The figure therefore demonstrates that there is potential for further developing these locations as well as other locations which are not so prominent in terms of bunker supply for suitability to supply alternative fuel bunkers. The bunkering in Indian Ports for 2022 equates to 35 million metric tonnes (equivalent to 1.58 EJ of energy). Comparing this with the fuel consumption data for Indian Fleet, it is apparent that Indian fleet fuel consumption is only 3% of India's bunker sales. This indicates that India is used as a bunkering destination.

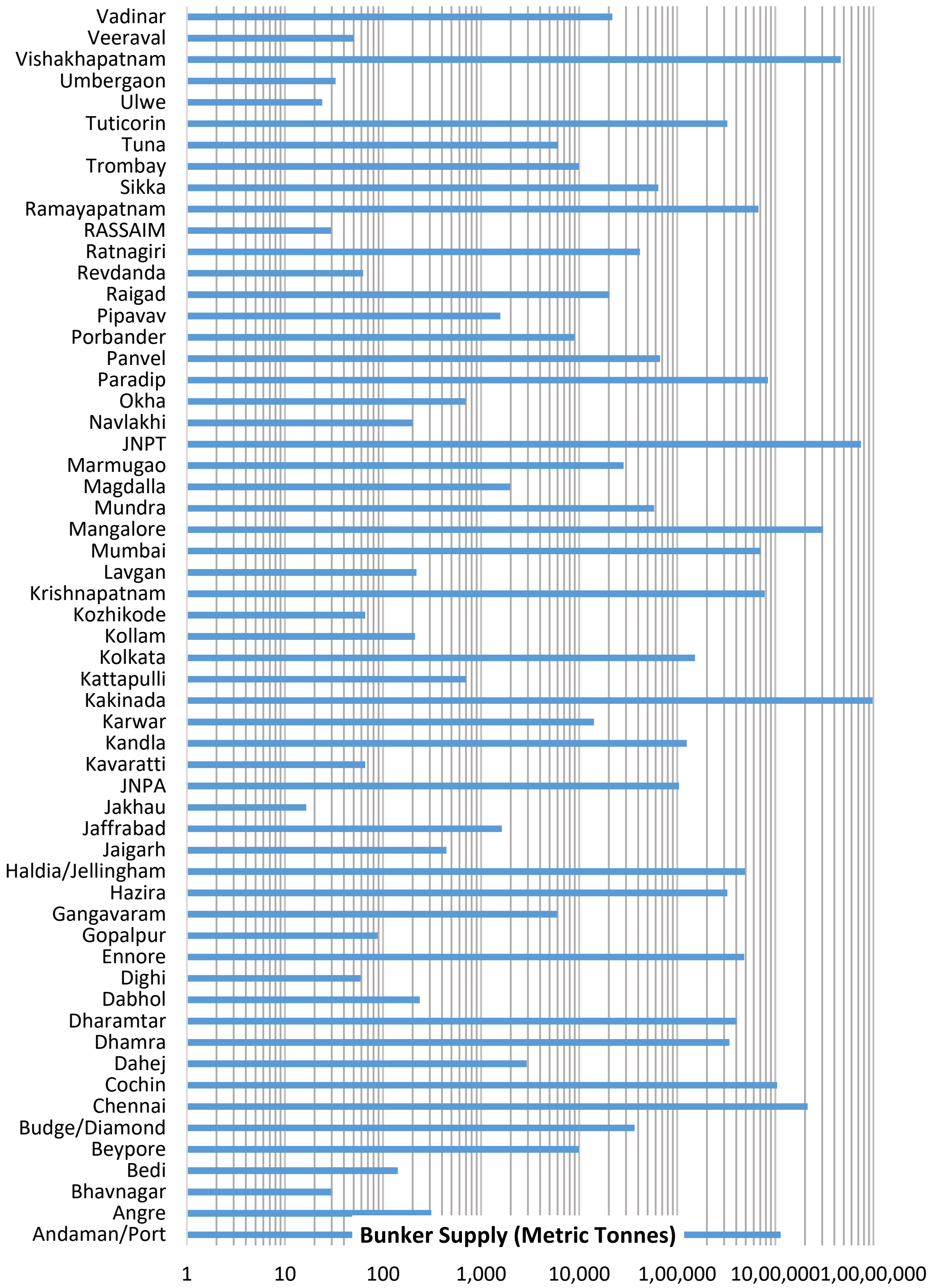


Figure 30: Bunker Supply Locations vs the total quantity of bunker supplied in India in 2022

As regards share of the bunkers sold between the locations on the west coast and the east coast, it can be observed that 62% of the bunkers were sold on the east coast of India as shown in Figure 31. The locations where bunkers are relatively less traded need to be further studied in order to understand the factors behind (e.g. low draft, proximity from nearest refineries, non-availability of space etc.) in order to expand their capacities especially for alternative fuels.

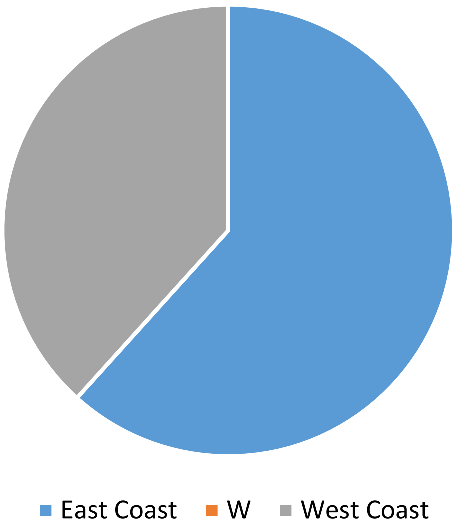


Figure 31: Distribution of the Bunkering Locations in terms of East and West Coast of India

Potential for Indian Ports to provide bunkering of alternative fuels

The present section investigates the potential for Indian Ports to provide alternative fuel bunkering. This can be preliminarily targeted if there are ports/terminals having berths for alternative fuels such as LNG, LPG, Methanol, Ammonia and Hydrogen for trade as cargo. Such locations would be prima-facie the initial targets for bunker supply of alternative fuels since it may be possible to provide truck to ship and ship to ship bunkering.

LNG

The following locations in India handle LNG as Cargo and/or have LNG bunkering facilities

1. Kochi (has LNG bunkering facilities). LNG Terminal has an annual capacity of 5 million metric tonnes
2. Ennore LNG Terminal (5 million metric tonnes)
3. Dabhol LNG Terminal (2 million metric tonnes)
4. Jafrabad LNG Terminal (5 million metric tonnes)
5. Hazira LNG Terminal (5 million metric tonnes)
6. Dahej LNG Terminal (5 million metric tonnes)
7. Mundra LNG Terminal (5 million metric tonnes)

Therefore, there exist several LNG installations on the Indian Coast (total capacity annually of 32 million metric tonnes) as regards LNG handling which may have the potential for developing LNG bunkering facilities.

Methanol

With regard to methanol, it is noted that Kandla and Jawaharlal Nehru Port have facilities for storage of methanol. These locations could be targeted as regards methanol bunkering projects at least on a pilot scale so as to gain experience.

Ammonia

The Government of India has identified Kandla, Paradip and Tuticorin ports to develop as export hubs for green hydrogen, green ammonia, and methanol. It may also be noted that the below mentioned companies utilize ammonia and are located on the Indian coastline which may help facilitate availability of ammonia.

1. PPL **Paradip** (Storage Capacity 50000 metric tonnes)
2. IFFCO **Paradip** (Storage Capacity 40000 metric tonnes)
3. Coromandal Fertilizers **Vizag** Ltd. (Storage Capacity 12000 metric tonnes)
4. Godavari Fertilizers and Chemicals Ltd. **Kakinada** (Storage Capacity 13000 metric tonnes)
5. Coromandal Fertilizers **Ennore** Ltd. (Storage Capacity 13000 metric tonnes)
6. Greenstar Fertilizers **Tamil Nadu** (Storage Capacity 30000 metric tonnes)
7. SPIC **Tuticorin** (Storage Capacity 10000 metric tonnes)
8. The Fertilizers and Chemicals Travancore Limited **Kochi** (Storage Capacity 10000 metric tonnes)
9. Mangalore Chemical and Fertilizers Ltd. **Mangalore** (Storage Capacity 10000 metric tonnes)
10. Zuari Industries Ltd. **Goa** (Storage Capacity 5000 metric tonnes)
11. DFPCL **Jawaharlal Nehru Port** (Storage Capacity 15000 tonnes)
12. Hindalco Industries **Dahej** (Storage Capacity 10000 tonnes)
13. IFFCO **Kandla** (Storage Capacity 38000 tonnes)
14. Gujarat State Fertilizers **Sikka** (Storage Capacity 65000 tonnes)

The above installations together account for 321000 metric tonnes of ammonia terminals capacity.

Hydrogen

The Government of India has identified Kandla, Paradip and Tuticorin ports to develop as export hubs for green hydrogen (in addition to green ammonia and methanol).

LPG

India has LPG import terminals at Kandla, Haldia, Dahej, Ennore, Hazira and Kochi. Five of the world's top 10 busiest LPG terminals are located in India. India's LPG imports are estimated to reach 20-21 million Metric Tonnes per annum by 2026.

Shore Power

Shore Power is being provided to ships at major port locations in India. This is depicted in Figure 32 as regards those Ports where shore power is available.

Figure 32: Locations in Indian Ports where Shore Power is available

Each port has it's capability for maximum power supply, the supply voltage and frequency as well as the typical ships to which shore power can be supplied.

The shore power supply at present is focused on power supply during drydocking and repair. If provision of shore power with view to charging batteries installed on ships is envisaged, then this will need development of infrastructure to provide fast charging facilities at these Ports so as to ensure power supply to ships during operations at berth. The electricity should be derived from green sources such as solar, wind, nuclear etc.

Inland Waterways

India has a rich network of inland waterways. These comprise of a network of rivers, canals, lakes, creeks, and backwaters. The Inland Waterways Authority of India (IWAI) reports on it's website that India has approximately 14500 km of navigable waterways which facilitate movement of 133 million metric tonnes of cargo annually. Principally the National Waterways 1 and 2 comprise of navigable portions on the river Ganges and the Brahmaputra respectively.

The IWAI owns a total of 121 vessels operating on the inland waterways as indicated on it's website.

Ship Fleet Operating on Inland Waterways

A study of the ship fleet operating on inland waterways was undertaken. This considered all ships as in January 2025 classed with the Indian Register of Shipping and assigned the IWL class notation. A total of 649 Ships were identified.

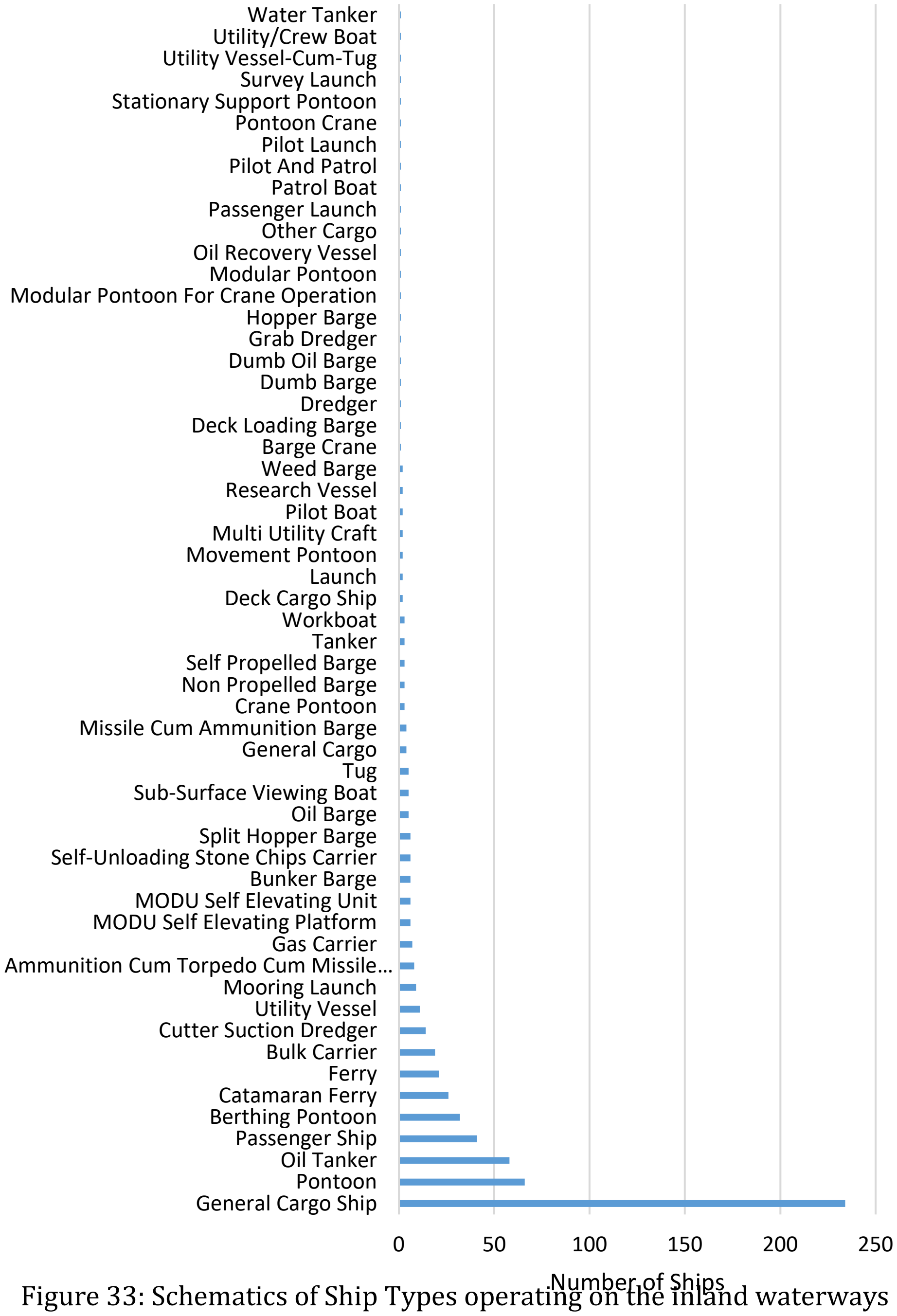


Figure 33: Schematics of Ship Types operating on the inland waterways

It can be observed that the General Cargo Ships category accounts for 36% of the total number of ships. In terms of self-propelled ships, the General Cargo Ships, Oil Tankers, Passenger Ships and Ferries, Dredgers and Bulk Carriers account for the majority of the ship types. The average gross tonnage of general cargo ships in the inland waterways category is 1450.

In terms of the total gross tonnage in terms of the ship types, Figure 34 shows the distribution. It can be observed that General Cargo Ships, Bulk Carriers, Oil Tankers, and Passenger ships/ferries account for a major chunk of the tonnage.

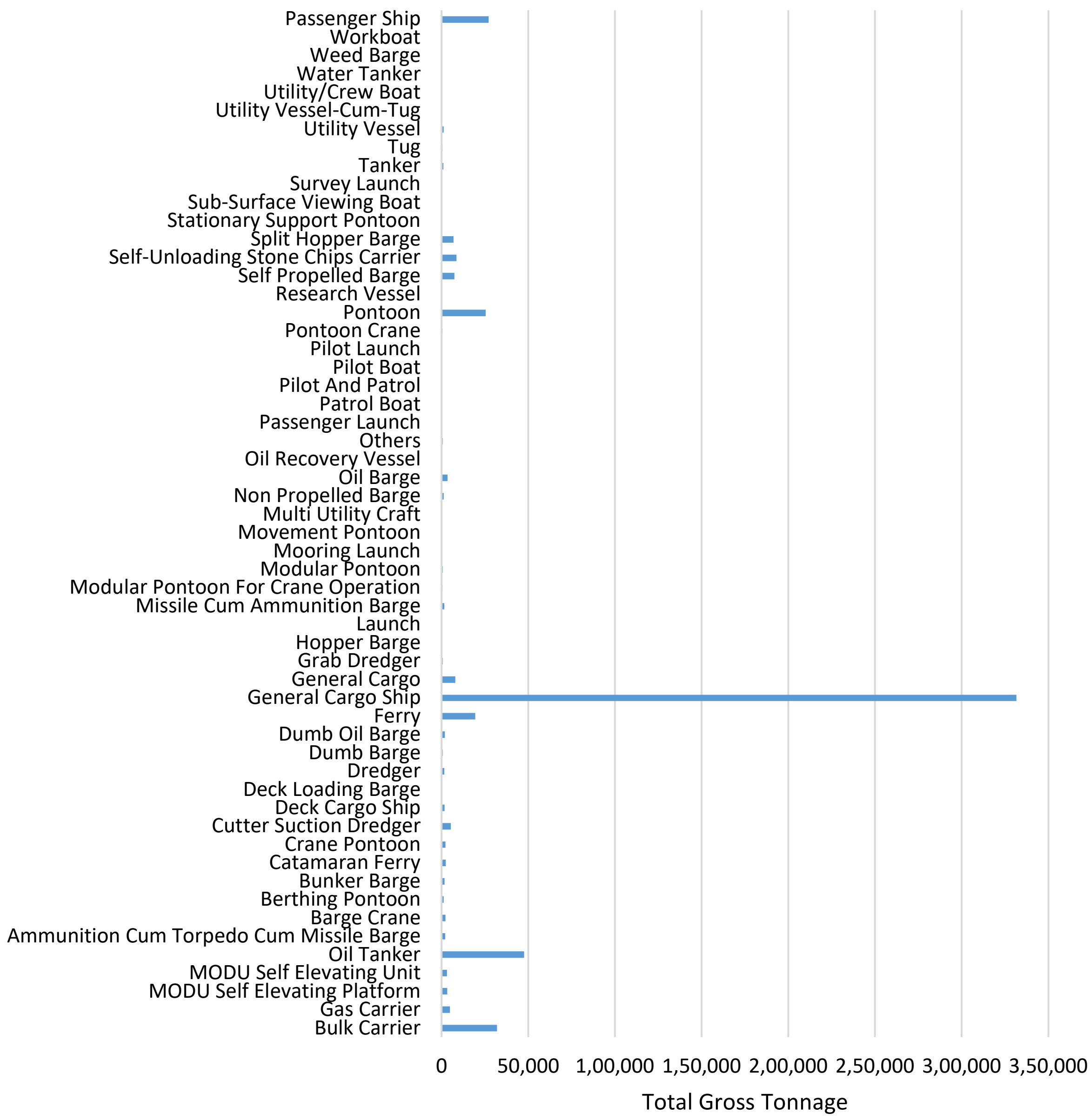


Figure 34: Contribution of Ship Type to Gross Tonnage

Further refinement of the ship fleet to exclude non-propelled vessels such as Pontoons yields a total of 491 ships. For such Ships, the installed power onboard was obtained and a profile of the power capacity is plotted as shown in Figure 35.

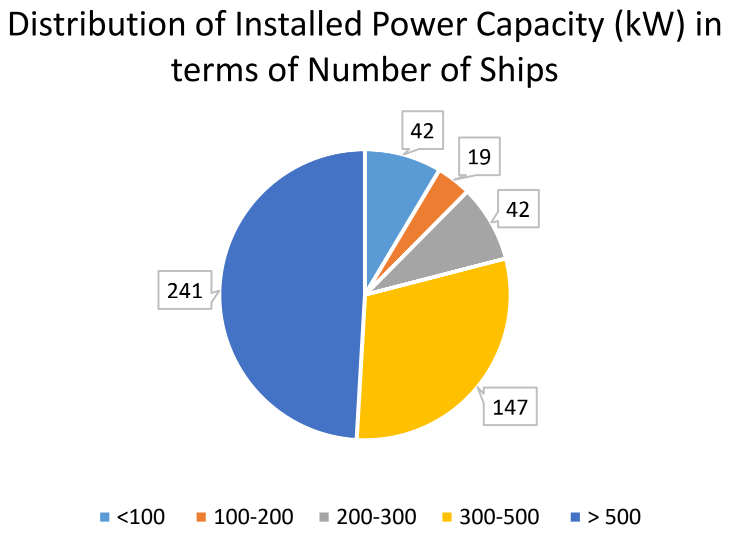


Figure 36: Installed Power Capacity distribution for self-propelled ships on Inland Waterways

It can be observed that nearly 50% of the ships have installed power capacity less than 500 kW. These may also be ships which may be amenable for fitting battery electric propulsion or fuel cell technology.

The age profile of the self-propelled ships is depicted in Figure 36.

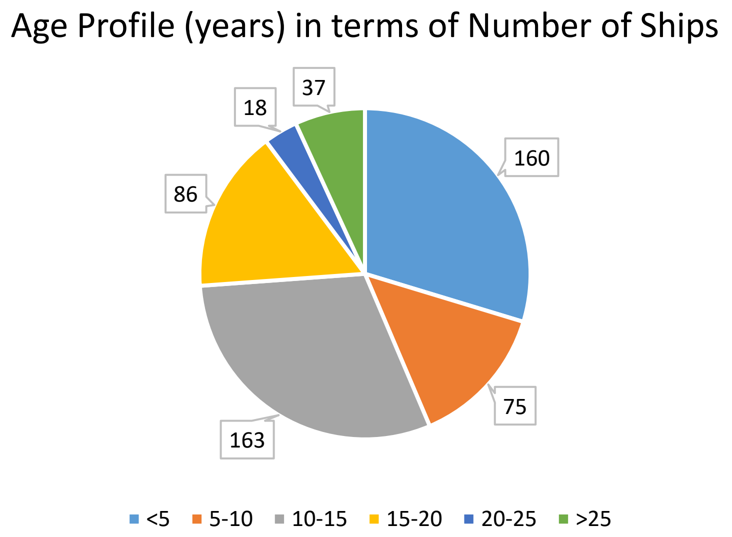


Figure 36: Age profile (Number of Ships) of self-propelled ships on Inland Waterways

The Ship Fleet age profile demonstrates that 26% of the number of ships are above 15 years of age. The majority of the present fleet is relatively young.

Summary

The following key points are summarized from the study of the inland waterways fleet:

1. The inland waterways fleet is composed mainly of general cargo ships, oil tankers, bulk carriers, and passenger ships/ferries. Non-propelled vessels such as pontoons are also a significant number in this category.
2. In terms of gross tonnage, the general cargo ships, oil tankers, bulk carriers and passenger ferries account for an overwhelming majority within the ship types.
3. Approximately 50% of the fleet has an installed power capacity of 500 kW or less. This presents the opportunity to consider these ships for electrification with batteries or installation of fuel cells (provided that technical and economic feasibility is established)
4. The Ships are relatively younger in age with 26% of the fleet above 15 years of age.

The following are the key considerations to drive green transition for the inland waterways in India:

- Retrofitting of vessels (if considered feasible) to operate on green fuels or technologies (e.g. battery assisted propulsion or fuel cell propulsion)
- Renewal of the aging ship fleet with vessels which operate on green fuels or technologies
- Developing the necessary infrastructure to ensure adequate supply of green fuels or infrastructure to support technology (e.g. charging of batteries installed on vessels) on the inland waterways. This may require upgrading of facilities at existing ports as well as possibility for construction of new ports (as may be feasible)
- Encouraging the uptake of green fuels and technologies by implementing suitable policies as to ensure financial viability
- Availability of facilities to support ship maintenance and repairs (as may be necessary)
- Developing and promoting indigenous ship design, construction, and technologies
- Availability of skilled personnel for operating the ships with the green fuels/technology as well as for Port Operations.

Greening of Vessels involved in navigation on these waterways would also contribute to the vision of the government has already summarized in the Maritime Amrit Kaal Vision 2047 as well as the "Harit Nauka" scheme. It may also be noted that inland transportation by waterways is more efficient in terms of the GHG emissions and economic considerations when compared to the other modes such as road or rail.

Chapter (V)

Financial Strategy for Future Fuel Transition of Maritime India

Funding Challenges in the Green Transition of the Indian Maritime Sector

India's maritime sector is integral to its trade and economic activities, and its green transition is essential to meet global sustainability goals and align with the International Maritime Organization's (IMO) revised greenhouse gas (GHG) strategy of achieving net-zero emissions by 2050. However, this transition faces several financial constraints that must be addressed to enable the adoption of green fuels and technologies, upgrade infrastructure, and enhance competitiveness in the global maritime landscape. This document elaborates on the specific funding challenges faced by the Indian maritime sector in this green transition.

High Capital Costs

The shift to green fuels and the required infrastructure upgradation entails substantial capital investments that pose a significant barrier. This section delves into the major components contributing to high capital costs and their implications for the Indian maritime sector.

Green Fuel Production Infrastructure: Producing green fuels like hydrogen and ammonia involves significant initial investments. In India, green hydrogen production costs range from ₹300-400 per kilogram ($3.6-$4.8/kg), compared to conventional marine fuels like Heavy Fuel Oil (HFO), which costs around ₹60-70 per kilogram ($0.72-$0.84/kg). This cost disparity arises due to the need for advanced production facilities and technologies, such as electrolyzers, which are essential for green hydrogen production. The estimated cost of setting up electrolyzer facilities in India is approximately ₹8-10 crores ($1-1.25 million) per megawatt. These high production costs make green fuels economically unviable without substantial subsidies or technological breakthroughs. Electrolyzers further require certain purity of water for their process. Production of ultra-pure water would also need additional technology to be acquired and installed.

Port Infrastructure Modernization: Adapting Indian ports to handle green fuels demands extensive upgrades, including cryogenic storage systems, corrosion-resistant pipelines, and advanced safety mechanisms like fire suppression and leak detection. These upgrades, estimated to cost ₹1,000 to ₹1,200 crores ($120-$145 million) per major port, aim to ensure safe handling and storage of fuels such as hydrogen and ammonia, which require ultra-low temperatures and robust systems. Despite their necessity, these high costs strain ports operating on limited budgets, highlighting the critical need for targeted financial and policy support. Cryogenic storage systems are critical for handling green fuels like hydrogen and ammonia, especially hydrogen which must be stored at extremely low temperatures. Developing these facilities involves high capital investments in advanced materials and safety systems. Indian ports currently lack the widespread availability of such infrastructure, necessitating significant expenditures to meet international standards.

Vessel Retrofitting and New Construction: Retrofitting existing vessels to use alternative fuels like green hydrogen or ammonia is another major cost driver. The retrofitting process involves installing advanced fuel supply systems, machinery, and safety features. Alternatively, constructing new vessels designed to run on green fuels may be 30-40% more expensive than building conventional ships. For example, a typical green-fuel-ready vessel may require advanced propulsion systems and onboard fuel processing units, further escalating the costs. These high expenses limit the willingness of ship-owners and operators to transition to green technologies.

Technological Gaps and Dependence on Imports: India's reliance on imported technologies for electrolysers, fuel cells, and cryogenic systems adds to the financial burden.

Domestic production capabilities for such advanced technologies are currently underdeveloped, leading to higher costs and longer implementation timelines. Import duties and logistical challenges further inflate the costs, making green transition projects less competitive on a global scale.

Uncertain Market Demand

Uncertain market demand presents a critical challenge for the green transition in India's maritime sector. This section explores the key factors contributing to this uncertainty and their implications.

High Fuel Costs and Price Volatility: Green fuels are currently much more expensive than traditional marine fuels. For example, the cost of green ammonia ranges between ₹75-100 per kilogram ($0.9-$1.2/kg), while conventional fuels like Heavy Fuel Oil (HFO) cost around ₹50-60 per kilogram ($0.6-$0.72/kg). This significant cost disparity discourages ship operators from adopting green fuels. Additionally, the price of green fuels is highly volatile due to fluctuating production costs and limited supply chains, further complicating investment decisions.

Limited Market Readiness: The infrastructure and technology required for widespread adoption of green fuels are still in nascent stages in India. The lack of adequate bunkering facilities and supply chain networks for green fuels means that even interested stakeholders face logistical barriers. This limited market readiness results in a low uptake of green fuels, reducing economies of scale and keeping costs high.

Absence of Long-Term Contracts: Ship operators and fuel suppliers are reluctant to enter long-term contracts for green fuels due to uncertainties in demand and pricing. The absence of such agreements leads to a lack of predictability in supply and demand, further dissuading investments in green fuel production and infrastructure.

Unclear Regulatory Signals: While India has set ambitious renewable energy targets, clear regulatory framework mandates for the adoption of green fuels in the maritime sector would be welcome. Regulatory ambiguity creates hesitation among investors and stakeholders, as they are unsure about future compliance requirements and potential incentives.

Global Trade Pressures: India's maritime sector also faces external pressures from global trade dynamics. Developed regions, such as the European Union, are implementing stricter emission regulations, including the "Fit for 55" initiative and the extension of the Emissions Trading System (ETS) to shipping. These measures could increase operating costs for Indian shipping companies, making green fuels more critical but simultaneously adding financial burdens.

Policy Gaps and Lack of Incentives

India's policy framework for renewable energy and decarbonization has yet to adequately address the unique requirements of the maritime sector. While the National Hydrogen Mission allocates ₹19,744 crores ($2.5 billion) for hydrogen production, it lacks specific provisions for maritime applications.

Lack of Fiscal Incentives: Currently, India's tax regime offers limited exemptions for importing green technologies or setting up renewable energy facilities at ports. High import duties on electrolyzers and fuel cells increase costs, dissuading stakeholders from investing in green technologies. Providing targeted tax breaks and subsidies for green infrastructure development could help alleviate this issue. It is acknowledged that the Government of India has provided incentives vide the National Green Hydrogen Mission for manufacturing electrolyzers in India by providing a performance linked incentive scheme.

Absence of Maritime-Specific Financial Policies: India has articulated its maritime aspirations through comprehensive frameworks like the Maritime India Vision (MIV) 2030 and the Maritime Amrit Kaal Vision (MAKV) 2047. These initiatives outline strategic objectives for port modernization, infrastructure development, and the promotion of sustainable practices. The MIV 2030 encompasses over 150 initiatives across ten themes, aiming to position India as a global maritime leader. Similarly, the MAKV 2047 builds upon these goals, setting long-term targets for the sector's development. While these policies provide a strategic roadmap, they do not explicitly address the financial frameworks necessary to support green maritime initiatives.

Need for an Integrated Financing Policy: To bridge this gap, India could benefit from an integrated policy akin to the National Green Shipping Policy (NGSP). Such a policy would focus on:

- Dedicated Green Funds: Establishing financial reserves specifically for green maritime projects.
- Tax Incentives: Providing fiscal benefits for investments in sustainable technologies.
- Public-Private Partnerships: Encouraging collaboration between government entities and private stakeholders to mobilize resources for green initiatives.

Implementing a targeted financing policy would complement existing maritime visions, ensuring that strategic goals are supported by the necessary financial infrastructure to achieve a sustainable and competitive maritime sector.

Insufficient Alignment with Global Mechanisms: International mechanisms like the IMO's Market-Based Measures (MBMs) could generate significant funds for maritime decarbonization. However, India has yet to advocate effectively for equitable access to these resources. Ensuring that developing countries receive a fair share of funds generated through carbon levies and other MBMs is critical to bridging the financing gap.

Lack of Infrastructure Development Schemes: Despite the growing importance of green ports, government schemes dedicated to port modernization and green fuel infrastructure are minimal. Introducing a dedicated green port development initiative could accelerate the adoption of sustainable practices at Indian ports.

Green Financing Models for Maritime Decarbonisation

Sustainable Financial Models for Green Financing in Maritime

The maritime sector's transition to green technologies and low-carbon fuels is critical for achieving global sustainability goals. To support this transition, sustainable financial models are being developed worldwide, focusing on mobilizing capital, reducing risks, and incentivizing investments in green projects. These models leverage public, private, and multilateral funding sources, ensuring equitable access to financing.

Green Bonds: Green bonds are debt instruments specifically issued to finance environmentally sustainable projects. These bonds attract institutional investors who are increasingly focused on Environmental, Social, and Governance (ESG) criteria. Issuers of green bonds commit to utilizing funds exclusively for green initiatives and maintaining transparency through regular reporting. In the maritime context, green bonds can be instrumental in financing projects such as green fuel bunkering facilities, port electrification, and renewable energy integration.

Public-Private Partnerships (PPPs): Public-Private Partnerships (PPPs) are collaborative frameworks where government bodies and private entities share the risks and rewards associated with green projects. These partnerships leverage public funding and private expertise to accelerate the implementation of sustainable initiatives. In the Indian maritime sector, PPPs can facilitate the development of hydrogen bunkering stations, zero-emission port retrofitting, and clean energy integration.

Sustainability-Linked Loans (SLLs): Sustainability-Linked Loans (SLLs) are a novel financial tool where the interest rates are tied to predefined sustainability performance indicators, such as CO_2 reduction targets. Companies that meet these targets benefit from reduced financial costs, encouraging continued progress in sustainability efforts. In the Indian context, SLLs can finance fleet upgrades and energy-efficient vessel retrofits, providing a direct incentive for shipping companies to adopt greener practices.

Multilateral Development Bank (MDB) Funding: Multilateral Development Banks (MDBs) such as the World Bank and the Asian Development Bank (ADB) play a crucial role in providing concessional loans and grants for green projects. The Global Maritime Decarbonisation Initiative is one such program that supports low-carbon technologies in the maritime sector. MDB funding is particularly beneficial for large-scale projects in developing economies, as it offers low-interest rates that significantly reduce capital costs. India can leverage MDB funding to support projects such as port electrification, green hydrogen production, and fleet modernization.

Blended Finance: Blended finance is a model that combines concessional funding from public or philanthropic sources with commercial capital to de-risk green investments. This approach addresses financial barriers, especially for high-risk projects, by leveraging public funds to attract private sector participation. The World Bank's Climate Investment Platform is an example of a blended finance initiative that supports renewable energy projects, including those in maritime applications. In India, blended finance can be utilized to develop renewable energy-powered ports and alternative fuel infrastructure.

Carbon Pricing Mechanisms: Carbon pricing mechanisms, such as carbon levies and emissions trading systems, internalize the cost of carbon emissions, providing economic incentives for emissions reduction. The European Union's Emissions Trading System (EU ETS) has been extended to the maritime sector, requiring operators to purchase emission allowances. Similarly, the IMO's proposed carbon levy aims to fund decarbonization efforts in developing countries. In India, introducing a maritime-specific carbon pricing system can generate significant revenue for financing emission-reduction technologies and green fuel adoption.

Table 22 Global Models of Sustainable Green Financing

Financial Model	**Mechanism**	**Global Examples**	**Application in Maritime**
Green Bonds	Debt instruments issued to finance environmentally sustainable projects, ensuring transparency and accountability.	NYK Line (Japan): LNG-powered vessels. Port of Los Angeles (USA): Electrification and zero-emission port operations.	Financing green fuel bunkering facilities, port electrification, and renewable energy integration.
Public-Private Partnerships (PPPs)	Collaborative frameworks where government and private entities share risks and rewards in green projects.	Singapore: Hydrogen bunkering and port electrification. Netherlands: Port hydrogen networks.	Developing hydrogen bunkering stations, zero-emission port retrofitting, and clean energy integration.
Sustainability-Linked Loans (SLLs)	Loans tied to sustainability performance indicators like CO_2 reduction targets, offering reduced financial costs for achieving goals.	Maersk: SLLs secured based on carbon intensity reduction targets.	Financing fleet upgrades and energy-efficient vessel retrofits.

Multilateral Development Bank (MDB) Funding	Concessional loans and grants from institutions like the World Bank and Asian Development Bank for large-scale green projects.	World Bank's Global Maritime Decarbonization Initiative: Low-carbon technologies. ADB: Climate-focused initiatives.	Supporting port electrification, green hydrogen production, and fleet modernization.
Blended Finance	Combining concessional funding with commercial capital to de-risk green investments, addressing high-risk project barriers.	World Bank's Climate Investment Platform: Renewable energy projects including maritime applications.	Developing renewable energy-powered ports and alternative fuel infrastructure.
Carbon Pricing Mechanisms	Internalizing the cost of carbon emissions through levies and emissions trading systems, providing economic incentives for emissions reduction.	EU ETS: Maritime emission allowances. IMO Proposed Carbon Levy: Funding decarbonization in developing countries.	Financing emission-reduction technologies and green fuel adoption through generated revenues.

Table 23 Recommended Green Finance Models for Maritime India

Recommendation	Details
Establish a National Green Maritime Fund	Pool resources from MDBs, private investors, and domestic sources to finance large-scale green maritime projects.
Leverage PPP Models	Collaborate with private entities to develop green infrastructure, focusing on hydrogen and ammonia bunkering facilities.
Adopt Sustainability-Linked Loans	Encourage Indian shipping companies to secure SLLs by setting clear emission reduction targets.
Integrate Carbon Pricing Mechanisms	Introduce a maritime-specific carbon pricing system to fund green projects.

Incentive Schemes for Green Financing in Maritime Decarbonisation: Lessons from Global Best Practices

Governments play a crucial role in facilitating the transition to low-carbon and sustainable maritime operations. Incentive schemes are critical tools to lower barriers to investment, accelerate adoption of green technologies, and ensure a competitive transition. By studying global best practices, governments can design effective incentives tailored to their maritime sectors.

Subsidies and Grants: Subsidies and grants are among the most direct tools for governments to encourage the adoption of green technologies. These financial aids significantly reduce the costs of adopting new technologies and fuels, providing immediate relief to stakeholders. India can introduce grants focused on retrofitting its fleet and developing alternative fuel bunkering infrastructure at major ports.

Tax Incentives: Tax incentives effectively reduce the financial burden of adopting green technologies by lowering operational and capital costs for shipping companies. India can consider offering accelerated depreciation benefits and tax holidays to companies transitioning to green fuels or investing in renewable energy-powered port operations.

Green Port Fee Structures: Green port fee structures reward vessels with lower emissions by reducing port charges for those complying with stringent environmental standards. Indian ports, such as Jawaharlal Nehru Port Trust (JNPT), can implement fee structures to incentivize greener shipping practices.

Low-Interest Loans and Financial Guarantees: Low-interest loans and government-backed guarantees are effective in de-risking green investments, encouraging private sector participation. India could establish a Green Maritime Finance Corporation to offer concessional loans for zero-emission vessel construction and retrofitting ports for cleaner operations.

R&D Incentives: Investments in research and development (R&D) are crucial for fostering innovation in green technologies. India can establish an R&D fund to support collaborative projects between maritime stakeholders and academic institutions, focusing on green fuel technologies and energy-efficient vessel designs.

Market-Based Measures (MBMs): Market-Based Measures (MBMs) internalize the cost of carbon emissions, creating economic incentives for the adoption of low-carbon solutions. The European Union's Emissions Trading System (EU ETS) requires shipping operators to purchase allowances for CO2 emissions, while the IMO's proposed carbon levy aims to fund decarbonization projects in developing countries. India should advocate for a global MBM framework that ensures equitable revenue redistribution, supporting green infrastructure development in developing nations.

Public-Private Partnerships (PPPs): Public-Private Partnerships (PPPs) enable collaboration between governments and private entities, leveraging public resources and private expertise. India can facilitate PPPs to develop hydrogen and ammonia bunkering facilities and electrified port operations, fostering innovation and shared responsibility.

Table 24 Global Incentive Schemes for Green Financing in Maritime

Incentive Scheme	**Description**	**Global Examples**	**Application for India**
Subsidies and Grants	Financial aids to lower costs of adopting green technologies, supporting R&D, retrofitting, and pilot projects for alternative fuels.	Germany's Green Shipping Fund: Subsidies for R&D and retrofitting. Singapore's Maritime Green Future Fund: Grants for hydrogen and ammonia projects.	Introduce grants to retrofit Indian vessels and develop alternative fuel bunkering infrastructure at major ports.
Tax Incentives	Reductions in taxes or accelerated depreciation benefits to lower operational and capital costs for companies adopting low-carbon technologies.	Denmark's Green Shipping Tax Rebate: Tax reductions for low-emission vessels. USA's Clean Energy Tax Credits: Renewable energy projects.	Provide tax holidays or rebates for companies transitioning to green fuels or using renewable energy at Indian ports.
Green Port Fee Structures	Reduced port charges for vessels meeting emission standards, incentivizing compliance with environmental regulations.	Port of Rotterdam (Netherlands): Discounts for low-emission vessels. Port of Gothenburg (Sweden): Fee reductions for green ships.	Implement tiered fee structures at Indian ports like JNPT to reward vessels with lower emissions and encourage greener shipping practices.
Low-Interest Loans and Guarantees	Concessional loans and government-backed guarantees to de-risk green investments, encouraging private sector participation.	Japan's Green Ship Finance Program: Loans for efficient vessels. Norwegian Export Credit Agency: Guarantees for green projects.	Establish a Green Maritime Finance Corporation to provide concessional loans for zero-emission vessel construction and retrofitting ports.
R&D Incentives	Funding collaborative research to innovate green maritime technologies, focusing on fuels like hydrogen and ammonia and energy-efficient vessel designs.	European Horizon 2020 Program: Low-carbon maritime R&D. Korea's Green Technology R&D Fund: Hydrogen-	Set up an R&D fund to support academia and industry collaborations in green fuel technologies and energy-efficient vessel design.

		powered vessel development.	
Market-Based Measures (MBMs)	Economic tools to internalize the cost of carbon emissions through levies or trading systems, funding decarbonization efforts.	EU ETS: Emissions trading for maritime. IMO's Carbon Levy: Funding decarbonization projects in developing nations.	Advocate for equitable MBM frameworks at IMO to support revenue redistribution for infrastructure development in developing countries like India.
Public-Private Partnerships (PPPs)	Collaborative projects leveraging public funds and private expertise to develop sustainable maritime infrastructure and technologies.	Singapore: Hydrogen infrastructure and port electrification through PPPs. Netherlands: Hydrogen bunkering network development.	Facilitate PPPs for hydrogen and ammonia bunkering facilities and electrified port operations in collaboration with private stakeholders.

Table 25 Recommended Incentive Schemes for Future Fuel Transition of maritime India

Recommendation	Description
Introduce Targeted Subsidies and Grants	Focus on retrofitting older vessels, port electrification, and development of alternative fuel infrastructure.
Implement Tiered Tax Incentives	Provide tax rebates for shipping companies adopting zero-emission vessels or renewable energy at ports.
Adopt Green Port Fee Systems	Reward vessels meeting emissions standards with reduced port charges at major Indian ports.
Establish a National Green Finance Fund	Offer low-interest loans and guarantees for maritime decarbonisation projects.
Create Dedicated R&D Support Mechanisms	Drive innovation in green fuels and energy-efficient vessel designs through academia and industry partnerships.
Advocate for Equitable MBM Frameworks	Ensure that India benefits from global decarbonisation measures by supporting fair revenue redistribution mechanisms.

Green Transition Investments Requirement in the Indian Maritime Sector

The green transition of India's maritime sector requires targeted investments to achieve decarbonisation and align with global sustainability goals. Each sector's projected investment has been rationalized based on current infrastructure, anticipated technological advancements, and global benchmarks. This document provides a detailed explanation of the rationale behind the projected funding requirements, supported by credible sources.

Sector-wise Investment Projections

Port Infrastructure: The modernization of ports is essential for the green transition, given their central role in maritime operations and significant contribution to emissions. Ports must transition to renewable energy and adopt alternative fuel infrastructure to reduce carbon intensity.

India's coastline has immense potential for solar and wind energy installations, which can make ports energy self-sufficient while significantly reducing emissions.

Electrification of berths through shore power systems is another critical measure, as it can eliminate emissions from vessels during docking, a notable source of port-related pollution. Additionally, with the global shipping industry shifting toward hydrogen, ammonia, and biofuels, it is crucial for Indian ports to establish bunkering facilities to remain competitive and support the decarbonisation of international shipping.

Reports by TERI and NITI Aayog highlight India's renewable energy potential and provide data on the feasibility of such initiatives.

The total projected investment for port infrastructure is INR 60,000 crore ($7.5 billion), which includes renewable installations, berth electrification, and green fuel bunkering facilities.

Shipping Fleet Modernization: Decarbonizing India's shipping fleet requires a two-pronged approach: retrofitting existing vessels with energy-efficient technologies and constructing new green ships.

Many Indian vessels currently rely on outdated technologies that are inefficient and highly polluting. Retrofitting these vessels with energy-efficient engines, air lubrication systems, and renewable fuel systems can extend their operational life while significantly reducing emissions. Simultaneously, the expansion of India's trade volume necessitates the construction of new vessels. Building ships powered by hydrogen, ammonia, or hybrid systems will ensure compliance with evolving global regulations and support the country's decarbonisation goals.

The rationale for these investments aligns with findings from IMO's 4th GHG Study, which outlines pathways for fleet decarbonisation.

The projected investment for fleet modernization stands at INR 90,000 crore ($11.2 billion), encompassing retrofitting and new vessel construction.

Logistics and Inland Waterways: Developing India's logistics and inland waterways infrastructure is critical for reducing congestion and emissions while enhancing connectivity between ports and hinterlands.

Electrification of logistics infrastructure, such as cranes, forklifts, and warehouse systems, can significantly reduce reliance on fossil fuels. Similarly, inland water transport offers a low-carbon alternative to road transport but requires investments in electrified and hybrid barges for cargo movement. The development of multimodal hubs integrating renewable-powered rail and road networks with ports further enhances efficiency and sustainability.

Data from the Inland Waterways Authority of India (IWAI) underscores the need for similar investments to modernize India's inland waterways. Additionally, reports from the Ministry of Ports, Shipping, and Waterways provide insights into the economic advantages of sustainable logistics.

The projected investment for logistics and inland waterways is INR 30,000 crore ($3.7 billion), covering electrification, barge development, and multimodal hubs.

Research and Development (R&D): Innovation in green maritime technologies is the cornerstone of the sector's green transition. Investing in R&D ensures the development of accessible and scalable solutions.

Cost-effective production methods for green fuels like hydrogen, ammonia, and biofuels are essential for widespread adoption. Advanced hull forms and propulsion systems can enhance energy efficiency, reducing overall emissions. Collaborative projects between academia and industry can drive technological innovation and facilitate the transfer of knowledge.

The total projected investment in R&D is INR 23,000 crore ($2.8 billion), supporting fuel development, energy-efficient designs, and collaborative projects.

Training and Capacity Building: A trained workforce is essential for the successful adoption and operation of new green technologies in the maritime sector. Developing the necessary skills and knowledge among seafarers, port workers, and engineers is a critical step in ensuring safety and efficiency.

Skill development programs focused on handling alternative fuels and renewable systems will prepare the workforce for the demands of a decarbonized maritime industry. Additionally, establishing specialized training facilities for green maritime practices aligns with global best practices, such as Singapore's Maritime and Port Authority's training frameworks.

Reports from the International Labour Organization (ILO) emphasize the importance of green skills development, while insights from the World Bank's decarbonization studies underscore the long-term benefits of capacity building. The projected funding for training and capacity building is INR 8,000 crore ($1 billion), encompassing both skill development programs and facility establishment.

Table 26 Sectoral Investment Need Projection for Indian Maritime Sector

Sector	Key Areas of Investment	Projected Investment (INR)	Projected Investment (USD)
Ports	Renewable energy, shore power, alternative fuels	60,000 crore	7.5 billion
Shipping	Retrofitting, new vessel construction	90,000 crore	11.2 billion
Logistics and Inland Waterways	Electrification, low-emission barges, multimodal hubs	30,000 crore	3.7 billion
Research and Development	Green fuel technologies, energy-efficient designs, partnerships	23,000 crore	2.8 billion
Training and Capacity Building	Skill development, training facilities	8,000 crore	1 billion
Total		**211,000 crore**	**26.2 billion**

International Cooperation for Green Financing

Decarbonizing India's maritime sector is a critical step towards achieving global climate goals and aligning with the International Maritime Organization's (IMO) Revised GHG Strategy 2023. International cooperation provides an opportunity to access financial and technical support, address investment gaps, accelerate innovation, and build capacity for sustainable operations. This note outlines potential funding sources and areas for collaboration to facilitate India's green maritime transition.

Multilateral Development Banks (MDBs): Multilateral Development Banks (MDBs) are pivotal in financing sustainable infrastructure projects in developing countries. The Asian Development Bank (ADB) has played a significant role in supporting green initiatives, such as port electrification and renewable energy integration. For instance, ADB's financing of the Vizag-Chennai Industrial Corridor includes sustainability-focused components. Similarly, the World Bank, through its Climate Investment Fund (CIF), offers loans and grants specifically aimed at decarbonization projects. The New Development Bank (NDB) focuses on infrastructure development among BRICS nations, providing financial support for projects like port modernization and green logistics. Another key player is the Global Environment Facility (GEF), which funds projects related to biodiversity conservation, climate change mitigation, and international waters, including maritime decarbonisation efforts.

Green Climate Fund (GCF): The Green Climate Fund (GCF) is a major international financial mechanism for climate mitigation and adaptation projects. India can utilize GCF resources to integrate renewable energy at ports, develop alternative fuel infrastructure, and electrify logistics networks. Aligning national projects with GCF's funding criteria will allow India to leverage substantial financial support to advance its decarbonisation goals.

International Renewable Energy Agency (IRENA): IRENA's Climate Investment Platform facilitates renewable energy investments in emerging economies. India can use this platform to fund solar and wind energy installations at ports, as well as battery storage systems to enhance energy reliability. Collaboration with IRENA can also provide access to advanced technologies and capacity-building initiatives to accelerate the green transition.

European Union (EU) Funding Mechanisms: The European Union provides multiple funding avenues for green maritime projects. Horizon Europe offers R&D grants for innovative technologies, such as hydrogen-powered vessels. The European Investment Bank (EIB) provides concessional financing for projects involving alternative fuel infrastructure and zero-emission vessels. These mechanisms can complement India's domestic efforts and enable access to cutting-edge technologies and expertise.

International Maritime Organization (IMO): The IMO is a central body for promoting maritime decarbonisation through programs like the Maritime Research Fund. This fund supports R&D in low-carbon technologies and advocates for equitable revenue distribution from global Market-Based Measures (MBMs). Active participation in IMO initiatives enables India to secure funding for strategic projects and contribute to shaping global decarbonisation policies.

Bilateral Cooperation: Bilateral partnerships with countries like Japan, Denmark, and Singapore offer significant opportunities for financial and technical collaboration. The Japan International Cooperation Agency (JICA) supports maritime decarbonization through concessional loans, while Denmark's Green Strategic Partnership with India focuses on sustainable maritime practices. These partnerships can foster pilot projects, joint ventures, and technology exchange in areas like alternative fuels and electrification.

Table 27 Review of Global Green Funding Platforms in the Indian context

Funding Agency	**Scope**	**Areas for Collaboration**	**Reasoning**
Asian Development Bank (ADB)	Green infrastructure, port electrification, renewable energy integration	Electrification of ports and inland waterways; development of hybrid logistics systems	ADB has a strong focus on sustainable infrastructure in developing countries, including India's ongoing green corridor projects.
World Bank	Climate Investment Fund (CIF); renewable energy, logistics electrification	Port modernization, alternative fuel infrastructure, and inland waterway electrification	The World Bank has extensive expertise in sustainable infrastructure financing, offering grants and concessional loans.
New Development Bank (NDB)	Infrastructure development in BRICS nations	Financing of green logistics hubs and electrified multimodal networks	NDB focuses on collaborative funding among BRICS nations, making it suitable for large-scale green logistics projects in India.
Global Environment Facility (GEF)	Biodiversity conservation, international waters, and climate change mitigation	Funding alternative fuel infrastructure and port electrification	GEF's focus on climate change mitigation aligns with India's maritime decarbonisation needs, especially in ports and alternative fuels.
Green Climate Fund (GCF)	Climate mitigation and adaptation in developing countries	Development of renewable energy infrastructure at ports and alternative fuel production facilities	GCF supports large-scale climate projects, making it ideal for funding India's renewable-powered port initiatives.
International Renewable Energy Agency (IRENA)	Renewable energy investments, technology transfer	Solar and wind energy systems at ports; energy storage solutions	IRENA's expertise in renewable energy and technology transfer can accelerate India's green transition in the maritime sector.
European Investment Bank (EIB)	Concessional financing for low-carbon technologies and zero-emission vessels	Hydrogen and ammonia bunkering infrastructure; financing zero-emission ships	EIB specializes in financing cutting-edge low-carbon technologies, providing access to advanced solutions for India's maritime sector.

Japan International Cooperation Agency (JICA)	Concessional loans for sustainable infrastructure	Pilot projects for green shipping technologies and electrified ports	JICA's focus on innovative green technologies aligns with India's need for alternative fuel infrastructure and pilot projects.
International Maritime Organization (IMO)	Maritime Research Fund; Market-Based Measures (MBMs)	R&D in low-carbon technologies and capacity building	IMO initiatives provide funding and policy guidance, aligning with India's goals for equitable decarbonisation in the maritime sector.
Horizon Europe (EU)	R&D grants for innovative green technologies	Collaborative research on hydrogen-powered vessels and energy-efficient hull designs	Horizon Europe supports cutting-edge R&D initiatives, fostering collaboration between India and EU nations on green maritime solutions.
Danish Maritime Authority (Denmark)	Sustainable shipping practices, green technologies	Hydrogen bunkering pilot projects; joint ventures in green fuel technologies	Denmark's expertise in green shipping makes it an ideal partner for advancing India's maritime decarbonisation projects.

The decarbonisation of India's maritime sector is both a national imperative and a global responsibility, aligning with the International Maritime Organization's (IMO) Revised GHG Strategy 2023 and India's broader climate commitments. As a critical pillar of India's economy, the maritime sector is poised for a transformative shift towards sustainability. Achieving this transition requires a robust financial strategy that integrates innovative funding mechanisms, international cooperation, and targeted investments. This Section outlines a comprehensive framework of actionable points to finance and implement India's maritime decarbonisation strategy, highlighting the role of public and private stakeholders, research and development, and global partnerships in creating a greener and more resilient maritime ecosystem.

Establishing a National Green Maritime Fund: A dedicated National Green Maritime Fund is essential to finance decarbonisation projects across India's maritime sector. With an initial corpus of INR 50,000 crore sourced through sovereign green bonds, public sector contributions, and revenues from carbon pricing mechanisms, the fund will de-risk early investments and attract private sector participation. This initiative aims to create a reliable financial backbone for green infrastructure and technology adoption, ensuring sustainable maritime operations.

Strengthening Multilateral and Bilateral Partnerships: International cooperation is a cornerstone of India's green maritime strategy. By collaborating with Multilateral Development Banks (MDBs) like the Asian Development Bank (ADB) and the World Bank, India can secure concessional loans for port electrification and alternative fuel projects. Bilateral partnerships with agencies such as JICA (Japan) and the Danish Maritime Authority will provide access to advanced technologies and pilot project opportunities, facilitating technology transfer and innovation.

Incentive-Based Mechanisms: Encouraging private sector investments in decarbonisation requires robust incentive mechanisms. Providing tax holidays and accelerated depreciation for investments in green port and fleet modernization projects will reduce financial barriers. Additionally, introducing green port fee discounts for vessels meeting emission reduction standards will accelerate the adoption of sustainable technologies and reward environmentally responsible practices.

Developing a Comprehensive R&D Framework: Innovation is critical for scaling green technologies tailored to India's maritime sector. Establishing a Green Maritime Innovation Fund with INR 10,000 crore will support collaborative R&D in alternative fuels, energy-efficient vessel designs, and renewable technologies. Partnerships with international programs like Horizon Europe and IMO's Maritime Research Fund will further enhance India's capacity to innovate and lead in maritime decarbonisation.

Creating Infrastructure for Alternative Fuels: Building a robust supply chain for alternative fuels such as hydrogen, ammonia, and biofuels is pivotal for the transition to zero-emission shipping. Developing green bunkering facilities at major ports like JNPT and Chennai and securing funding from the Green Climate Fund (GCF) and European Investment

Bank (EIB) will lay the foundation for a sustainable alternative fuel ecosystem, aligning India with global compliance standards.

Electrifying Ports and Inland Waterways: Reducing emissions from auxiliary port operations and inland transport requires extensive electrification. Ports must transition to using shore power systems and electrified equipment, while inland waterways need hybrid and electric barges. These measures will enhance energy efficiency, decrease fossil fuel reliance, and significantly reduce the sector's carbon footprint.

Building Capacity and Training the Workforce: Equipping the workforce with the skills to manage new green technologies is essential for the success of maritime decarbonisation. Setting up green maritime training centres, supported by government funding of INR 4,000 crore, and developing specialized curricula focused on alternative fuels and renewable energy systems will ensure a skilled workforce ready to drive the transition.

Advocating for Equitable Revenue Redistribution from IMO Mechanisms: Active engagement in IMO discussions is crucial to ensure India benefits from global decarbonisation initiatives. Advocating for a fair share of revenues from Market-Based Measures (MBMs) will enable India to use these funds for infrastructure development and capacity building in developing countries, aligning international mechanisms with national priorities.

Promoting Public-Private Partnerships (PPPs): Public-Private Partnerships (PPPs) can mobilize private sector expertise and funding for decarbonisation projects. Facilitating PPPs for port electrification, alternative fuel infrastructure, and logistics modernization, coupled with government-backed guarantees to de-risk investments, will foster innovation and resource mobilization for sustainable maritime operations.

Monitoring and Evaluating Progress: Effective implementation of decarbonisation strategies requires continuous monitoring and evaluation. Establishing performance metrics for emission reductions, renewable energy adoption, and infrastructure upgrades, along with regular stakeholder reporting, will maintain accountability and enable data-driven refinements to strategies.

Financial Strategy

The transition of India's maritime sector to greener and more sustainable operations requires a robust financial plan that bridges investment requirements with sustainable financing models. This section provides a structured approach to correlate the projected investments with viable financing mechanisms while identifying gaps that necessitate government incentives or other interventions. It offers justifications for each funding requirement and outlines actionable steps to mobilize resources effectively.

Table 28 Sectoral Financial Models for Decarbonization of Indian Maritime

Investment Area	Projected Requirement (INR)	Sustainable Financing Models	Gap Funding / Incentives Required
Port Infrastructure	60,000 crore ($7.5 billion)	Green bonds, PPPs for renewable energy integration, MDB loans for electrification projects.	Government support for initial investments in shore power systems and alternative fuel infrastructure through grants and tax incentives.
Shipping Fleet Modernization	90,000 crore ($11.2 billion)	Sustainability-linked loans (SLLs), corporate green bonds, MDB funding for retrofitting and fleet renewal.	Subsidies for retrofitting older vessels and R&D grants for green vessel construction.
Logistics and Inland Waterways	30,000 crore ($3.7 billion)	MDB loans for multimodal hubs, PPPs for low-emission barge development, carbon pricing revenues.	Tax rebates for electrification of logistics equipment and hybrid barge projects.
Research and Development	23,000 crore ($2.8 billion)	Grants from government R&D funds, partnerships with international agencies, and global climate finance.	Government co-funding for R&D in alternative fuels and hull designs.
Training and Capacity Building	8,000 crore ($1 billion)	Capacity-building grants, private-sector training partnerships, MDB technical assistance programs.	Direct government funding for establishing training facilities and developing skill development curricula.
Total	211,000 crore ($26.2 billion)	Mixed financing from sustainable models combined with public sector contributions.	Structured government incentives to address gaps and de-risk early-stage projects.

Summary (V)
Financial Strategy for Future Fuel Transition of Maritime India

- The shift to green fuels and the required infrastructural upgrades entails substantial capital investments that pose a significant barrier. Producing green fuels like hydrogen and ammonia involves significant initial investments. Further, port infrastructure upgrades, estimated to cost ₹1,000 to ₹1,200 crores ($120-$145 million) per major port, aim to ensure safe handling and storage of fuels such as hydrogen and ammonia. To support the transition to green fuels, sustainable financial models are being developed worldwide, focusing on mobilizing capital, reducing risks, and incentivizing investments in green projects. These models leverage public, private, and multilateral funding sources, ensuring equitable access to financing. These include Green Bonds, PPPs, Sustainability Linked Loans and Carbin Pricing mechanisms.

Production, Infrastructure, and Investment: The strategy includes scaling up green ammonia and hydrogen with $8-10 billion investment and $1 billion for biofuels. Developing bunkering infrastructure requires $4.5-6 billion. Financial support will come from green bonds, PPP, and a Green Shipping Fund. By 2030, global investment in maritime green fuel production infrastructure is projected to exceed $100 billion.

Capacity Building and Collaboration: Maritime Energy Training Facility (METF) aims to train 10,000 personnel by 2030 in handling green fuels. Collaboration with Singapore, Japan, and Norway will help access technologies and funding. Training and capacity-building efforts are critical to achieving the skill set needed to handle an estimated 30% green fuel adoption by 2035.

Green Corridors and Fleet Modernization: India plans green corridors like the India-Singapore route and aims to develop 5 green corridors by 2035 to support zero-emission vessels. Fleet modernization includes retrofitting existing vessels, which could cost $8-15 million per vessel, and new builds optimized for green fuels, projected to account for 20-30% of new ship orders by 2040.

Chapter (VI)

Future Fuel Strategy for India

The global maritime industry is undergoing a major transformation, with a clear emphasis on sustainability and emission reduction. India, a significant player in the maritime sector, must align with these changes by adopting cleaner, sustainable fuel alternatives. The Future Fuel Strategy for Maritime India serves as a comprehensive plan to transition the Indian maritime fleet towards greener fuels, ensuring compliance with international standards, enhancing competitiveness, and supporting national environmental commitments. This strategy also supports the initiatives of the IMO Revised GHG Strategy 2023, Maritime India Vision 2030, Maritime Amrit Kaal Vision-2047 and the National Hydrogen Mission, positioning India as a proactive participant in the global move towards green shipping.

India's maritime sector is on the cusp of a transformation, with a significant focus on reducing greenhouse gas emissions and transitioning towards greener and sustainable fuel alternatives. This future fuel strategy aims to provide a comprehensive roadmap that addresses key areas such as fuel types to be adopted, investments required, regulatory interventions, and capacity-building measures necessary for a smooth and efficient transition. This strategy is aligned with international commitments like the IMO Revised GHG Strategy 2023, the Maritime India Vision 2030, and national initiatives such as the National Hydrogen Mission.

India's Climate Commitments and Performance:

India's National Commitments at COP26

At the 26th Conference of the Parties (COP26) in Glasgow, India announced the **"Panchamrit"** strategy, comprising five key commitments to combat climate change:

Non-Fossil Energy Capacity: Achieve **500 GW** of non-fossil energy capacity by **2030**. This includes capacity from renewable sources like solar, wind, and hydroelectric power. Currently, India's non-fossil fuel capacity is approximately **176 GW** as of 2024, which includes over **120 GW** from renewable energy sources.

Renewable Energy Share: Ensure **50%** of energy requirements are met from renewable sources by **2030**. India has already increased its renewable energy share to about **42%** of installed capacity as of 2024, with significant growth in solar and wind energy production.

Emission Reduction: Reduce total projected carbon emissions by **one billion tonnes** by **2030**. According to the Ministry of Environment, Forest, and Climate Change (MoEFCC), India is on track to achieve this target by implementing measures like energy efficiency improvements, afforestation, and promotion of electric vehicles.

Carbon Intensity Reduction: Lower the carbon intensity of the economy by **45%** by **2030**, compared to 2005 levels. As of 2024, India has already achieved a **35%** reduction in carbon intensity, primarily due to its growing renewable energy capacity and energy efficiency programs under the **Perform, Achieve, and Trade (PAT)** scheme.

Net-Zero Target: Achieve **net-zero emissions** by **2070**. India has launched several long-term initiatives like the **National Hydrogen Mission** and **National Action Plan on Climate**

Change (NAPCC)** to help achieve this target. The emphasis is on scaling up renewable energy, green hydrogen production, and promoting electric mobility.

These commitments were formalized in India's updated Nationally Determined Contributions (NDCs) submitted to the **United Nations Framework Convention on Climate Change (UNFCCC)**. The updated NDCs include increased renewable energy capacity, afforestation efforts, and specific measures to achieve carbon intensity reduction.

India's Climate Change Performance:

In the **Climate Change Performance Index (CCPI) 2023**, India improved its ranking to **8th place**, reflecting its enhanced climate performance and commitment to sustainability. The assessment highlighted the following:

Low Per Capita Emissions: India's per capita CO2 emissions remain at 2.4 tons, significantly lower than the global average of 4.5 tons. This low per capita emission is largely due to India's focus on renewable energy and sustainable development.

Increasing Renewable Energy Share: India ranks among the top countries in renewable energy growth, with a focus on solar power. The National Solar Mission has led to the installation of over 70 GW of solar power capacity by 2024. India aims to reach 280 GW of solar capacity by 2030, contributing to its overall target of 500 GW of non-fossil energy capacity.

The **CCPI 2023** report praised India's proactive stance on climate action, particularly its efforts to scale up renewable energy and the strong policy framework supporting emission reductions. However, it also highlighted challenges such as the need for faster implementation of green infrastructure projects and addressing air pollution from non-renewable energy sources.

Developing a Future Fuel Strategy for Maritime India

The roadmap below presents a comprehensive approach to fuel types, investments, regulatory interventions, and capacity-building measures to achieve a sustainable maritime future. This includes the adoption of an integrated and focused policy framework, identifying the right fuel mix, increasing green fuel production, developing bunkering infrastructure, establishing financial models for green transition, incentivizing green fuels, capacity building, international collaboration, developing green corridors, fleet modernization, and retrofitting initiatives.

Integrated & Focused Policy Frameworks

Integration of Sector-Specific Policies: Align all maritime stakeholders—ports, shipowners, logistics providers, fuel suppliers, and regulatory bodies—through a unified National Green Shipping Policy. This integrated framework will avoid fragmented efforts and ensure all players work towards the common goal of decarbonisation. The Green Shipping Policy should incorporate the Maritime India Vision 2030 and Maritime Vision 2047, providing a cohesive approach to sustainable growth.

Acknowledge International Policy Drivers: Adopt policies that align with international regulations set by the IMO, such as the Revised GHG Strategy 2023, to ensure that the Indian maritime sector remains competitive globally. Aligning with international frameworks like the European Union's Fit for 55 initiative and the IMO's Green Voyage 2050 will also provide economic opportunities by accessing international funding and ensuring market access for Indian vessels.

Identify and Focus on the Right Fuel

The transition to green fuels will be facilitated by using a variety of sustainable energy sources suited to the maritime sector's specific needs. The key fuel types include:

Liquefied Natural Gas (LNG): A transitional fuel expected to reach a peak share of 10% by 2030. The Petronet LNG project in Kochi and the recent expansion of LNG bunkering facilities at Hazira Port are examples of ongoing efforts to establish LNG as a key transitional fuel.

By 2030

1. Target to ensure availability of LNG Bunkering facilities at Kochi, Mundra, Dabhol, Hazira, Jafrabad, Dahej, Ennore. Other Ports may also be encouraged to develop LNG bunkering facilities.
2. Target to ensure combined bunkering capacity of LNG in India of 1 million metric tonnes per annum.

By 2030

Target to ensure availability of Green LNG or Bio-LNG at the Ports mentioned above. Capacity for the combined bunkering capacity should be 1 million metric tonnes per annum.

Methanol

i. By 2030
1. Target to ensure availability of methanol for bunkering at Kandla and Jawaharlal Nehru Port
2. Capacity of methanol bunkering targeted at 350000 metric tonnes

ii. By 2050
1. Target to ensure availability of green methanol or bio-methanol at the above-mentioned ports
2. Capacity of methanol bunkering unchanged at 350000 metric tonnes

Green Ammonia: Projected to play a significant role in long-haul shipping, with a target share of 30% by 2050. India's National Green Ammonia Mission aims to produce 3 million tons of green ammonia annually by 2035, supporting both domestic shipping and exports.

i. By 2030
1. Target to ensure availability of Ammonia as bunker at Kandla, Paradip and Tuticorin Ports

2. Target availability of ammonia bunker at 250000 metric tonnes per annum

ii. By 2050

1. Target availability of Green Ammonia as bunker at Kandla, Paradip and Tuticorin Ports. Additionally expand availability of Green Ammonia at five additional ports on the Indian Coastline
2. Target availability of Green Ammonia at 5 million metric tonnes per annum.

Hydrogen: Expected to represent 20% of the maritime fuel mix by 2050, playing a mainstream role in medium-haul and coastal shipping.

i. By 2030

1. Target to ensure availability of Hydrogen Bunker (preferably green or blue hydrogen) at Kandla, Paradip and Tuticorin Ports.
2. Target availability of Hydrogen bunker at 37000 metric tonnes per annum

ii. By 2050

1. Target to ensure availability of Green Hydrogen Bunker at Kandla, Paradip and Tuticorin Port. Additionally expand availability of Green Hydrogen at five additional ports on the Indian Coastline
2. Target availability of Green Hydrogen bunker at 272000 metric tonnes per annum

Biofuels: Suitable for coastal and inland waterways, with an estimated 8-15% share by 2050. The MoPNG's Biofuel Policy 2018 aims to blend 20% biofuels in marine fuel by 2030,

i. By 2030

1. Target to ensure availability of biofuels for bunkering at least two Indian Ports – Kochi or Kandla and Tuticorin or Vishakhapatnam
2. Target availability of biofuel bunkers at 150000 metric tonnes per annum

ii. By 2050

1. Target to ensure availability of biofuel at at least two additional ports (one on the west coast and one on the east coast)
2. Target availability of biofuel bunkers at 900000 metric tonnes per annum.

Carbon Capture:

Develop onshore carbon dioxide reception facilities (annual capacity of 13 million tonnes by 2050) at Ports.

Nuclear:

Initiate research into possibility of using nuclear propulsion or shore power supply using nuclear energy generation onshore (considering 2025 budget provisions of Government of India for Nuclear Energy)

Table 29 Identifying Green Fuel Mix for Maritime India

Fuel Type	Role	Target Share in Fuel Mix	Rationale of Projection	Sources of Information
Liquefied Natural Gas (LNG) or CNG, Liquefied Petroleum Gas	Transitional fuels to bridge the shift from conventional marine fuels to zero-emission alternatives	**40% by 2030**, and decline to **15%** by 2050	Lower greenhouse gas emissions compared to heavy fuel oil, effective for establishing early bunkering infrastructure	Future Fuel Mix Forecast is based upon projections by International Energy Agency. (Please see Chapter II for additional details)
Methanol	Transition to bridge the period between conventional marine fuels and zero carbon fuels such as ammonia and hydrogen	**3% by 2050**	Green methanol can significantly reduce emissions. Engines capable of using methanol are commercially available.	
Green Ammonia	Significant role in long-haul shipping	**44% by 2050**	Carbon-free, high-energy density, suitable for large vessels. Potential to leverage renewable energy for production	
Hydrogen	Mainstream fuel for medium-haul and coastal shipping	**19% by 2050**	High energy efficiency, potential for domestic production through renewable sources	
Biofuels	Suitable for coastal and inland waterways, particularly for smaller vessels	**19% by 2050**	Domestic production, compatible with existing internal combustion engines, cost-effective for retrofitting	
Carbon Capture	Considering the focus this technology is obtaining worldwide; India needs to target an annual carbon dioxide reception facility of 13 million tonnes annually	**-**	No emissions of carbon dioxide obtained from combustion of fuels. Ships can also operate on conventional fuels. The carbon dioxide received onshore at Ports can be used to develop synthetic fuels or be used in other industrial applications	
Nuclear	Considering the focus this technology is obtaining globally in the world and in maritime, a roadmap on this technology would be desirable	**-**	Clean source of energy. Bunkering of ships installed with nuclear power may not be frequently needed during the lifetime of the ship.	

Increasing Green Fuel Production

Green Ammonia and Hydrogen Production: Establish large-scale production facilities for green ammonia and hydrogen with investments driven by renewable energy. Reliance Industries' $10 billion green hydrogen project in Jamnagar aims to produce green hydrogen at $1 per kg by 2030, making it globally competitive. Expansion of renewable energy capacity, such as the 30 GW renewable energy park in Kutch, will provide the electricity required for hydrogen production.

Biofuel Production: Boost biofuel production through collaboration with the Ministry of Agriculture for a consistent biomass supply, with incentives for farmers contributing agricultural residues. The Ethanol Blended Petrol (EBP) program, which targets a 20% ethanol blend by 2025, can be extended to marine fuels with biofuel hubs set up in coastal states like Maharashtra and Tamil Nadu.

R&D Investment: Allocate $500 million to improve fuel storage, bunkering safety, and fuel cell efficiency, with collaboration from international partners like Japan and Denmark. The Indian Institute of Science (IISc) and IIT Bombay are currently leading research projects in hydrogen storage and fuel cell development.

Develop Bunkering and Supply Chain Infrastructure for Green Fuels

Develop bunkering capabilities for LNG, hydrogen, ammonia, and biofuels at key ports, such as Mumbai, Chennai, Kochi, Mundra, Kandla, and Paradip. The LNG bunkering facility at Ennore Port, with a capacity of 5 million metric tonnes per annum, is a prime example of infrastructure expansion to support green shipping.

Establish **multi-fuel capabilities** at bunkering stations for fuel flexibility, ensuring ports can adapt as new technologies emerge. Ports such as Mundra and Kandla are being upgraded with ammonia and hydrogen bunkering facilities.

Integrate specialized storage facilities, adhering to international safety standards, and efficient transportation networks to distribute green fuels from production sites to ports. The proposed hydrogen pipeline from Jamnagar to Hazira will play a critical role in transporting hydrogen to key maritime hubs.

Encourage **Public-Private Partnerships (PPP)** for infrastructure development, providing financial incentives to promote private participation. Singapore-based Pavilion Energy's joint venture with Indian Oil Corporation to develop LNG bunkering infrastructure in Chennai is an example of leveraging PPPs.

Designate Kochi, Kandla and Tuticorin Ports to install facilities pertaining to liquid carbon dioxide reception from ships with total capacities of 6 million metric tonnes by 2030 and

15 million metric tonnes by 2050. Carry out feasibility studies for Synthetic Fuel Production plant close to Kochi, Kandla or Tuticorin Ports.

Establish Financial Models for Green Transition

Approximate the total costs for fleet renewal, infrastructure development, and green fuel production to be around $30-40 billion over the next 25 years.

Establish a **Green Shipping Fund** for loans and grants to support the green transition, using diverse funding sources like green bonds and climate finance. For instance, India can replicate the model of Norway's NOx Fund, which uses levies from polluting activities to provide subsidies for green initiatives.

Introduce financial models inspired by global best practices, such as the European Investment Bank's (EIB) Green Bonds program and Singapore's PPP initiatives to finance green port and fleet infrastructure.

Incentivize Production and Usage of Green Fuels

Offer **direct financial incentives** such as capital subsidies of up to 30% for setting up green fuel production plants and **production-based incentives (PBIs)** for green fuel production. The Central Government can offer similar benefits as those provided in the Production Linked Incentive (PLI) scheme for solar manufacturing.

Implement tax holidays for 10 years and import duty exemptions for companies involved in green fuel production and retrofitting existing vessels. The Ministry of Finance's recent amendments for reducing GST on green technologies can be expanded to support maritime fuel technologies.

Provide reduced port fees (up to 30%) and priority berthing for green vessels at key ports like Mumbai, Mundra, and Chennai. The Port of Rotterdam has used similar incentives successfully, increasing the uptake of LNG and biofuels among vessel owners.

Capacity Building

Establish a **Maritime Energy Training Facility (METF)** to train seafarers and maritime personnel on handling new fuels like LNG, green ammonia, and hydrogen. The METF will target training 10,000 personnel by 2030, leveraging existing infrastructure at the Indian Maritime University (IMU) campuses in Mumbai and Chennai.

Collaborate with Singapore's Green Fuel Training Centre for technical and knowledge exchange, ensuring that Indian seafarers are trained to international standards. This collaboration will include joint certification programs and exchange of instructors.

Collaborate Internationally

Develop partnerships with countries like Japan, Norway, and Singapore to leverage advanced technologies for green fuels and bunkering infrastructure. The Indo-Danish Centre of Excellence in Green Shipping, established in collaboration with Denmark, will focus on developing best practices for hydrogen and ammonia bunkering.

Participate in international initiatives like IMO's GreenVoyage2050 and the **Getting to Zero Coalition** to facilitate technology sharing and secure funding. India can collaborate with the World Bank's Carbon Offset and Reduction Scheme for International Aviation (CORSIA) to explore similar models for maritime emissions.

Develop Green Corridors in India

Establish **Green Corridors** on key international trade routes, such as the India-Singapore route, with green fuel bunkering infrastructure, financial incentives for green vessels, and industry collaboration. The India-Singapore Green Corridor project, in collaboration with the Maritime and Port Authority of Singapore (MPA), aims to establish LNG and ammonia bunkering stations by 2026.

Initiate pilot projects to assess the feasibility of green corridors and leverage international funding to support their development. Pilot projects on the India-UAE and India-Sri Lanka routes will help gather data and create a scalable model for other routes.

Fleet Modernization

Replace outdated vessels with new, green fuel-compatible ships, focusing on enhancing operational efficiency, compliance, and emission reduction. The Government's Sagarmala Programme includes provisions for financial assistance of up to 50% for ship-owners investing in green vessels.

Use incentives to encourage ship-owners to replace older vessels and invest in **new builds** capable of using LNG, hydrogen, or ammonia. The Shipping Corporation of India (SCI) is currently building two LNG-powered vessels in collaboration with Cochin Shipyard Limited, setting an example for fleet modernization.

The Directorate General of Shipping (DGS) in India has taken progressive steps towards fleet modernization by issuing **DGS Order No. 06 of 2023**, which prescribes age norms for vessels operating under the Indian flag. This order aims to phase out older, less efficient vessels and promote the acquisition of newer, fuel-efficient ships that align with India's decarbonisation goals.

Aspect	Cost/Benefit	Description
Capital Investment	Cost	Estimated at **$50-70 million per vessel**, depending on the type of fuel system and vessel size.
Fuel Efficiency	Benefit	New vessels using LNG, hydrogen, or ammonia can achieve **30-40%** improvement in fuel efficiency compared to traditional vessels.
Emission Reductions	Environmental Benefit	CO2 emissions reduced by up to **90%** depending on the green fuel used, with zero emissions for hydrogen and ammonia.
Operational Cost Savings	Benefit	Reduced fuel costs, as well as lower maintenance requirements, can lead to **20-30%** savings in operational expenses over the vessel's lifecycle.
Compliance and Market Access	Benefit	New builds designed to meet **IMO's 2050 net-zero targets** ensure compliance with international standards and unrestricted access to global trade routes.
Longevity and Lower Risks	Benefit	New vessels have a longer operational life, estimated at **25-30 years**, and offer reduced risks of breakdowns and higher safety standards.
Reduced Maintenance Costs	Benefit	New vessels equipped with advanced systems have **15-20%** lower maintenance costs compared to retrofitted or older vessels.

Table 30 Cost vs Environmental Benefits of Fleet Modernization

Retrofitting Engines for Green Fuels

Retrofitting offers a cost-effective solution for transitioning existing vessels to green fuels. Focus on LNG, hydrogen, and ammonia retrofits to ensure significant emission reductions while extending the operational life of existing vessels. Retrofitting projects like the ONGC's conversion of offshore supply vessels to LNG are setting an example for the industry.

Develop retrofitting capabilities within Indian shipyards to minimize dependency on foreign expertise, create jobs, and promote cost-effective green transition services. Cochin Shipyard has recently established a retrofitting division to focus on green fuel conversion.

Upgrading Port Infrastructure for Green Ships

LNG, Hydrogen, and Ammonia Bunkering: Ports will be upgraded to include facilities for LNG, hydrogen, and ammonia bunkering. Ennore Port and Kandla Port are leading these upgrades, with an estimated investment of $500 million to establish bunkering infrastructure for multiple green fuels.

Shore **Power and Electrification**: Implement shore power infrastructure at major ports to reduce emissions from docked vessels. Shore power facilities, or cold ironing, will be installed at Mumbai and Chennai ports by 2027, providing clean electricity to vessels while in port.

Operational Efficiency: Electrify cargo-handling equipment and introduce automation to improve operational efficiency at ports. Mundra Port has initiated an electrification project for its rubber-tired gantry cranes (RTGs), replacing diesel engines with electric motors, thereby reducing emissions by 30%.

Establish Robust Regulatory Frameworks

Fuel Standards and Life Cycle Assessment: Establish stringent fuel standards and adopt Life Cycle Assessment methodologies to evaluate environmental impacts. Safety Standards and Lifecydcle Assessment Methodology for use of alternative fuels to be developed taking into account international standards/guidelines being developed by IMO.

Bunkering Guidelines and Safety Standards: Develop guidelines for safe bunkering of methanol, hydrogen, ammonia, and other alternative fuels.

Seafarer Training and Certification: Align seafarer training programs with IMO's standards for handling green fuels. Training modules will be introduced at maritime institutes, including Indian Maritime University, focusing on the safe handling, and bunkering of hydrogen and ammonia.

Active Involvement in International Regulatory Developments: Participate in the development of international regulations, including Market-Based Measures and IMO safety guidelines. India will actively participate in IMO's Intersessional Working Groups to ensure its interests are represented in the development of green fuel regulations.

Cohesive National Framework: Align sectoral policies like the National Hydrogen Mission and Biofuel Policy under a cohesive national framework. The National Green Shipping Council, to be constituted under the MoPSW, will oversee the alignment of various policies to ensure consistency in implementation.

Monitoring and Review of Future Fuel Strategy

IMO Data Collection System (DCS): Implement a national data collection system for monitoring emissions and fuel usage. This system will be modelled after the IMO's DCS and will require shipowners to report fuel consumption data, helping in tracking emissions reductions.

Port Emission Inventories: Develop an inventory of emissions from major ports to monitor and manage emission reduction initiatives. The emission inventories will be used to benchmark port performance and identify opportunities for further reductions.

Green Port Indexing: Introduce a Green Port Index to rank ports based on sustainability efforts and incentivize green initiatives. Ports will be ranked annually, and top performers will receive financial incentives and recognition to encourage competition in green initiatives.

Real-Time Monitoring Systems: Use digital platforms for real-time monitoring and data sharing to enhance transparency. The National Maritime Digital Platform, being developed by the Directorate General of Shipping, will integrate real-time data from vessels and ports for monitoring compliance with green targets.

Regular Reviews and Feedback: Conduct annual reviews to evaluate progress, with adjustments to policies based on stakeholder feedback. A committee comprising members from MoPSW, shipping companies, shipyards, classification societies and maritime universities will review the implementation of the roadmap and recommend improvements.

Centralized Monitoring Agency: Establish a centralized agency to coordinate data collection, policy implementation, and stakeholder collaboration. The Green Shipping Monitoring Agency (GSMA) will be responsible for tracking the progress of green fuel adoption, infrastructure development, and emissions reductions across the maritime sector.

Setting Timelines for Roadmap of Future Fuel Strategy

The maritime industry is undergoing a major transformation as nations around the world take concerted actions to decarbonize their fleets and reduce greenhouse gas emissions. As one of the largest maritime nations, India is poised to lead this change by establishing a robust and sustainable future fuel strategy for its maritime sector. This roadmap outlines a comprehensive plan to transition India's maritime industry to greener, low-emission fuels, thereby aligning with the Maritime India Vision (MIV) 2030 and Maritime Vision 2047 (MAKV 2047). The roadmap is structured into short-term, medium-term, and long-term timelines to ensure a systematic and targeted approach to achieving sustainability goals, supporting economic growth, and maintaining international competitiveness. Each phase of the strategy focuses on key initiatives, such as policy development, green fuel production, fleet modernization, bunkering infrastructure, financial models, and international collaboration.

Table 31 Timelines for Roadmap of Future Fuel Strategy

Phase	Timeline	Key Actions
Policy Framework Development	2025-2030	• Formulate National Green Shipping Policy integrating Maritime India Vision 2030, IMO Revised GHG Strategy 2023, and the National Hydrogen Mission. • Conduct stakeholder workshops to align efforts across ports, shipowners, fuel suppliers, and regulatory bodies. • Finalize sectoral action plans ensuring policy coordination. • Identify specific projects, such as integrated regulatory frameworks and digital compliance systems, to streamline green fuel adoption.
Regulatory Framework Development	2025-2030	• Develop and implement regulatory standards for green fuel adoption, aligning with international regulations and IMO guidelines. • Establish emissions control standards and compliance mechanisms for green fuels. • Collaborate with state and central authorities to ensure alignment across regulatory bodies.
Identify Fuel Mix	2025-2047	• Pilot LNG bunkering infrastructure at key ports like Mumbai, Chennai, and Kochi as a transitional fuel by 2026. • Initiate green ammonia production by collaborating with renewable energy producers. • Increase hydrogen adoption for medium-haul and coastal shipping by 2030, targeting a 20% fuel mix share by 2040. • Develop domestic biofuel production capabilities, targeting 8-15% of the maritime fuel mix by 2047. • Phase out LNG by 2047 in favour of green ammonia, which is expected to constitute 30% of the fuel mix.

		• Highlight specific production models, such as public-private partnerships (PPP) for LNG and green hydrogen infrastructure.
Green Fuel Production	2025-2040	• Collaborate with the Ministry of Agriculture to ensure a consistent biomass supply for biofuel production. • Target $1 billion investment in biofuel facilities by 2028. • Develop green hydrogen and ammonia production plants using renewable energy-driven electrolysis, with a targeted investment of $5 billion for hydrogen production and $3 billion for ammonia synthesis facilities by 2040. • Highlight the expansion of renewable energy hubs in Gujarat, Tamil Nadu, and Rajasthan to support hydrogen and ammonia production. • Leverage technology transfer agreements with countries like Japan and Denmark to accelerate green hydrogen production.
Bunkering & Supply Chain Infrastructure	2025-2040	• Identify key ports (Mumbai, Chennai, Kochi, Mundra, Kandla, Paradip) for green fuel bunkering facilities. • Establish LNG bunkering infrastructure by 2028, with an investment of $1.5-2 billion. • Develop hydrogen and ammonia terminal infrastructure at selected ports by 2030, requiring $3-4 billion in investment. • Implement multi-fuel bunkering capabilities to support LNG, hydrogen, ammonia, and biofuels by 2040. • Highlight strategic port selection criteria, public-private collaboration models, and the use of digital platforms for real-time supply chain monitoring.
Upgradation of Ports	2025-2040	• Upgrade port infrastructure to handle green fuels, including LNG, hydrogen, and ammonia by 2030. • Implement energy-efficient technologies in port operations to reduce emissions. • Establish shore-to-ship power supply systems to reduce emissions from ships at berth. • Highlight specific ports for infrastructure development and timeline for phased upgrades.
Financial Models for Green Transition	2025-2040	• Establish a Green Shipping Fund by 2026 to offer low-interest loans, grants, and subsidies for green projects. • Issue green bonds for funding infrastructure projects like bunkering facilities and production plants. • Introduce a carbon credit trading system by 2030 to incentivize emission reductions. • Strengthen Public-Private Partnerships (PPP) to mobilize investments for fleet modernization, bunkering infrastructure, and green fuel production. • Highlight specific financial models, such as Norway's NOx Fund and Singapore's PPP model, to provide guidance for India's initiatives.

Incentives for Green Fuel	2025-2030	• Introduce tax holidays for companies involved in green fuel production by 2025. • Provide import duty exemptions for green technology related to hydrogen and ammonia production by 2026. • Roll out financial incentives, such as grants for bunkering infrastructure development and reduced port fees for green vessels by 2028. • Offer priority berthing for vessels using green fuels by 2030. • Highlight successful international incentive models, such as Germany's Renewable Energy Sources Act (EEG) and Norway's NOx Fund.
Capacity Building & Training	2025-2030	• Establish the Maritime Energy Training Facility (METF) by 2025 in collaboration with the IMO to train personnel on handling green fuels, including LNG, hydrogen, and ammonia. • Train 3,000 maritime personnel through METF by 2027, and expand training to 10,000 personnel by 2030. • Upgrade maritime training institutes, such as the Indian Maritime University (IMU), for hands-on training in alternative fuel systems. • Highlight collaborations with Singapore's Green Fuel Training Centre and initiatives to develop joint training programs with international partners.
Green Corridor Development	2025-2040	• Pilot the India-Singapore Green Corridor by 2025 to demonstrate the feasibility of green shipping routes. • Expand green corridor initiatives to include routes to Sri Lanka, UAE, and Southeast Asia by 2028. • Develop domestic green corridors by 2040, focusing on key coastal and inland routes. • Highlight collaboration models with partner nations, public-private investments in green fuel infrastructure, and international funding opportunities, such as the Green Climate Fund.
Fleet Modernization	2025-2047	• Prioritize new builds for hydrogen and ammonia readiness, targeting 40% fleet replacement by 2040. • Achieve 70% fleet compatibility with green fuels by 2047. • Highlight projects such as government-backed fleet modernization grants and collaboration with global shipyards for technology transfer.
Retrofitting of Engines	2025-2047	• Begin retrofitting vessels to LNG by 2026, investing $1-5 million per vessel to reduce emissions while extending operational life. • Retrofit existing vessels to be compatible with hydrogen, methanol, and ammonia by 2040. • Leverage incentives and grants to support retrofitting projects across the fleet.
International Collaboration	2025-2040	• Establish bilateral agreements with Denmark, Japan, and Singapore for technology transfer, capacity building, and infrastructure development by 2025.

		• Participate in international initiatives like IMO GreenVoyage2050 and establish joint research projects by 2030. • Leverage international funding to develop bunkering infrastructure and enhance collaboration on green maritime routes. • Highlight specific agreements, partnerships with international maritime technology leaders, and shared R&D initiatives.
MRV System Development	2025-2030	• Establish Monitoring, Reporting, and Verification (MRV) systems to track emissions by 2026. • Implement digital tracking and real-time data integration across green corridors by 2030 to optimize operations and reduce emissions. • Highlight the use of digital technologies, such as IoT sensors and block chain, to facilitate real-time monitoring and compliance.

Key Milestones

Table 32 Key Milestones

Year	Milestones
2025-2030	✓ National Green Shipping Policy formulated. ✓ LNG bunkering projects initiated. ✓ METF establishment completed. ✓ Integrated policy framework implemented. ✓ Green corridor pilot launched. ✓ Hydrogen production expanded. ✓ Integrated supply chain infrastructure developed. ✓ Capacity building initiatives expanded. ✓ Regulatory framework established.
2031-2040	✓ Full-scale green fuel infrastructure completed. ✓ Training capacity expanded. ✓ Green corridor expansion to additional routes. ✓ PPP investments strengthened. ✓ Port infrastructure upgraded for green fuel handling.
2040-2047	✓ 70% fleet compatibility with green fuels achieved. ✓ Leadership in maritime decarbonization established. ✓ Phased-out LNG usage. ✓ Fleet retrofitting for green fuels completed.

Aligning Roadmap Milestones with National Policy Targets

The Future Fuel Strategy for Maritime India is a comprehensive plan that aligns with the **Maritime India Vision 2030 and Maritime Amritkaal Vision 2047** to ensure India's leadership in sustainable maritime practices. The roadmap has been divided into short-term (2025-2030), medium-term (2030-2040), and long-term (2040-2047) phases, focusing on key initiatives to transition towards green fuels, develop infrastructure, enhance training capabilities, and foster international collaborations. By 2047, India aims to achieve 70% fleet compatibility with green fuels, phase out LNG, and firmly establish itself as a leader in maritime decarbonisation. The strategy emphasizes a systematic and inclusive approach that brings together all stakeholders to achieve the ambitious yet crucial goal of a sustainable maritime future.

Table 33 Roadmap Timelines aligned with National Policies

Roadmap for Implementation of Future Fuel Strategy	Short-Term (2025-2030) (MIV 2030)	Medium-Term (2030-2040)	Long-Term (2040-2047) (MAKV 2047)
Policy Framework Development	Develop a comprehensive National Green Shipping Policy (2025-2026)	Formulate a unified policy framework to address fragmented efforts (2026-2030)	-
Regulatory Framework Development	Develop regulatory standards for alternative fuels and green shipping practices (2025-2027)	Enforce compliance with new regulatory standards and assess effectiveness (2030-2040)	Update and strengthen regulations to meet evolving international standards (2040-2047)
Identify Fuel Mix	LNG & Biofuel as a Transitional Fuel: Peak adoption at 10% of fuel mix (2025-2030)	Hydrogen and Ammonia Introduction: Begin adoption (2030-2040)	Focus on Green Hydrogen and Ammonia as major fuels (2040-2047)
Green Fuel Production	Develop biofuel production capabilities ($1 billion investment) (2030-2040)	Establish Green Ammonia and Hydrogen Production facilities ($5 billion investment) (2025-2035)	Expand production capacity for hydrogen and ammonia to meet future demand (2040-2047)
Bunkering & Supply Chain Infrastructure	Begin LNG bunkering infrastructure development at key ports (2025-2026)	Establish multi-fuel bunkering capabilities (2026-2030)	Complete bunkering terminals for hydrogen and ammonia (2030-2040)
Upgradation of Ports	Assess current port conditions and develop a port infrastructure upgradation strategy (2025-2026)	Implement measures for port infrastructure upgradation, focusing on green technology enhancements (2030-2040)	Conduct ongoing monitoring and invest in long-term port infrastructure resilience (2040-2047)

Financial Models for Green Transition	Establish Green Shipping Fund and Green Bonds (2025-2026)	Develop PPP model and introduce carbon credit trading (2026-2030)	Implement PBIs and tax holidays for green fuel production (2030-2035)
Incentives for Green Fuel	Introduce tax benefits for green fuel technology (2025-2030)	Provide grants for infrastructure development and capital subsidies (2030-2040)	Introduce further financial incentives to scale green fuel adoption (2040-2047)
Capacity Building & Training	Establish Maritime Energy Training Facility (METF) (2025-2026)	Partner with Singapore's Green Fuel Training Centre and develop vocational programs (2026-2030)	Expand training programs to include new green fuel technologies (2040-2047)
Green Corridor Development	Identify and implement pilot projects along strategic green corridors (2025-2028)	Expand green corridors to other routes, including India-Singapore route (2028-2035)	Establish additional green corridors to promote low-emission shipping (2040-2047)
Fleet Modernization	Implement DGS Order No. 06 of 2023 for fleet modernization (2025-2030)	Continue fleet modernization with new builds ($50-70 million per vessel) (2035-2040)	-
Retrofitting of Engines	Retrofitting existing vessels for LNG, hydrogen, and ammonia (2026-2035)	-	-
International Collaboration	Establish technology transfer agreements (2025-2026)	Develop Indo-Ocean Centre of Excellence for Sustainable Maritime Transport (2026-2030)	Secure funding from global bodies like GCF and World Bank (2030-2035)
MRV System Development	Establish a monitoring system for tracking fuel adoption and emissions reduction (2025-2027)	Conduct regular reviews to evaluate the progress of the Future Fuel Strategy (2030-2040)	Implement advanced monitoring technologies and refine targets based on data (2040-2047)

Conclusion

The Future Fuel Strategy for Maritime India is an ambitious plan to establish India as a global leader in green maritime technology, driving sustainable transformation in the sector by implementing specific, time-bound measures. The strategy focuses on transitioning the fuel mix, developing green fuel production capabilities, upgrading port infrastructure, and establishing green corridors to ensure a cohesive transition. The roadmap, with clearly defined timelines, sets milestones for policy development, regulatory frameworks, financial models, and international collaboration, covering the period from 2025 to 2047. The short-term actions (2025-2030) prioritize policy formation, LNG adoption, green bunkering infrastructure, and incentives for early adopters of green technologies. In the medium term (2030-2040), the emphasis is on hydrogen and ammonia adoption, port infrastructure upgrades, multi-fuel bunkering, and capacity building, while long-term initiatives (2040-2047) focus on establishing advanced monitoring systems and expanding the adoption of green hydrogen and ammonia.

The strategy also highlights significant steps to enhance the existing maritime infrastructure, such as modernizing the fleet through the implementation of DGS Order No. 06 of 2023, retrofitting engines to accommodate alternative fuels, and ensuring the continuous upgradation of ports with a focus on green technology. Capacity building and training are essential components, with initiatives such as the establishment of the Maritime Energy Training Facility (METF) and partnerships with Singapore's Green Fuel Training Centre to train maritime personnel. A critical component of the roadmap is the development of green corridors, starting with the India-Singapore route, to foster low-emission maritime transport and enhance India's standing in sustainable international shipping.

In terms of financial support and incentives, the strategy introduces various funding mechanisms, such as the Green Shipping Fund, green bonds, public-private partnerships (PPPs), and tax benefits to encourage early adoption of green fuel technologies. Additionally, the strategy aims to secure international collaboration for technology transfer and financial support from global bodies like the Green Climate Fund (GCF) and the World Bank. The Monitoring, Reporting, and Verification (MRV) system will be developed to track progress, refine targets, and ensure adherence to international standards throughout the transformation. By following this detailed roadmap, India aims to achieve a significant reduction in greenhouse gas emissions, positioning itself at the forefront of the global green shipping movement by 2047.

Summary (VI)
Roadmap for Future Fuel Strategy for Maritime India

India's maritime sector aims to transition to green fuels, aligned with the **IMO Revised GHG Strategy 2023**, **Maritime India Vision 2030**, and the **National Hydrogen Mission**. The strategy integrates policy frameworks, green fuel production, bunkering infrastructure, financial models, incentives, capacity building, international collaboration, and fleet modernization.

Policy Framework and Fuel Mix

- **National Green Shipping Policy**: Aims to align ports, shipowners, and regulatory bodies for decarbonization, following international standards.
- **Fuel Mix by 2050**:
    - **Fossil Fuels including LNG/LPG**: 15% Share by 2050.
    - **Methanol: 3% share by 2050**
    - **Green Ammonia**: **44% share** for long-haul shipping.
    - **Hydrogen**: **19% share** for medium-haul and coastal routes.
    - **Biofuels**: **19% share** for coastal and inland waterways.

Green Fuel Production and Infrastructure

- **Green Hydrogen**: **$10 billion** investment by Reliance to produce hydrogen at **$1/kg** by **2030**.
- **Biofuels**: Collaboration with the Ministry of Agriculture to ensure biomass supply, creating biofuel hubs.
- **Bunkering Infrastructure**: Multi-fuel bunkering at ports at strategic locations, with **$4.5-6 billion** investment in ammonia and hydrogen facilities.
- **Carbon Dioxide Reception Facilities (13 million tonnes annually by 2050)**
- **Pilot Project for production of Synthetic Fuels**

Financial Models, Incentives, and Capacity Building

- **Investment**: Estimated **$30-40 billion** for fleet renewal and green fuel production over 25 years.
- **Incentives**: **Capital subsidies up to 30%**, tax holidays, and reduced port fees.
- **Capacity Building**: **Maritime Energy Training Facility (METF)** to train **10,000 personnel by 2030** on LNG, hydrogen, and ammonia.

Green Corridors and Fleet Modernization

- **Green Corridors**: Establish key routes like **India-Singapore**, with pilot projects for **India-UAE** and **India-Sri Lanka**.
- **Fleet Modernization**: Retrofitting vessels for green fuels and building new, green-compatible ships.

Regulatory and Monitoring Framework

- **Regulatory Standards**: Develop fuel and bunkering standards for hydrogen and ammonia.
- **Emissions Monitoring**: Implement real-time systems and conduct annual reviews to track progress.

Implementation Timeline

- **Short-Term (2025-2030)**: Policy formation, LNG adoption, green infrastructure, capacity building.
- **Medium-Term (2030-2040)**: Expand hydrogen and ammonia adoption, green corridor development.
- **Long-Term (2040-2047)**: Scale up hydrogen and ammonia use, phase out LNG, enhance monitoring systems.

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