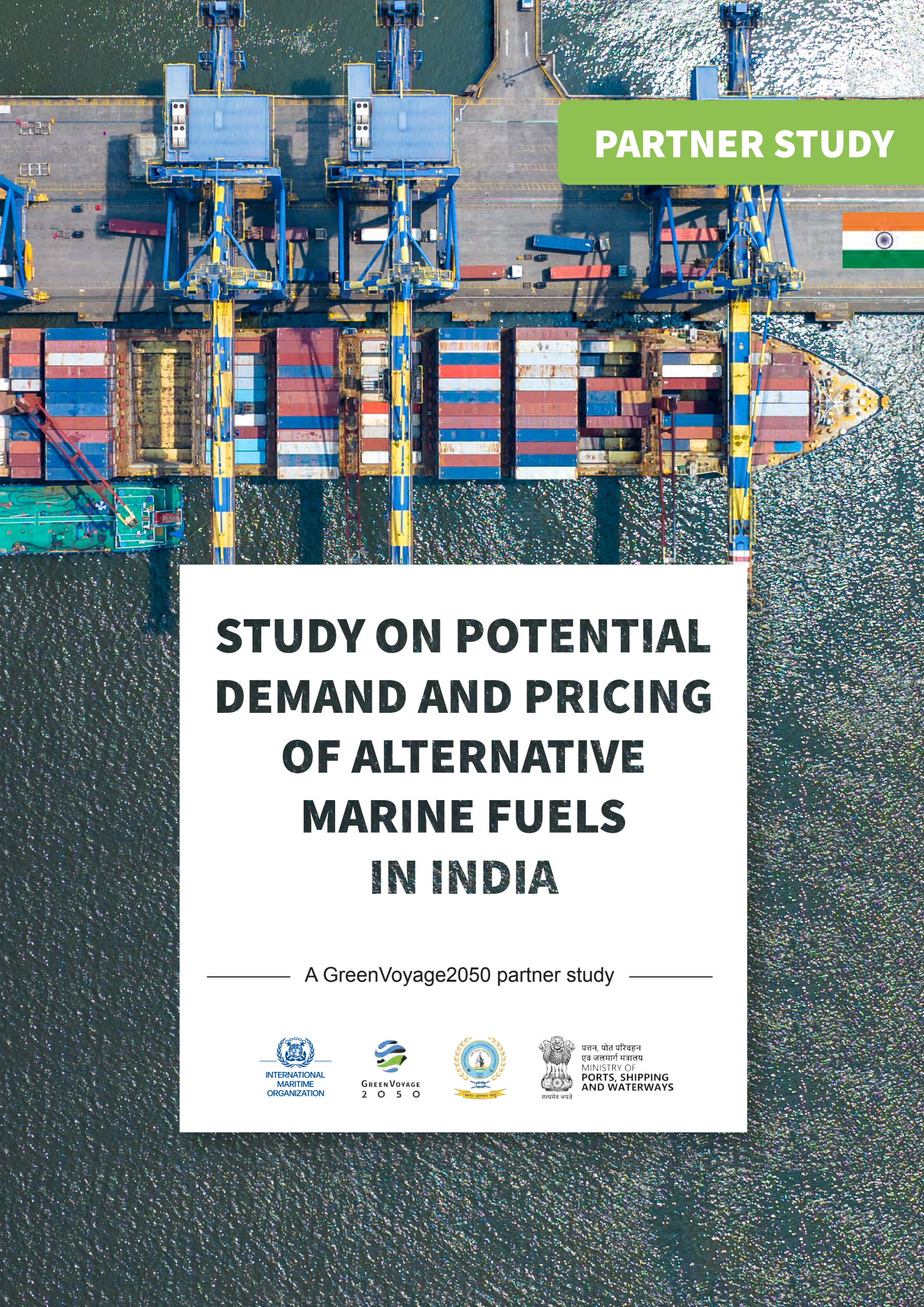




PARTNER STUDY

STUDY ON POTENTIAL DEMAND AND PRICING OF ALTERNATIVE MARINE FUELS IN INDIA

———— A GreenVoyage2050 partner study ————



पत्तन, पोत परिवहन
एवं जलमार्ग मंत्रालय
MINISTRY OF
PORTS, SHIPPING
AND WATERWAYS

At a glance

Study on Potential Demand and Pricing of Alternative Marine Fuels in India

Introduction

India is strategically located along major East–West shipping routes and has significant renewable energy, biomass, and alternative fuel production potential. However, India currently accounts for a relatively small share of international bunkering, with around 2.25 million tonnes of bunker sales in 2024. This highlights a significant opportunity for India to capture a larger share of the regional bunkering market.

About the Study

The study assessed the potential demand, pricing and competitiveness of alternative marine fuels in India and explored how the country could position itself as a regional bunkering hub for low- and zero-carbon marine fuels.



Key findings



Potential alternative fuel demand is significant, especially from container vessels

Demand is expected to come primarily from vessels already calling at Indian ports, and could reach 42–65 PJ by 2035 and 113–293 PJ by 2047.



Initial demand is likely to concentrate at a few ports

Initial demand is expected around major gateways, particularly Mundra, JNPT, Chennai, and Tuticorin, supported by nearby hydrogen hubs. Focusing early investment there can help achieve the scale needed for cost competitiveness.



Cost competitiveness is crucial

India can compete regionally across all major alternative fuel pathways, and recent renewable ammonia auctions have already reached prices within the study's estimated competitive range for 2035. However, competitiveness will ultimately depend on delivered fuel prices, supported by efficient logistics, predictable port charges and reliable bunkering operations.

Recommendations: A phased approach

PHASE 1 Establish

2026 - 2030

Establish alternative fuel bunkering at a small number of ports with strong container traffic. Methanol is the most suitable starting fuel, with a potential first pilot at Mundra, supplied from Deendayal (Kandla), before expanding to the other main gateways.

PHASE 2 Scale

2030 - 2035

Expand successful pilots to include additional ports and linking services. Begin preparations for ammonia bunkering, including through the development of safety guidance and port-specific feasibility assessments.

PHASE 3 Position

2035 - 2047

Strengthen India's long-term competitiveness and establish its position as a regional bunkering hub. Develop multi-fuel bunkering capability at ports with sustained demand and connect Indian ports with regional and global green shipping corridors.

About GreenVoyage2050 Programme

GreenVoyage2050 is the International Maritime Organization's flagship technical cooperation programme supporting developing countries in turning the ambitions of the 2023 IMO GHG Strategy into practical action.

Now in its second phase (2024–2030), the programme supports countries through technical assistance, policy development, capacity-building and pilot initiatives aimed at reducing greenhouse gas emissions from shipping and advancing maritime decarbonization.

The GreenVoyage2050 Programme is technology- and fuel-neutral, responding to requests for technical assistance in response to annual open calls for expression of interest to participate in the Programme.

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FINAL REPORT

Study on Potential Demand and Pricing of Alternative Marine Fuels in India

International Maritime Organisation

In partnership with: Directorate General of Shipping and Ministry of Ports, Shipping & Waterways, Government of India

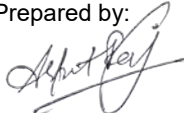
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ABBREVIATIONS

Table 1: List of abbreviations

Abbreviation	Full Form
AIS	Automatic Identification System
DGS	Directorate General of Shipping
FO	Fuel Oil
GH ₂	Green Hydrogen
GT	Gross Tonnage
HFO	Heavy Fuel Oil
IMO	International Maritime Organization
JNPT	Jawaharlal Nehru Port Trust
LCA	Life Cycle Assessment
LFO	Light Fuel Oil
LNG	Liquefied Natural Gas
MGO	Marine Gas Oil
MT	Metric Tonne
OCCS	Onboard Carbon Capture System
OECD	Organization for Economic Co-operation and Development
PJ	Petajoule
RMF	Residual Marine Fuel
TEU	Twenty-foot Equivalent Unit
UAE	United Arab Emirates
ULSFO-RM	Ultra-Low Sulphur Fuel Oil – Residual Marine
VLSFO-RM	Very-Low Sulphur Fuel Oil – Residual Marine
VOC	V.O. Chidambaranar Port Trust

1 EXECUTIVE SUMMARY

India is well placed to participate in the transition of global shipping toward low- and zero-carbon fuels. India's location along major East–West trade routes, combined with a large and growing network of ports, provides a natural advantage in supporting the bunkering of next-generation marine fuels.

At present India remains a small player in international bunkering compared with established global hubs. In 2024, Singapore recorded around **54.92 million tonnes** of bunker sales, followed by Rotterdam at **9.39 million tonnes**, Fujairah at **7.5 million tonnes**, and Zhoushan at **7.26 million tonnes**. In comparison, Indian ports bunkered roughly **2.25 million tonnes** in the same period. This shows both the scale of the current gap and the opportunity for India to build a stronger regional role over time.

Alternative fuel bunkering is also linked to India's wider energy transition. Today, India remains dependent on imported fossil fuels, including conventional marine fuels and related energy inputs. Developing domestic supply chains for low- and zero-carbon marine fuels can therefore support maritime decarbonisation while also improving energy security, creating new industrial opportunities, and using India's renewable energy potential more effectively.

However, this opportunity is not driven simply by the volume of ships passing near India. A large volume of international shipping passes close to India's coastline, but experience from global bunkering markets shows that ships rarely deviate from established routes unless price, reliability, and operational efficiency are clearly competitive. Geographic proximity alone does not translate into bunkering demand, and India will need to demonstrate that it can offer delivered fuel costs and port conditions that are comparable with, or better than, established hubs in the region.

The study therefore finds that India's most practical starting point is not passing traffic, but vessels that are already calling at Indian ports for cargo operations, particularly container vessels operating on fixed schedules. These vessels provide a predictable and scalable demand base which are among the earliest adopters of alternative fuels globally.

The assessment is based on route and port traffic analysis, baseline energy demand analysis, future fuel demand forecasting, future fuel pricing and competitiveness assessment, total cost of voyage case studies, stakeholder interviews, and a multi-stakeholder workshop used to validate key findings and recommendations.

Where will demand come from

Current fuel demand linked to Indian ports is already concentrated. More than 80% is associated with international fleets, with container vessels forming the largest share. These vessels rely on predictable turnaround times and integrated port services, which makes them more likely to bunker where they already call, rather than deviate elsewhere.

Looking ahead, demand for alternative fuels could grow significantly. Under different scenarios, it may reach around 42-65 PJ by 2035 and 113-293 PJ by 2047. In the early years, uptake is expected to be led by fuels such as biofuels and methanol, which are easier to integrate. Fuels such as ammonia are likely to play a larger role later, once supply chains, infrastructure, and safety frameworks are more established.

This demand is not expected to spread evenly across all ports. Instead, it is likely to concentrate at a few major gateways with strong cargo volumes and existing infrastructure - particularly Mundra, JNPT, Chennai, and Tuticorin. These ports can be supported by nearby production centers and hydrogen hubs such as Deendayal (Kandla) and Tuticorin, allowing supply to be organized efficiently through bunker vessels.

This concentration is important. Alternative fuel bunkering will require scale, specialised infrastructure, trained personnel, and reliable delivery systems. Attempting to spread initial investment across too many ports would increase costs and reduce the chance of building reliable services.

What will determine success

Across all scenarios, one factor stands out clearly - delivered fuel cost at the vessel is the main factor that will determine whether India is chosen as a bunkering location.

For ship operators, the decision to bunker at a port is not based on fuel price alone. It depends on the full cost and reliability of the port call, including fuel price, port charges, pilotage, towage, berth hire, deviation distance, time loss, and operational certainty. This is particularly important for container vessels, where schedule reliability is critical.

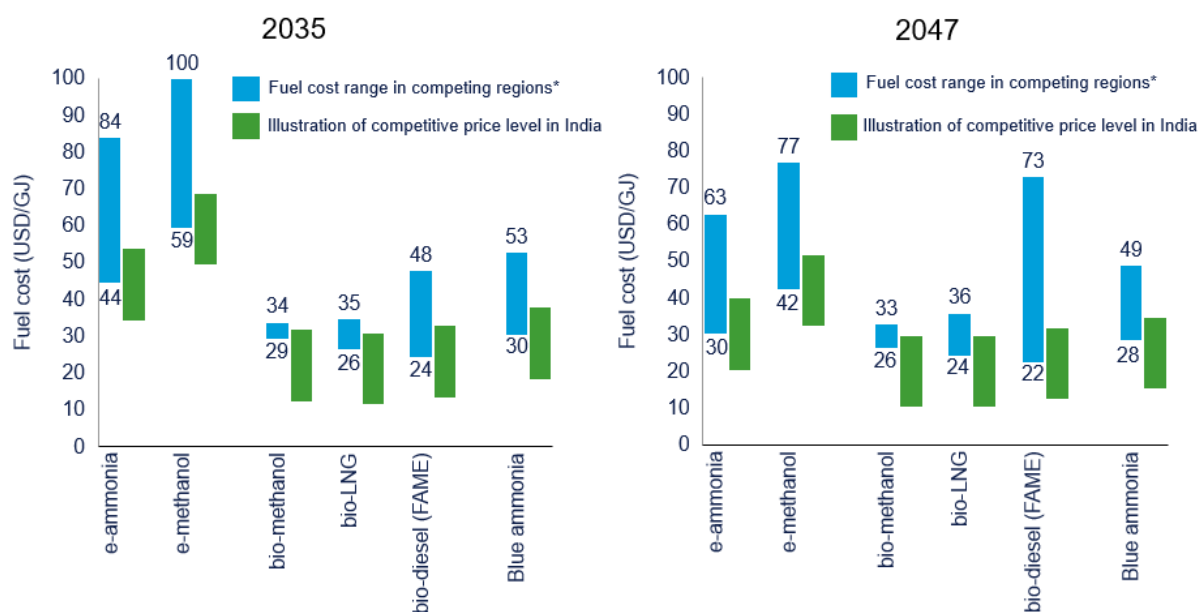
India's current competitiveness gap is significant. The report's cost comparison shows that HFO prices at Indian ports are around **USD 545/t**, compared with **USD 353/t** in Singapore. Port fees are also much higher, at around **USD 9,500-10,500 per call** in India compared with **USD 700-900 per call** in Singapore. Bunkering and operational charges are broadly comparable, but India also applies **5% GST**, while Singapore, Fujairah, and Rotterdam apply no equivalent tax in the comparison. This makes the competitiveness challenge very concrete: India does not only need competitive fuel production; it also needs lower and more predictable delivered costs at the vessel.

The future picture is more promising, but still conditional. India has strong long-term advantages for alternative fuel production, particularly through renewable electricity, biomass resources, and hydrogen-related policy support. However, these advantages will only matter for shipowners if they translate into competitive delivered prices at the vessel.

The total cost of voyage case studies show how sensitive bunkering decisions are to small price differences. For a large container vessel using bio-methanol, bunkering in India becomes attractive only if the delivered fuel cost is approximately **5.5% lower** than the competing bunkering location. In price terms, this means around **USD 30/GJ in India** compared with around **USD 32/GJ** at the competing hub.

For e-ammonia, the required price advantage is higher. The case study shows that India would need to offer e-ammonia at around **USD 51/GJ**, compared with around **USD 55/GJ** at the competing hub, equivalent to roughly **7% lower** delivered cost. These results do not mean that India cannot compete. They show what India needs to achieve: lower delivered cost, predictable port charges, reliable operations, and fuel availability at the right ports.

The below figure illustrates the price levels at which India can be competitive with regional hubs in 2035 and 2047. The shaded bands show that India can attract additional bunkering demand if its delivered fuel costs sit toward the lower end of the global ranges.



*Based on fuel cost estimates from DNV's Fuel Cost Mapper tool for Southeast Asia, Greater China, Middle East and North Africa, and the OECD Pacific region

At present, India's delivered costs are typically higher. This is not only due to fuel production costs, but also because of port dues, marine service charges, taxes such as GST, and relatively low volumes that limit economies of scale. Closing this gap will require a combination of measures on both the supply and port sides, including lowering non-fuel cost elements and enabling larger, more predictable volumes that can support investment and reduce unit costs over time.

What is holding back development

The study identifies a set of practical constraints that explain why alternative fuel bunkering has not yet moved beyond early-stage activity in India.

Demand remains uncertain and largely spot-based, making it difficult for fuel producers and infrastructure developers to commit to long-term investments. At the same time, high production costs for fuels such as e-methanol and e-ammonia keep prices above levels that shipowners are willing to accept.

On the operational side, approval processes are fragmented across multiple authorities, and there is limited clarity on safety procedures, operational standards, and responsibilities. Infrastructure investments such as storage, pipelines, and bunker vessels are capital intensive and difficult to justify without clear demand visibility.

A specific operational constraint is the limited availability of dedicated bunker vessels. Even where fuel supply and port interest exist, the absence of suitable bunker vessels can prevent pilot projects from becoming repeatable commercial services. This issue was raised repeatedly during stakeholder engagement and is important because alternative fuel bunkering will often need flexible delivery options, especially in the early stages before permanent infrastructure is fully developed.

Bunkering is also not yet fully integrated with other port services such as cargo handling, crew change, repairs, supplies, and ship services. This reduces the attractiveness of Indian ports as complete service locations, especially for liner operators that need to minimise delays and combine multiple activities within one port call.

These challenges are closely linked. Without demand, investment is delayed. Without investment, costs remain high. Without bunker vessels and clear procedures, operations remain difficult to repeat. And without competitive costs and reliable operations, demand does not materialise.

What needs to be done

To break this cycle, the study proposes a phased and practical approach, focused on building confidence step by step rather than attempting large-scale deployment from the outset.

1. Establish (2026 - 2030): Make bunkering work at a few ports

The first phase is about creating a system that works in practice at a limited number of ports with strong container traffic.

Methanol is identified as the most suitable starting fuel, reflecting both global fleet trends and early demand potential. A first pilot can be developed at **Mundra**, supported by supply from the **Deendayal (Kandla) hub**, and then extended to nearby ports such as JNPT through a hub-and-spoke model. Similar development can follow in the Chennai–Tuticorin corridor.

During this phase, India should avoid spreading effort too widely. The priority should be to prove that alternative fuel bunkering can be done safely, reliably, and competitively at selected ports. This means aligning fuel supply, storage, bunker vessel availability, port permissions, and operational procedures around a small number of initial locations.

At the same time, it is important to establish a clear national framework covering approvals, safety requirements, and operational procedures, so that projects can move forward with greater certainty. Ports should also position bunkering as part of a broader service offering, allowing vessels to combine cargo operations, bunkering, and other services within a single call.

Cost competitiveness needs to be addressed early. This includes reducing or rationalizing taxes and port charges and introducing targeted support mechanisms to help bridge the cost gap for alternative fuel production. Basic training and competency requirements should also be developed to support safe operations.

2. Scale (2030 - 2035): Expand where demand is proven

Once initial operations are established, India should scale only where demand and operational performance have been demonstrated.

The main trigger for Phase 2 should be evidence that pilot ports can deliver safe, repeatable, and commercially viable bunkering services. This would include confirmed demand from vessel operators, reliable fuel supply, functioning approval processes, trained personnel, and availability of bunker vessels.

In this phase, bunkering can expand from individual ports to regional clusters, with a West Coast cluster linking Deendayal (Kandla), Mundra and JNPT, and an East Coast cluster connecting Chennai, Tuticorin and selected bulk ports such as Paradip and Visakhapatnam, allowing shared infrastructure and logistics to improve efficiency.

Permanent storage and fuel-handling infrastructure should be developed at primary gateway ports where utilisation levels justify investment. Shared logistics, coastal fuel transport, and bunker vessel networks can support nearby ports without requiring each port to duplicate the same infrastructure.

Ammonia preparation should also begin during this phase, but in a controlled manner. DGS, with input from PESO and other relevant safety bodies, should issue interim ammonia bunkering safety and operational guidelines for **2–3 selected pilot ports**. These should cover safety distances, SIMOPS restrictions, emergency response, transfer procedures, and allocation of responsibilities between ports, bunker suppliers, and vessels. Selected ports should then conduct port-specific safety and feasibility studies to define infrastructure requirements and approval conditions before commercial ammonia bunkering is introduced.

The objective of this phase is to move from isolated pilots to stable commercial operations, while ensuring that infrastructure expansion follows proven demand.

3. Position (2035 - 2047): Build long-term competitiveness

In the longer term, India can strengthen its position by scaling successful clusters and integrating into regional and global green shipping networks.

By this stage, the earlier phases should have created operational experience, demand visibility, trained personnel, and clearer approval processes. Ports with sustained demand can then develop multi-fuel bunkering capability, including methanol, ammonia, and other emerging fuels, where demand and safety frameworks support their use.

India can also use green shipping corridors to connect its bunkering development with international trade routes and partner ports. Relevant corridor opportunities include the **Rotterdam–India–Singapore corridor**, the **Kandla–Tuticorin coastal corridor**, and the **Singapore–India Green and Digital Shipping Corridor**. These corridors can help align vessel demand, fuel supply, certification, port readiness, and commercial partnerships.

This long-term phase should be linked to the **Maritime Amrit Kaal Vision 2047**, which sets the wider national direction for India's maritime sector. By 2047, the objective should be for India to move from early alternative fuel pilots to a mature and credible regional bunkering position, supported by competitive fuel supply, reliable port operations, and multi-fuel readiness at selected hub.

Policy direction

India already has a strong policy foundation for green shipping and alternative fuels. Relevant frameworks include the Nationally Determined Contributions, National Green Hydrogen Mission, biofuel policy, green finance initiatives, Sagarmala, Maritime India Vision 2030, Maritime Amrit Kaal Vision 2047, Harit Sagar Green Port Guidelines, and competitive support mechanisms such as SECI ammonia auctions. The ongoing development of the National Green Shipping Policy also provides an important opportunity to bring these strands together into a more coordinated maritime decarbonisation framework.

The key gap is therefore not the absence of national policy direction. The next step is to translate this policy landscape into clear port-level and operational measures.

Several actions can proceed regardless of how quickly the global alternative fuel market develops. These are “no-regret” measures because they improve readiness, reduce uncertainty, and support both conventional and alternative fuel competitiveness:

- define a national approval pathway for alternative fuel bunkering projects;
- clarify SIMOPS requirements and fuel-specific bunkering safety procedures;
- rationalise GST treatment and port charges for marine fuels supplied to vessels;
- develop training and certification requirements for alternative fuel bunkering;
- enable deployment of dedicated or shared bunker vessels;
- standardise port-level operating procedures and documentation;
- improve transparency of port tariffs and marine service charges.

These actions are practical, near-term, and within India's ability to advance before large-scale demand is fully visible.

What this means for India

India does not need to compete immediately with established global bunkering hubs. Instead, it can build a competitive regional position by focusing on what it already has: strong cargo flows, strategic port locations, growing energy capabilities, and a national policy direction that supports maritime decarbonisation.



The immediate priority is to close the gap between policy ambition and port-level execution. This means making bunkering safe, predictable, cost-competitive, and repeatable at a small number of high-potential ports.

By concentrating efforts on a small number of ports, improving delivered cost competitiveness, and creating clear and predictable operating conditions, India can move from pilot projects to reliable bunkering services and over time, establish itself as a credible regional hub for alternative marine fuels.

2 INTRODUCTION

International shipping is undergoing a major transformation as the industry moves toward cleaner, low-carbon fuels. This shift is being driven by global climate commitments and tightening regulations, prompting the sector to rethink how ships are powered and how marine fuels are produced and supplied. Ports and supply chains around the world are preparing for new fuel types that differ significantly from conventional marine fuels, reshaping long-term planning for ports, fuel suppliers, and maritime authorities. In this context, India is well positioned to play an important role in the global transition. Its location on major international trade routes, combined with a large and diverse network of ports, gives India the potential to serve both international and domestic shipping. As global fuel choices diversify, this strategic position becomes increasingly important. With the right preparation, India could emerge as a key bunkering location for next-generation marine fuels, supporting global shipping routes while also contributing to India's own decarbonization goals and long-term maritime growth.

To support this opportunity, the International Maritime Organization (IMO) through its GreenVoyage2050 programme¹ and in close collaboration with India's Directorate General of Shipping (DGS) and the Ministry of Ports, Shipping and Waterways (MoPSW), commissioned DNV to study the Potential Demand and Pricing of Alternative Marine Fuels in India. This partnership brings together international expertise and national leadership to assess how India can position itself as a strategic bunkering hub for low and zero-carbon fuels along major shipping routes, particularly the Asia–Europe corridor.

India's ambition to become a regional bunkering hub for low- and zero-carbon fuels is reflected in the Maritime Amrit Kaal Vision² which sets a long term target for the maritime sector extending to 2047 and is further supported by the National Green Hydrogen Mission³. In parallel, India is also advancing the development of its National Green Shipping Policy (NGSP), which aims to provide a broader framework for strengthening the maritime sector through infrastructure development, fuel transition, financing mechanisms, regulatory measures, and skill development. Building on the country's move toward cleaner fuels for shipping, these national initiatives provide a strong basis for developing the infrastructure, regulations, and supply chains needed to support a multi-fuel future. Together, they offer an opportunity to strengthen the maritime sector, contribute to national decarbonisation goals, and support broader economic growth.

While the direction of shipping decarbonization is clear, there is still uncertainty about the level of demand that may develop at Indian ports, and the ability to supply these fuels at competitive prices. These uncertainties make long-term planning challenging for ports, fuel suppliers, and policymakers. To address this, the study provides an assessment of how alternative fuel uptake may evolve, the scale of potential demand at Indian ports, and the key factors that will shape India's competitiveness as an emerging bunkering location in the region.

The assessment is done in a structured way, where first vessel traffic patterns and cargo flow to and from India, as well as passing traffic, has been analysed to identify ports with the greatest potential for alternative fuel bunkering. A baseline energy demand estimation is analysed next to establish the current fuel demand for vessels calling at Indian ports, segmented by fleet category, size and ship type, thereby providing a reference for future fuel demand and pricing assessment. Future fuel demand forecasting is analysed next to project how demand for alternate marine fuels could evolve under different scenarios up to 2047, aligned with India's long-term maritime vision. Fuel pricing and competitiveness is then evaluated, considering expected production and supply costs for alternative fuels in India and benchmarking them against major regional bunkering hubs. Finally, an analysis of the total cost of voyage for two cases, comparing the total trip cost for selected ships bunkering in India versus other hubs.

Throughout the study, stakeholder interviews with shipping companies, fuel suppliers, port authorities, and policy makers have been conducted to validate assumptions, gather market perspectives, and ensure that recommendations reflect practical realities and industry expectations. These inputs were further complemented by a stakeholder workshop, which provided an opportunity to discuss key findings and validate the proposed approach.

¹ <https://greenvoyage2050.imo.org/>

² <https://shipmin.gov.in/en/content/maritime-amrit-kaal-vision-2047>

³ <https://mnre.gov.in/en/national-green-hydrogen-mission/>



All inputs are collated at the end to provide recommendations and actionable steps in a phased roadmap for India to position itself as a regional bunkering hub for low- and zero-carbon fuels, aligned with national policy direction and long-term targets up to 2047

3 SCOPE & METHODOLOGY

This study aims to evaluate India's potential to emerge as a regional bunkering hub for low and zero carbon marine fuels. The analysis focuses on vessel traffic connected to Indian ports, including domestic, regional, international, and nearby passing traffic, and assesses current and future fuel demand, pricing, and competitiveness of alternative fuels in the Indian context.

The scope has been refined in consultation with the International Maritime Organization (IMO), the Directorate General of Shipping (DGS), and the Ministry of Ports, Shipping and Waterways (MoPSW), with particular emphasis on passing traffic, the role of hydrogen hubs in supporting future fuel supply, and the impact of bunkering decisions on voyage costs.

The study uses both data analysis and stakeholder inputs to assess demand, pricing, and operational aspects of alternative fuels.

3.1 Approach

The assessment is carried out through a structured set of analytical steps:

1. **Route analysis:** Review of vessel traffic to and from India, including passing traffic with potential to bunker.
2. **Baseline energy demand:** Estimation of current fuel use associated with vessels calling at Indian ports.
3. **Future fuel demand forecasting:** Development of scenarios for alternative fuel demand up to 2047.
4. **Fuel pricing and competitiveness:** Assessment of future alternative fuel pricing and competitiveness of India
5. **Total cost of voyage assessment:** Assessment of voyage cost implications of bunkering in India for selected vessel types in comparison to other regional hubs
6. **Recommendations and roadmap:** Development of recommendations and a long-term roadmap for India
7. **Stakeholder interviews and workshop:** Engagement with shipowners, ports, fuel suppliers and policymakers to validate assumptions, understand operational realities, and align analytical outputs with market expectations

Detailed methods, assumptions, and supporting analysis are provided in the relevant chapters and appendices.

Shipping activity, cargo flows, fuel demand, pricing, and operational aspects have been considered together to support conclusions. Stakeholder inputs, including interviews with shipowners, fuel providers, port authorities, and policymakers, have been used to align the analysis with practical considerations. Figure 1 presents an overview of the steps and their interlinkages.

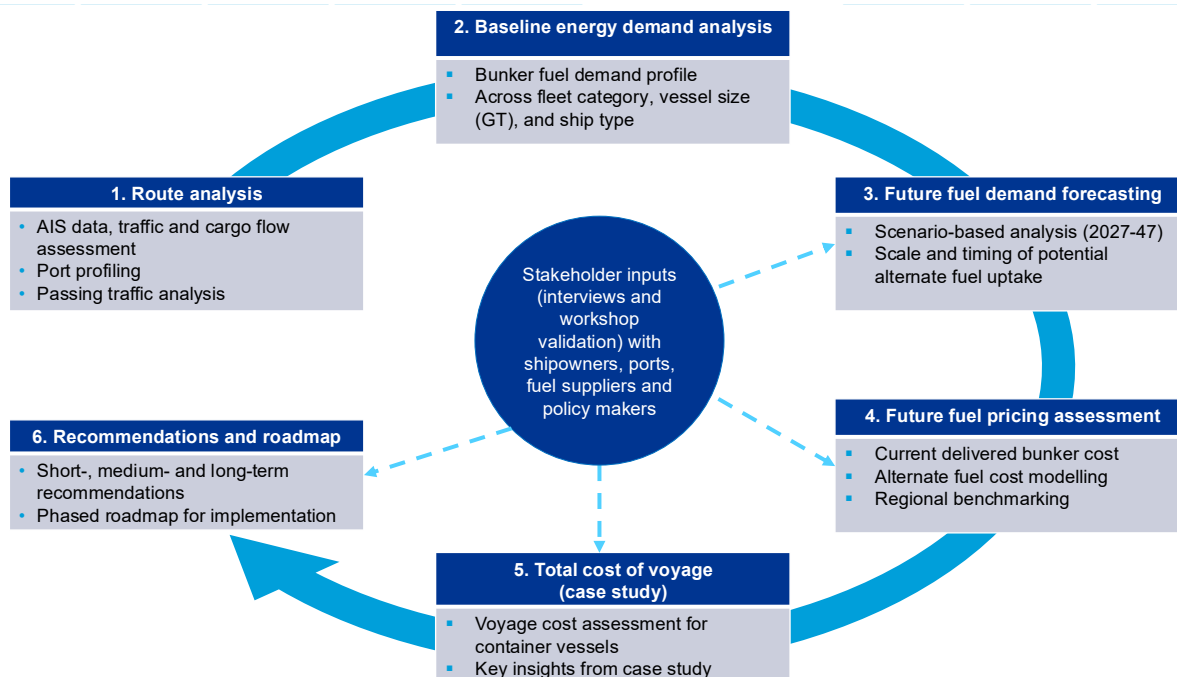


Figure 1 : Overview of steps and activities

3.2 Scope limitations and out-of scope areas

While the study provides a comprehensive assessment of demand, pricing, and competitiveness of alternative marine fuels in India, certain areas are outside the scope of this analysis.

The study models fuel adoption pathways at an aggregate level but does not include a detailed techno-economic comparison of individual fuels. This means that aspects such as levelised cost of production, infrastructure requirements, and safety or operational considerations specific to each fuel (e.g., methanol, ammonia, biofuels) are not evaluated in detail.

The assessment of fuel supply is limited to a high-level view of potential availability and linkages to production hubs. It does not include plant-level feasibility, detailed CAPEX or OPEX modelling, or optimisation of logistics such as storage, pipelines, or transportation systems.

Competitiveness of India as a bunkering hub is assessed using pricing benchmarks, case studies, and stakeholder inputs. However, the study does not include detailed market modelling such as price elasticity, probabilistic market share analysis, or full competitive simulations against other global bunkering hubs.

The analysis of shipowner decision-making is based on selected total cost of voyage case studies and does not represent a full fleet-wide behavioural model, including contractual structures or fuel availability risk considerations.

Operational feasibility is assessed at a conceptual level and does not include real-world pilot testing, simulation of port operations, or validation of bunkering procedures under live conditions.

Regulatory aspects are considered at a high level and primarily from a pricing and framework perspective. The study does not provide a detailed mapping of permitting processes, approval timelines, or agency-level responsibilities.



Finally, while stakeholder engagement has been carried out to validate assumptions and gather industry perspectives, the number of consultations is limited and may not fully represent all stakeholder views across the maritime value chain.

These limitations should be considered when interpreting the results and are intended to be addressed through further detailed studies, pilot projects, and implementation planning.

4 ROUTE ANALYSIS

The route analysis provides a comprehensive assessment of vessel movements and port visits to, from, and passing by India, with a focus on identifying potential bunkering opportunities. Covering the period from October 2022 to September 2025, the analysis focuses on vessels above 400 GT. It examines vessel traffic patterns, major trade routes, port visits and calls, and cargo flows to determine areas where bunkering demand can be captured. The study identifies and shortlists candidate ports with the greatest potential to support alternative fuel bunkering in the future for detailed evaluation, including analysis of port calls by ship type, primary fuel type, and gross tonnage. These outputs will serve as inputs for subsequent assessments of energy demand, fuel demand, and pricing. A detailed description of the methodology, underlying assumptions, and illustrative examples is provided in Appendix A.1

4.1 Port traffic analysis and comparative profiling of key Indian ports

Based on AIS analysis⁴, this section examines vessel port calls to and from India to map vessel movements and port utilization patterns. From this analysis, eight key ports representing India's major commercial gateways, regional hubs, and bulk-focused terminals have been selected for detailed profiling, as shown in Figure 2 and Table 2.

From Table 2 it is evident that India's port system exhibits a functional hierarchy. Mundra and JNPT (Nhava Sheva) emerge as the primary mainline container gateways, driven by high volumes and extensive carrier coverage, and serving as key nodes for containerised cargo and multi-commodity consolidation. South-west coast ports such as Cochin and Tuticorin benefit from the shortest approach distances, supporting their roles as regional hubs and feeder ports with rapid access to trunk routes. East coast ports, including Visakhapatnam and Paradip, are more bulk-oriented, with limited container services, while Chennai maintains a balanced, multi-purpose profile with regular container and feeder activity. (see Appendix A.1.3 for supporting details)

Global shipping lines concentrate at West Coast gateways, while secondary and bulk-centric ports show more selective coverage. Mundra and JNPT offset longer approach distances through scale, frequency, and strong hinterland connectivity, whereas Cochin and Tuticorin offer faster sea access and efficient regional consolidation. This supports a hub-and-spoke configuration, with mainline services centred on Mundra and JNPT, regional and coastal relays via Cochin, Tuticorin, and Chennai, and bulk corridors anchored by Paradip, Visakhapatnam, and Mormugao, consistent with the grouped trade-route analysis in the report.

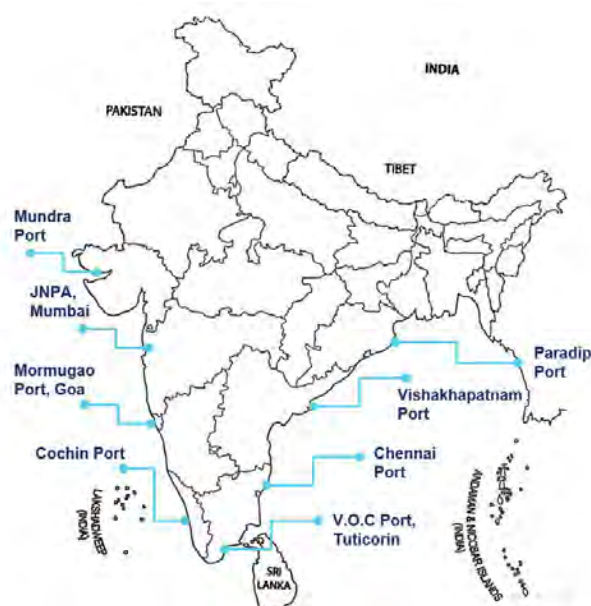


Figure 2: India's major ports

⁴ AIS analysis was conducted for vessels above 400 GT from October 2022 to September 2025, focusing on vessels calling at or passing by Indian ports.

AIS data are further aggregated by vessel type, size category, and fuel type to derive the quantitative metrics underpinning the analysis, including total port calls (defined as distinct AIS-recorded vessel arrivals) and cumulative gross tonnage handled at each port over the three-year period. These metrics provide the analytical basis for the port selection described above and are used to validate traffic intensity, vessel mix, and scale effects, as well as to qualitatively screen alternative-fuel bunkering initiatives and assess policy alignment.

For the purpose of demand segmentation, fleets are classified using a fair-share principle as domestic (c), and international. This classification supports differentiated demand assessment and strategy development for each fleet category. The fair-share principle attributes a vessel's total annual fuel consumption to India based on trading using port-call patterns to reflect the vessel's operational linkage to India. Fleets are first classified based on port-call distribution: domestic vessels have more than 80% of port calls in India, regional vessels have more than 60% of port calls in regional countries⁵ and 10–80% in India, international vessels (all remaining vessels with limited Indian port calls). For these fleet, a fair-share allocation factor is calculated as the share of a vessel's global port calls occurring at Indian ports and applied to its total annual fuel consumption to derive the energy demand attributed to India. For the domestic fleet, which operates predominantly within Indian waters, the fair-share factor is effectively 100%, and the full annual fuel consumption of domestic vessels calling at Indian ports is attributed to India, ensuring domestic activity is fully captured without reliance on AIS completeness.

Port profiling in this section provides the basis for the scenario analysis, pricing assessment, and voyage-cost evaluation that follow. It ensures that all projections, cost analyses, and recommendations reflect the actual operational landscape of Indian ports, making the study both robust and actionable. Table 2 below provides simplified classification of key Indian ports selected for profiling—distinguishing multi-fuel hubs, bulk-centric locations, and regional nodes—derived directly from AIS-based evidence and operational data.

Table 2: Indian ports selected for profiling

Port	Connectivity	Connectivity	Bunker uptake potential ⁶	Cargo focus		Trade characteristic		Key operators
				% of fair share energy demand by ship segment ⁷		% of fair share energy demand by category ⁸		
Bunkering Location	Distance to trade lane 1 (Suez-East Asia)	Distance to trade lane 2 (Middle East Gulf-East Asia)	% of fair share energy demand	From left: Container (blue), dry bulk (green) and wet bulk (grey)		From left: Domestic (blue), regional (green) and international (grey)		
Mundra Port (Mundra)	864 nm	400 nm	15%	59	30 11	2 5 93		- MSC Mediterranean Shipping Co - CMA CGM SA - The French Line - Maersk A/S
Jawaharlal Nehru Port Authority (Nhava Sheva / Mumbai)	775 nm	323 nm	17%	51	23 25	7 5 88		- MSC Mediterranean Shipping Co - CMA CGM SA - The French Line - Maersk A/S

⁵ Regional countries: Singapore, United Arab Emirates, Oman, Saudi Arabia, Qatar, Kuwait, Bahrain, Malaysia, Thailand, Iran, Pakistan, Sri Lanka, Bangladesh, Myanmar, Iraq, Yemen

⁶ The results from bunker demand analysis have been included in this section to support and justify the selection of ports for profiling, more information on this is available in chapter 6 and appendix A2

⁷ From left to right: Container, dry bulk and wet bulk

⁸ From left to right: Domestic (Vessels with >80% of port calls in India), regional (Vessels with >60% of port calls in regional countries i.e. Singapore, United Arab Emirates, Oman, Saudi Arabia, Qatar, Kuwait, Bahrain, Malaysia, Thailand, Iran, Pakistan, Sri Lanka, Bangladesh, Myanmar, Iraq, Yemen and 10–80% of port calls in India), international (All remaining vessels with limited Indian port calls)

Mormugao Port Authority (Goa)	614 nm	365 nm	1%	0	91	9	12	1	87	- Oldendorff Carriers GmbH & Co - Shipping Corp of India Ltd - Zodiac Maritime Ltd
Cochin Port Authority (Cochin / Kochi)	135 nm	112 nm	3%	28	24	48	34	2	64	- MSC Mediterranean Shipping Co - Wan Hai Lines Ltd - Shipping Corp of India Ltd
V.O. Chidambaram Port Authority (Tuticorin)	136 nm	136 nm	3%	9	79	12	11	1	88	- MSC Mediterranean Shipping Co - BBC Chartering GmbH & Co KG - Oldendorff Carriers GmbH & Co
Chennai Port Authority (Chennai)	431 nm	431 nm	8%	25	45	30	12	4	84	- MSC Mediterranean Shipping Co - BBC Chartering GmbH & Co KG - Maersk A/S
Visakhapatnam Port Authority (Visakhapatnam)	700 nm	700 nm	7%	7	78	15	6	2	92	- MSC Mediterranean Shipping Co - Oldendorff Carriers GmbH & Co - Shipping Corp of India Ltd
Paradip Port Authority (Paradip)	840 nm	840 nm	5%	0	91	9	15	1	84	- Oldendorff Carriers GmbH & Co - Starbulk SA - Shipping Corp of India Ltd

The strategic relevance of these ports reflects their role as major cargo gateways, proximity to dense international shipping routes, and function as established or emerging multi-cargo hubs, with existing bunkering activity or planned energy-transition infrastructure. Alignment with national decarbonization objectives is assessed through port-level initiatives linked to Maritime India Vision 2030, the National Green Hydrogen Mission and the Harit Sagar Green Port Guidelines., with preference given to ports actively planning or implementing alternative fuels, renewable energy integration, or low-carbon port operations.

4.2 Passing Vessel Traffic Analysis

Passing traffic off the coast of India is analysed and is segregated into zones A, B and C depending on their distance from the Indian coast, as shown in Figure 2 (see Appendix A.1.1 and A.1.2 for more details). Where a vessel's voyage traverses more than one zone during a single voyage, the zone closest to India is assigned for analysis.

Zone A: Zone A represents the area closest to the Indian coastline. Vessels transiting through this zone require minimal deviation from their primary trade routes to access Indian ports. The probability of bunkering in India is high because vessels can refuel without significant schedule disruptions.

Zone B: Zone B lies at an intermediate distance from India. Vessels in this zone would need moderate deviation to reach Indian ports. The probability of bunkering is medium and largely dependent on competitive pricing and infrastructure readiness.

Zone C: Zone C is the farthest from the Indian coastline and typically aligns with major eastbound trade routes toward established bunkering hubs such as Singapore and Malaysia. Vessels in this zone are unlikely to divert north to Indian ports due to the significant deviation required. The considerable size of Zone C is due to its inclusion of vessels and

voyages transiting through major international maritime routes such as the Suez Canal and the Cape of Good Hope, which are critical corridors for global trade connecting Europe, Asia, and Africa.

The zone-based traffic analysis is closely integrated with port visit patterns to identify candidate ports for alternative fuel bunkering. Ports located adjacent to high-density passing traffic zones, particularly Zone A, have the greatest potential for attracting vessels with minimal route deviation. This approach ensures that shortlisted ports combine strong existing call volumes with strategic proximity to international shipping lanes, thereby maximizing the feasibility of future bunkering infrastructure. Table 3 below shows the zone segregation and prominent trade routes.

Table 3: Zone segregation and prominent trade routes

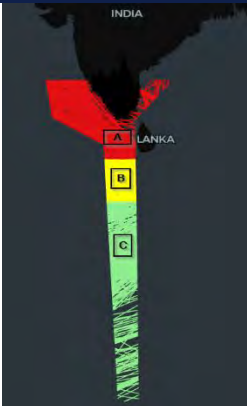
Traffic in the zones on map	Trade	Zone A	Zone B	Zone C	Grand Total
	Africa - East Asia	9.1%	7.4%	11.2%	27.7%
	Africa - Middle East	0.1%	0.0%	0.0%	0.1%
	Africa - West Asia	0.0%	0.0%	0.0%	0.0%
	America - East Asia	0.6%	0.1%	2.2%	3.0%
	East Asia - East Asia	5.2%	0.2%	0.0%	5.4%
	East Asia - Europe	1.4%	0.1%	1.0%	2.5%
	East Asia - Middle East	53.2%	0.0%	0.1%	53.3%
	East Asia - West Asia	8.0%	0.0%	0.0%	8.0%
Grand Total		77.6%	7.8%	14.6%	100.0%

Figure 3 : Zone segregation on the basis of traffic

The passing-traffic analysis shows that more than 77% of vessels operating on major routes particularly East Asia–Middle East and Africa–East Asia pass very close to India (Zone A).

Figure 3 compares the percentage of voyages by ship type across the three zones. Container ships account for the majority of voyages, followed by Ro-Ro Cargo and Liquid Gas carriers, while passenger and specialized cargo types have minimal representation.

Container vessels account for nearly half of all passing ship traffic near India, making them the dominant segment by a wide margin. Ro-Ro cargo vessels and liquefied gas carriers follow, each representing roughly 10% of voyages. The majority of this passing traffic is concentrated in Zone A.

These findings indicate that container vessels should be the primary focus of any strategy aimed at attracting bunkering demand from passing ships. The results are used to define the upper bound of potential bunkering demand that could be captured if a share of passing traffic is diverted to Indian ports chapter [6], to highlight the importance of highly competitive pricing and efficient services relative to established bunkering hubs chapter [8.3], and to inform the modelling of cost and operational feasibility for vessels deviating from their main routes to bunker in India chapter [9].

Based on the outcomes of this chapter, container vessel segments are selected for detailed deviation and cost-feasibility analysis in [9]. The choice of specific vessel types and trade routes is directly informed by the traffic patterns and port-call characteristics identified here, ensuring that the subsequent analysis reflects actual shipping behaviour around India.

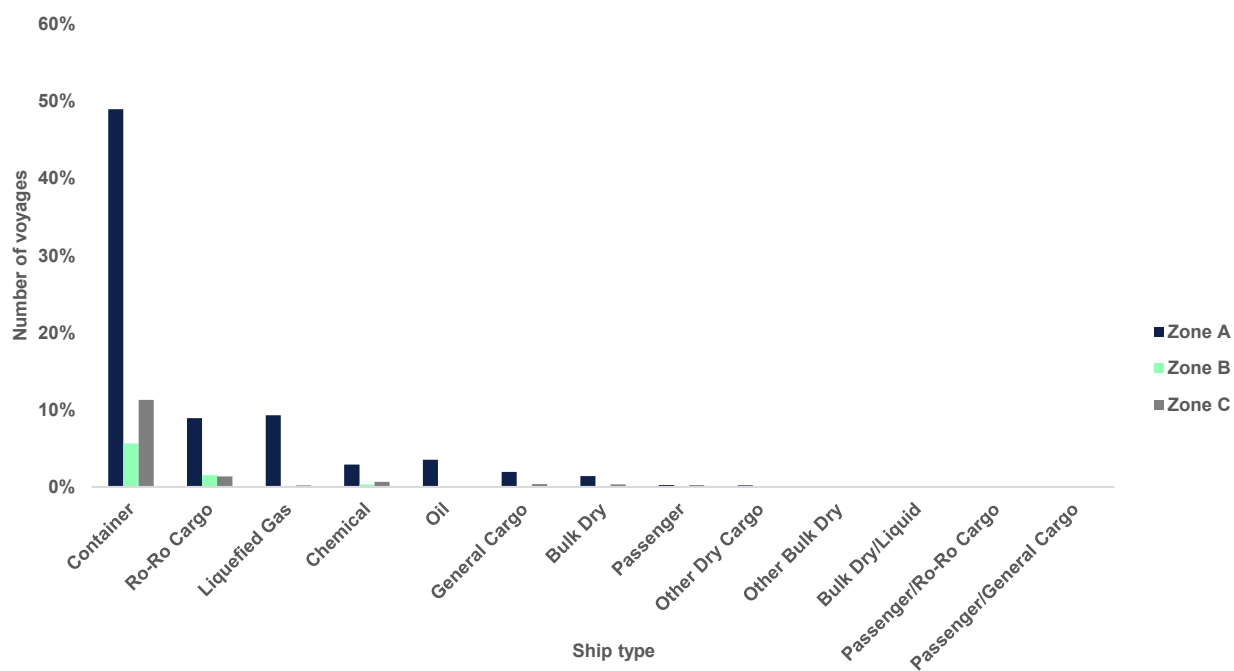


Figure 4 : Voyage share by Ship Type Across Zones for the period October 2022 – September 2025

5 BASELINE ENERGY DEMAND ANALYSIS

This chapter establishes a baseline estimate of bunker fuel demand associated with vessels calling at Indian ports during the period from October 2022 to September 2025. The assessment covers vessels above 400 GT and excludes harbour craft. Assessment periods are defined as follows: Period 1 (1 October 2022 – 30 September 2023), Period 2 (1 October 2023 – 30 September 2024), and Period 3 (1 October 2024 – 30 September 2025).

For the domestic fleet, the full energy demand is attributed to bunkering in India, reflecting their predominantly national trading patterns. For regional and international fleets, fuel demand is estimated using a fair-share principle (refer to 4.1), whereby each vessel's total fuel consumption is allocated to India in proportion to the share of its port calls at Indian ports relative to its total global port calls. India's fair share allocation factor is determined by dividing the number of a vessel's port calls at Indian ports by its total global port calls, while the fair-share bunker volume is obtained by multiplying this allocation factor by the vessel's annual fuel consumption. This ensures that fuel demand attributed to India reflects its relative share of global port-call activity rather than actual bunkering behaviour. This approach attributes energy demand based on port-call activity rather than actual bunkering behaviour and provides a consistent basis for demand benchmarking and scenario analysis.

International fleets account for more than 80% of the total fair-share bunker volume associated with vessels calling at Indian ports (see Figure 4). This dominance reflects the high absolute fuel consumption of large ocean-going vessels engaged primarily in international trade, even where Indian port calls represent a relatively small share of their overall trading activity. Domestic and regional fleets contribute smaller shares of the total volume, though an upward trend is observed for both international and domestic fleets over the assessment periods, indicating growing energy requirements linked to port activity in India⁹

Figure 5 further disaggregates the fair-share bunker volume by fleet category and gross tonnage (GT) range. International fleets in the 20,000–49,999 GT range dominate across all assessment periods, while domestic and regional fleets remain limited across GT classes.

This baseline demand profile serves as a foundational input for the Future fuel demand forecasting, Future fuel pricing assessment, and therefore Total cost of voyage case study, enabling consistent scenario development, competitiveness assessment, and cost evaluation across subsequent chapters.

⁹ Assessment periods are defined as follows: Period 1 (1 October 2022 – 30 September 2023), Period 2 (1 October 2023 – 30 September 2024), and Period 3 (1 October 2024 – 30 September 2025).

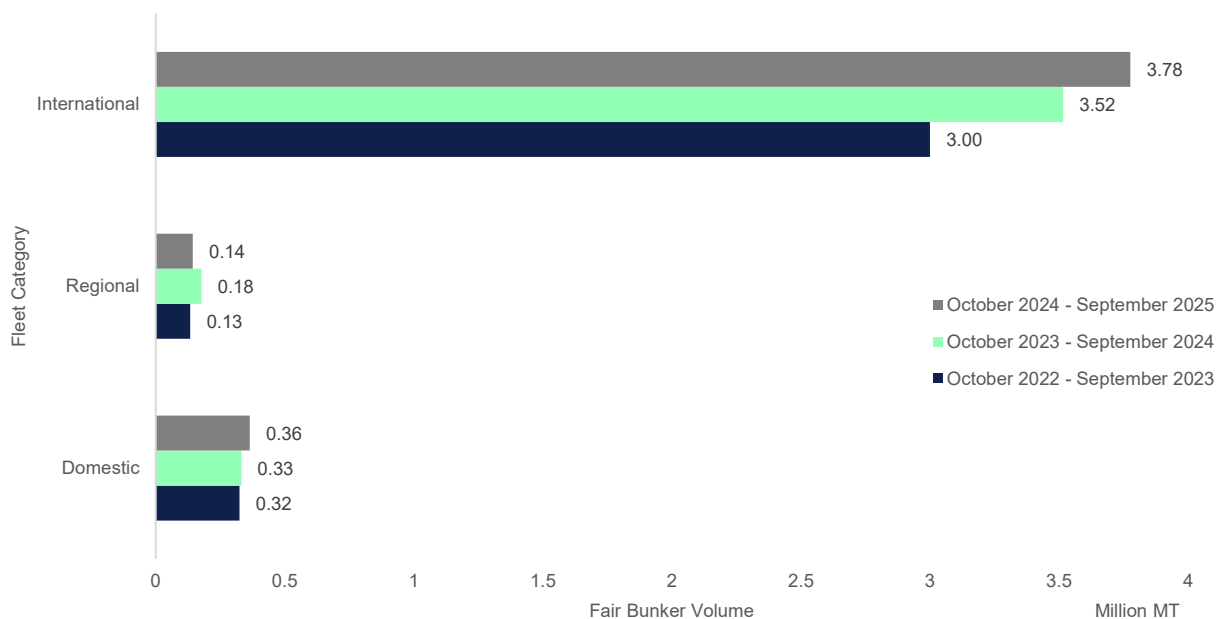


Figure 5 : Fair share bunker volume (Metric Ton (MT)) by fleet category for the period October 2022 – September 2025

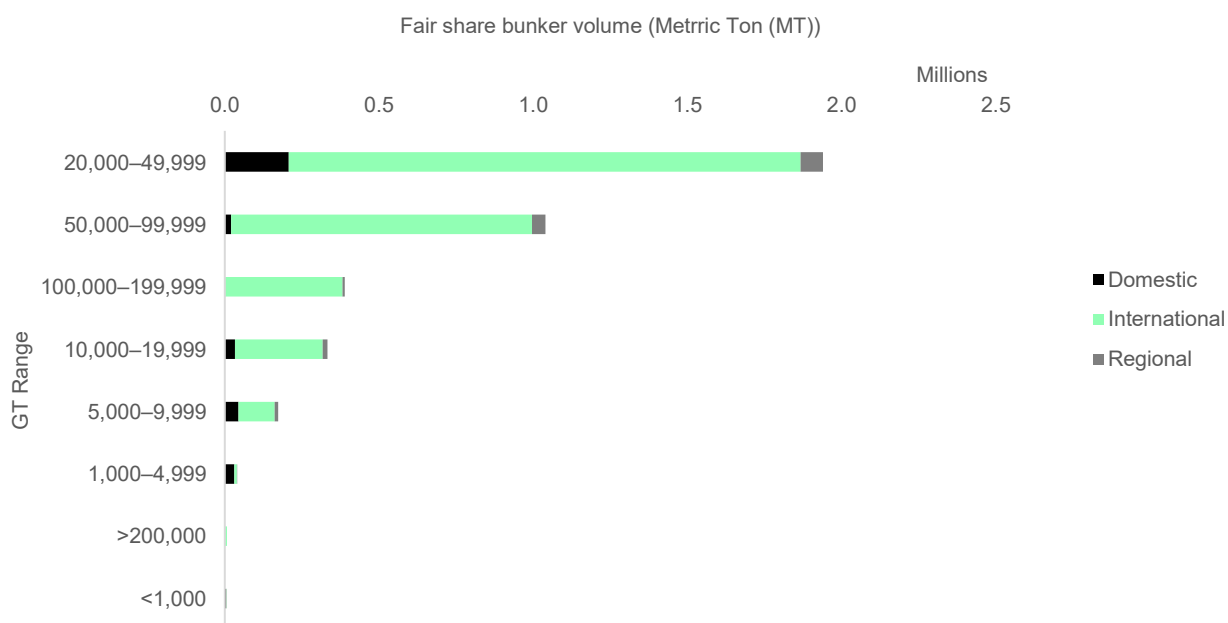


Figure 6 : Fair share bunker volume by GT range and fleet category for the period October 2022 – September 2025

6 FUTURE FUEL DEMAND FORECASTING

The future fuel demand forecast examines the demand for alternative marine fuels in India, expected to develop in the short, medium, and long term between 2027 and 2047. Building on the traffic patterns from route analysis and baseline energy demand, the analysis uses a scenario-based approach to explore how fuel demand may change across different trajectories of growth, technology and infrastructure development.

The results show the annual demand for alternative fuels in petajoules (PJ), reflecting how India's role in bunkering could grow under different development pathways (the "scenarios"). The energy amounts are converted to a selection of alternative fuels using IMO's conversion factors from the LCA Guidelines¹⁰. The scenarios help illustrate the scale and timing of potential demand, as well as the conditions under which India could strengthen its position as a regional bunkering hub.

The forecast provides the demand outlook used in the pricing assessment and total cost of voyage analysis. Detailed assumptions, scenario definitions, and supporting analysis are presented in Appendix A.2

6.1 Demand composition and drivers

Alternative fuel demand in India is projected under three scenarios (see Table 4), all fundamentally shaped by the IMO 2023 Revised GHG strategy targeting net-zero emissions by or around 2050. Each scenario represents a distinct narrative, reflecting different trajectories of growth and technological progression, ranging from moderate to increasingly ambitious pathways that assume substantial structural shifts and further technological development. The scenarios assess India's potential role in supplying fuels during this transition and illustrate how different national developments could lead to varying market shares (bunkering uptake). Additionally, the fuel mix is expected to evolve—initially dominated by biofuels such as bio-methanol and biodiesel until roughly 2033–2038, before e-fuels like e-methanol and e-ammonia, gain momentum. A more detailed explanation can be found in Appendix A.2.1

6.2 Scenario Summary

The three scenarios outlined in Table 4 illustrate how India's maritime trade growth and bunkering uptake could evolve under different assumptions about competitiveness, infrastructure development, and transshipment capture. Each scenario reflects a distinct trajectory—from conservative growth aligned with global averages defined in the DNV Maritime Forecast to 2050 publication¹¹ (2025 edition) to an ambitious pathway positioning India as a leading alternative fuel bunkering hub. The table summarises the drivers, compound annual growth rates (CAGR), and projected bunker fuel demand for 2035 and 2047 under each scenario. The results are given in Peta Joules (PJ) and million-ton HFO equivalents (HFOeq.) for easy conversion to different fuels.

In scenario 1 as shown in Figure 7, India aligns with global growth trends but makes only minimal investments and offers limited policy incentives to expand its alternative fuel market. In the short term, this will generate some demand from internationally trading vessels that require fuel when calling at Indian ports for cargo operations. Methanol-powered container ships are expected to account for most of this demand, which is projected to reach approximately 500,000 tons of methanol by 2029. Looking ahead to the medium and long term, most of India's domestic fleet is anticipated to adopt alternative fuel capabilities. However, its contribution to overall demand will remain moderate due to the relatively small size and lower fuel consumption of the domestic fleet.

In Scenario 2, shown in Figure 8, India is assumed to capture **up to 50%** of the transshipment traffic currently handled by Sri Lanka, **reflecting ongoing efforts to internalise Indian cargo flows through domestic hubs such as Vizhinjam and reduce reliance on foreign transshipment ports**, by offering container transshipment services on Far East–Middle East and Europe routes. Additionally, India's bunker uptake factor is projected to grow at a compound annual rate of 1.5%

¹⁰ Methanol: 19.9 GJ/ton, Ammonia: 18.6 GJ/ton, Hydrogen: 120 GJ/ton

¹¹ <https://www.dnv.com/maritime/maritime-forecast/>

between 2027 and 2040, and 2.8% between 2040 and 2047, reflecting moderate port development, improved reliability, and pricing comparable to large bunkering hubs such as Singapore. Even though some previously passing ship traffic is captured by India in scenario 2, the international trading fleet still account for 78% of total demand.

In scenario 3 as shown in Figure 9, India becomes a leading low- and zero-carbon bunkering hub by combining stronger trade growth, higher transshipment capture, competitive delivered fuel prices, and reliable multi-fuel port operations. Under these conditions, India attracts additional bunkering demand beyond its expected fair share, with the uptake factor increasing to 0.9 by 2040 and 1.20 by 2047. This scenario assumes that India captures up to 80% of the transshipment volumes currently handled by Sri Lanka, reflecting a significant shift of Indian-linked cargo to domestic hubs under an accelerated development pathway.

Table 4: Scenario summary with main drivers, CAGR (2027-2047), and projected alternative fuel demand in 2035 and 2047

Scenario	Drivers and rationale	CAGR 2027-2047	Demand 2035	Demand 2047
1- Slow and Steady Growth	India's maritime growth is in line with global projections. Bunkering uptake factor reflects organic growth with no major competitiveness improvements for alternative fuels. India does not attract/receive passing traffic, so bunker demand is driven entirely by ships calling at Indian ports for cargo operations.	22%	42 PJ / 1.0-million-ton HFOeq.	113 PJ / 2.8 million-ton HFOeq.
2- Accelerated Progress	India's maritime trade grows moderately faster than the global average (+0.5% uplift per year). India transfers 50% of transshipment volumes from Sri Lanka into India. Bunkering uptake factor reflects a small competitive edge compared to the region with improved reliability and targeted port improvements	24%	49 PJ / 1.2-million-ton HFOeq.	166 PJ / 4.1 million-ton HFOeq.
3- Breakthrough Growth	India's maritime trade grows faster than the global average (+1.5% uplift per year). India cements itself as a world-class alternative fuels bunkering hub attracting 80% of container transshipment volumes currently stopping in Sri Lanka and South Africa based on the route and traffic analysis	28%	65 PJ / 1.6 million-ton HFOeq.	293 PJ / 7.3 million-ton HFOeq.

For context, even under the Breakthrough Growth scenario (~7.3 million tonnes HFOeq. by 2047), India's alternative fuel bunkering demand remains modest compared to current conventional bunkering hubs. For example, Singapore recorded ~55 million tonnes of bunker sales in 2024, with other major hubs such as Rotterdam (~9 million tonnes), Fujairah (~7.5 million tonnes), and Zhoushan (~7.3 million tonnes).

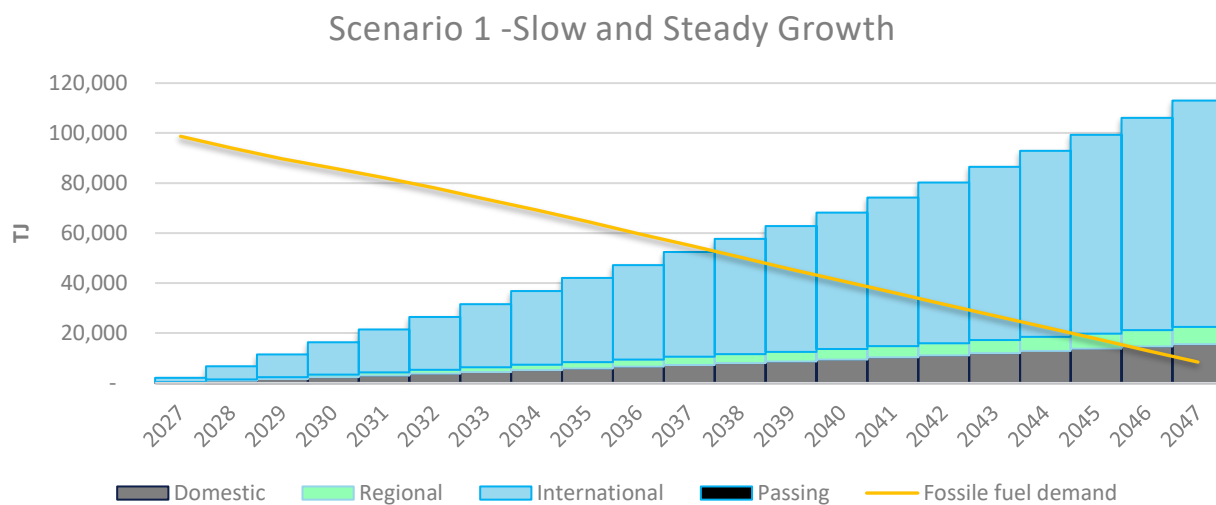


Figure 7: Alternative fuels bunker demand in India for Scenario 1

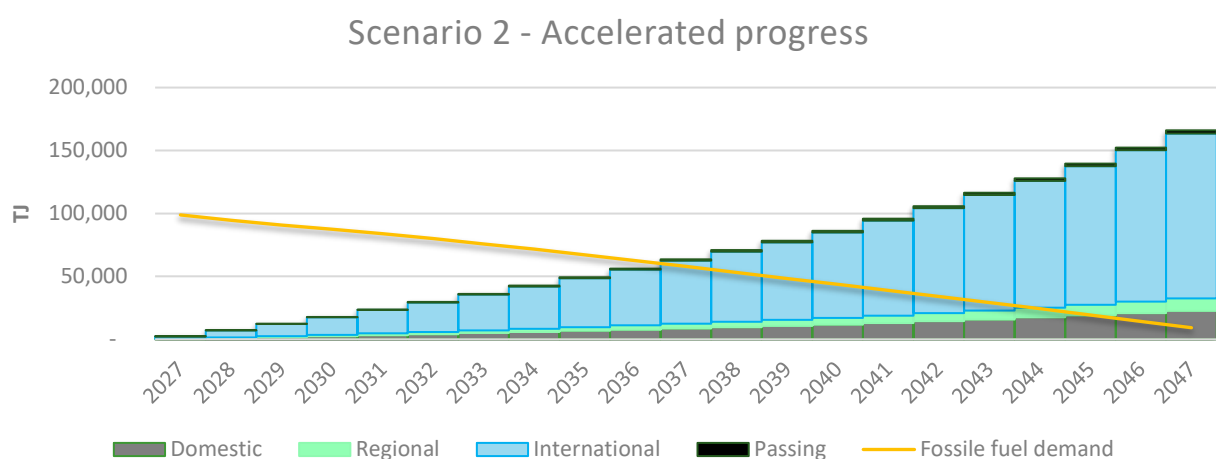


Figure 8 Alternative fuels bunker demand in India for Scenario 2

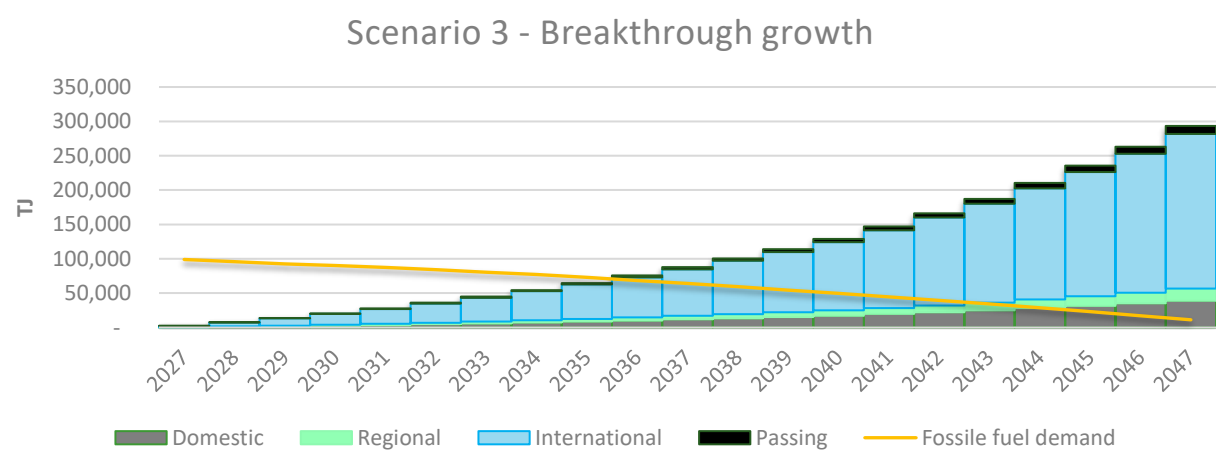


Figure 9: Alternative fuels demand in India for Scenario 3

6.3 Evaluation of logistical requirements from designated hydrogen hubs

Building on port selection and port profiling in chapter 4.1, this section evaluates the logistical requirements from the designated hydrogen hubs and how they influence the feasibility of bunkering at logistical ports. The findings are summarised in Table 5

As shown in Table 5, V.O.C Port can serve Tuticorin (dry bulk), Chennai (mixed), and southern ports within a ~325–600 km range, while Deendayal can cover Mundra (container) and Mumbai (container) within ~75–700 km. Paradip, with a strong dry bulk orientation, can support eastern ports like Visakhapatnam. These port characteristics—container, dry bulk, and wet bulk—are key because they indicate vessel types and trade patterns, which determine both the scale of alternative fuel demand and the complexity of bunkering infrastructure; container hubs typically attract large mainline vessels that are early adopters of green fuels, wet bulk ports already handle hazardous liquids making them easier to adapt for ammonia or hydrogen, and dry bulk ports can leverage industrial hinterlands for integrated fuel supply chains.

For ports farther from hubs, such as Mormugao, supply remains feasible via coastal tankers, but targeted investment in intermediate storage and handling facilities will be needed. For ports located within practical range of designated hydrogen hubs, a shared bunker vessel model can optimise logistics—one vessel serving multiple ports from the same hub. LNG bunker barges today typically operate within 250–500 km ranges (e.g., Shell's LNG vessel in Singapore and Gas Agility in Europe), providing a benchmark for hydrogen/ammonia bunkering strategies.

Designated hydrogen hubs—Deendayal, V.O.C Port (Tuticorin), and Paradip—are strategically located to serve high-demand ports, reducing supply chain complexity and leveraging planned infrastructure. V.O.C Port is particularly well-positioned on busy East–West trade lanes with minimal deviation, making it an efficient supply point for southern ports, including emerging transshipment hubs such as Vizhinjam identified under Sagarmala and Maritime India Vision 2030¹². Other potential hubs include JNPT and Chennai, which feature in official plans for deep-water container handling and hub development.

¹² [India's Maritime Vision: Shaping the Future of Global Trade through Vizhinjam Port](#)

Table 5: Mapping of projected bunkering demand to preferred hydrogen supply hubs with indicative logistics considerations

Port candidate (bunkering location)	Annual bunkering demand (PJ/thousand-ton HFO eq.)	Preferred supplying hub	Rationale (distance, logistics, scale)	Approx. distance, sailing time ¹³	Primary mode(s)
Mundra Port (Mundra)	<u>2035: 7.4 / 183</u> 2047: 24.9/ 616	Deendayal GH ₂ Hub (candidate)	Closest hub with strong industrial corridor; pipeline connection feasible	~75 km	Pipeline, rail, barge
Jawaharlal Nehru Port Authority (Nhava Sheva / Mumbai)	<u>2035: 8.4 / 208</u> 2047: 28.2 / 698	Deeyandal GH ₂ Hub (candidate ¹⁴)	Western coast corridor; strong export logistics; rail/coastal link	~700 km (~380 nm, ~1.5 day)	Coastal tanker, rail
Mormugao Port Authority (Mormugao / Goa)	<u>2035: 0.5 / 12</u> 2047: 1.7 / 41	Deeyandal GH ₂ Hub (candidate)	Long haul: coastal tanker preferred	~1100 km (~600 nm, 2.5 days)	Coastal tanker
Cochin Port Authority (Cochin / Kochi)	<u>2035: 1.5 / 37</u> 2047: 5.0 / 123	VOC GH ₂ Hub (designated)	Positioned on southern corridor; short coastal link enables supply	~450 km (~240 nm, 1 day)	Coastal tanker, rail
V.O. Chidambaranar Port Authority (Tuticorin)	<u>2035: 1.5 / 37</u> 2047: 5.0 / 123	VOC GH ₂ Hub (designated ¹⁵)	Hub–port co-location; proximity to industrial corridors; export orientation	Co-location	Direct pipeline
Chennai Port Authority (Chennai)	<u>2035: 4.0 / 98</u> 2047: 13.3 / 329	VOC GH ₂ Hub (designated)	Southern corridor; short coastal link	~600 km (~325 nm, 1.3 day)	Coastal tanker, rail
Visakhapatnam Port Authority (Visakhapatnam)	<u>2035: 3.5 / 86</u> 2047: 11.6 / 287	Visakhapatnam GH ₂ Hub (announced ¹⁶)	Planned large- scale hub; east coast supply	Co-location	Direct pipeline,
Paradip Port Authority (Paradip)	2035: 2.5 / 61	Paradip GH ₂ Hub (designated ¹⁷)	Co-located; strong industrial demand ; east-coast corridors	Co-location	Direct pipeline

¹³ Assuming average sailing speed of 12 knots plus 10%-time margin for weather and operational delays.

¹⁴ Candidate: Ports included based on strategic location and traffic; no official designation

¹⁵ Designated: Announced by MNRE, [Oct 2025](#) (National Green Hydrogen Mission guidelines), have formal status and will receive policy support and incentives

¹⁶ Announced hub: Visakhapatnam (foundation stone laid by PM, Jan 2025, [PIB press release](#))

¹⁷ Designated hub – Paradip port ([PIB press release](#))

7 STAKEHOLDER INSIGHTS ON MARKET ATTRACTIVENESS, COMPETITIVENESS AND POLICY CONDITIONS FOR ALTERNATIVE-FUEL BUNKERING

Table 6 below summarises the key insights from stakeholder interviews, structured by stakeholder group, and integrates these perspectives with findings from the demand analysis to assess India's market attractiveness, competitiveness, and policy considerations for alternative-fuel bunkering.

These insights are further complemented by a multi-stakeholder workshop conducted during the study, which was used to validate key findings, discuss practical constraints across the value chain, and refine the proposed recommendations.

Together with the future fuel price assessment in Chapter 8 and the total cost of voyage case study in chapter 9, these insights inform how India can position itself in the evolving marine fuel market.

Table 6: Key Stakeholder Insights on Bunkering Uptake and Market Implications.

Stakeholder group (No. of interviews)	Key Insights and Implications
Shipowners/operators (4)	Cost and reliability: Adoption depends on price parity with hubs like Singapore and Fujairah. Even after India cut GST on bunker fuel to 5 %, local prices remain much higher, discouraging vessels from bunkering in India. Operational choices: Owners will not deviate from main routes for bunkering unless ports offer reliable multi-fuel supply and ancillary services (crew exchange, spares, provisions). Clarity and incentives: Stakeholders require clear timelines for fuel availability, safety standards, and liability frameworks; targeted incentives such as reduced port charges could support early adoption. Market implication: Passing traffic is unreliable demand source; India must focus on capturing vessels already calling at ports for cargo, then offering integrated cargo-bunkering-services differentiation. Operational reliability, service quality, and speed of operations matter as much as fuel price.
Port authorities and terminal operators (3)	Infrastructure gaps: Ports need dedicated storage tanks, bunkering barges and faster pumping systems. Deep-water facilities like Vizhinjam illustrate how combining cargo operations with bunkering can reduce dependence on foreign trans-shipment hubs. Early mover positioning: Less-congested ports (Tuticorin, Kandla, Vizhinjam) better positioned for early pilot projects; larger gateways like Mumbai suitable only as late movers once technology and costs stabilise. Safety and standards: Ports call for clear handling codes for methanol, ammonia, and hydrogen, and seek policy support for on-shore power and green-tug programmes. Market Implication: Infrastructure investment must precede demand growth, requiring government co-investment in bunkering barges, storage, and training facilities. Port competitiveness depends on integrated cargo-fuel-services value proposition, streamlined processes, and operational reliability—not pure fuel supply capacity. Government-backed pilots essential to de-risk initial infrastructure investment.
Fuel suppliers (4)	Cost and scale: Alternative fuels are expensive to produce; suppliers expect costs to fall with scale but require demand aggregation and policy certainty. Supply chain development: Dedicated storage, handling and blending facilities are needed before large-scale supply is feasible. Market Implication: Suppliers look for incentives (e.g., viability-gap funding, preferential tariffs) and clear standards for blending and storage; they also highlight that fuel costs depend heavily on electricity prices and feedstock availability.
Regulators/policy makers (2)	Fuel pathway: Green hydrogen derivatives (methanol and ammonia) are prioritised for the long term, with biofuels as a transitional option where cost and infrastructure constraints persist. Cost levers: India's lower renewable energy costs, combined with scale-up and assured demand, are expected to drive cost reductions, drawing on parallels with the fertilizer sector. Infrastructure alignment: Hub-and-spoke supply models are being evaluated to serve both major and smaller ports, supporting domestic coastal demand while enabling regional bunkering capability. Market implication: Government-enabled pilots and coordinated port–industry development are viewed as essential to de-risk early investment and establish initial bunkering capability.
Consultants/industry associations (1)	Strategic positioning: India's location is advantageous, but price and reliability gaps must be closed through rationalised taxes, efficient operations and transparent pricing models. Phased roll-out: Experts recommend starting with LNG and methanol pilots, then scaling to ammonia and hydrogen as technology matures; ports like Tuticorin and Kandla offer low-risk testing grounds.

- **Market Implication:** Quality standards, transparent pricing, and reliable supply are essential to build confidence. Government-backed pilot projects with domestic fleets can demonstrate feasibility while keeping execution risk manageable. Clear regulations and safe-harbour provisions for early adopters are needed to encourage investment.

Across both stakeholder interviews and the workshop, a consistent message emerged: India's success in alternative fuel bunkering will depend less on geographic advantage and more on delivered cost competitiveness, operational reliability, and clarity of regulatory and commercial frameworks.

Stakeholders broadly agreed that progress should focus on a limited number of ports and vessel segments, supported by coordinated policy action, rather than attempting widespread deployment from the outset. The workshop discussions further reinforced the importance of aligning fuel supply, port infrastructure, approvals, and demand signals in a phased and integrated manner.

8 FUTURE FUEL PRICING ASSESSMENT

The future fuel pricing assessment looks at the future fuel cost level and the regional competitiveness of alternative marine fuels supplied from Indian bunkering hubs. It focuses on expected fuel production costs rather than short-term market prices, recognising the high uncertainty associated with market dynamics, margins, and volatility.

The analysis covers ammonia (e- and blue-), methanol (bio- and e-), bio-LNG and biodiesel. It is based on results from DNV's Energy Transition Outlook 2025¹⁸ (continued research work from DNV for last 10 years, with a yearly update) and the DNV Marine Fuel Cost Mapper¹⁹ (a proprietary DNV cost-modelling tool), described in Appendix A.3. India's competitiveness is assessed by comparing projected alternative fuel production costs in the neighbouring regions. Differences driven by energy costs, feedstock availability, and production routes are captured quantitatively, while the potential influence of policies and regulations on final fuel prices is discussed qualitatively.

Insights from stakeholder interviews with industry and government representatives are used to contextualise cost assumptions, validate modelling outputs, and inform expectations on future pricing levels and regulatory impacts. The background, methodology and results are summarized in this chapter – elaborations and details can be found in Appendix A.3.

8.1 Current bunkering behavior and competition

International shipping is fundamentally driven by cost. Once fuel availability, quality, and compliance are assured, total delivered bunker cost—including fuel price, port charges, and operational costs—becomes the decisive factor in where vessels bunker. As a result, ship operators follow an opportunistic bunkering strategy, concentrating fuel purchases at locations that minimise total cost and operational risk.

Consistent with this behaviour, global bunkering activity remains concentrated in a small number of large, integrated hubs such as Singapore and Fujairah, which combine lower bunker fuel prices, scale-driven efficiencies, and predictable operations. In contrast, Indian ports today primarily serve captive, route-specific, or domestic bunkering demand, rather than functioning as preferred regional or international bunkering hubs.

A comparative price assessment and insights from stakeholder interviews, described in Appendix A.3, indicates that India is currently not cost-competitive as a discretionary bunkering location. Bunker fuel prices at Indian ports are significantly higher than those at major global hubs (50-70% higher) even before port charges, operational costs and tax are considered. When port dues, pilotage, tug requirements, bunkering service charges and the Indian GST (Goods and Services Tax) are included, the cost gap widens further. Stakeholders consistently attributed this to structural operational factors, including smaller bunker barges, lower pumping rates, longer and less integrated logistics chains, limited bunkering-at-anchor options, and more fragmented and port-specific procedures. These factors increase time, uncertainty, and per-call costs compared to established hubs, where high volumes, larger barges, and streamlined processes dilute fixed costs and improve predictability.

As illustrated by the delivered cost comparison in the Appendix (Figure A 37 and Table A 7), the cumulative effect of higher fuel prices, elevated port charges, and less efficient bunkering operations makes Indian ports unattractive for discretionary bunkering on international routes. This cost structure explains why rising vessel traffic at Indian ports has not translated into a corresponding increase in bunkering volumes, as vessels continue to bunker predominantly at lower-cost regional hubs along their trading routes. Addressing this gap will require coordinated action across fuel pricing, port tariffs, operational efficiency, and infrastructure reliability rather than isolated interventions.

¹⁸ <https://www.dnv.com/energy-transition-outlook/2025/>

¹⁹ [Alternative Fuels Insight \(AFI\) for the shipping industry](#)

8.2 Expected change in bunkering behaviour with alternative fuels

When transitioning to alternative fuels, bunkering behaviour and market is expected to look different than today's fossil fuel market. Most alternative fuels will require more frequent bunkering due to lower energy density and additional dedicated infrastructure at ports²⁰. Market immaturity will to some extent lead to long-term offtake agreements, and regulatory frameworks such as carbon-neutral corridors will influence future bunkering patterns. The difference in operational and logistical costs described for India vs larger hubs is expected to be less significant when transitioning to sustainable fuels, at least in a transition period where we expect alternative fuel facilities and offtakers entering into binding offtake agreements.

The future development of market dynamics and bunkering practices for various fuels remains uncertain. Nevertheless, as markets and technologies evolve, it is likely that the shipping fuel landscape will become more fragmented than today with several different fuel types, with greater regional price differences due to higher transportation costs of fuels with lower densities and local feedstock price differences such as electricity and biomass.

8.3 Alternative fuel price assessment

8.3.1 India's advantages for alternative fuel production

India's competitive advantage in future fuel pricing is closely tied to strong renewable energy fundamentals. As solar and wind power scale rapidly toward 2050, electricity costs in India are expected to decline significantly—this is important as electricity accounts for the majority of production costs for green hydrogen, ammonia and e-fuels. DNV modelling projects a sharp fall in levelised cost of renewables over the next two decades, positioning India as one of the lowest-cost producers of green hydrogen globally.

Beyond renewable electricity, India also ranks high globally in sustainable biomass availability. DNV's regional analysis shows that Indian Subcontinent ranks third out of ten global regions in biomass resource potential—this opens the door for scaling advanced biofuels and bio-methanol production, especially in synergy with existing refining and agricultural value chains. Given that feedstock availability is a key determinant of long-term fuel prices, India's domestic biomass supply can offer price stability and reduce reliance on volatile international commodity markets. These natural advantages, combined with targeted policy support under the Green Hydrogen Mission and production-linked incentives, suggest India has the ingredients to offer globally competitive bunker fuel prices in the medium to long term.

8.3.2 Methodology for assessing future fuel price levels

To analyse what price levels for alternative fuels are required in India to be competitive, the forecasted fuel costs in the regions around India are assessed. The assessment has used DNV's Marine Fuel Cost Mapper tool (see Appendix A.3.4) to estimate future fuel production costs for the relevant regions around India; Southeast Asia, Middle East and North Africa, Greater China and OECD Pacific. For India to be competitive, the required price range must match the lower part of the fuel cost range in the surrounding regions, including any expected added costs for distribution, bunkering and port charges.

The feedstock prices, incl. levelized cost of hydrogen (LCOH), is based on DNV Energy Transition Outlook 2025²¹ "most likely future. To address uncertainties in future fuel cost and price forecasts we have included sensitivities of 20% higher and lower LCOH and biomass costs in the cost ranges presented. The most important risk to address is if fuel costs in the competing regions ends up being lower than forecasted here. We believe creating a fuel cost range including all the relevant regions and the 20% sensitivity will cover most of the possible scenarios. See Appendix A.3.4 for details on methodology and the fuel cost forecast.

²⁰ <https://globalmaritimeforum.org/news/zero-emission-shipping-fuels-methanol-and-ammonia/>

²¹ <https://www.dnv.com/energy-transition-outlook/2025/>

8.3.3 Alternative fuel cost forecast

Figure 10 shows alternative fuel cost ranges for 2035 and 2047 for the aforementioned competing regions around India from DNV's Marine Fuel Cost Mapper tool. Regional HFO price is added as a reference. The costs include feedstock and fuel production costs, as well as costs related to transport and fuel storage. It does not include cost elements like port charges, taxes and specific bunkering costs.

High investment and electricity costs drives up the production costs for e-ammonia and e-methanol, and large regional differences in electricity costs and high uncertainty leads to a wide cost variation for these fuels. Biofuels are expected to keep having lower costs than the hydrogen derivatives.

DNV expects most of the fuel volumes to be produced in the regions achieving the lowest production cost and either transported to major bunkering hubs or sold close to the production location. Hence, it is expected that the fuel available will be in the lower level of the estimated range.

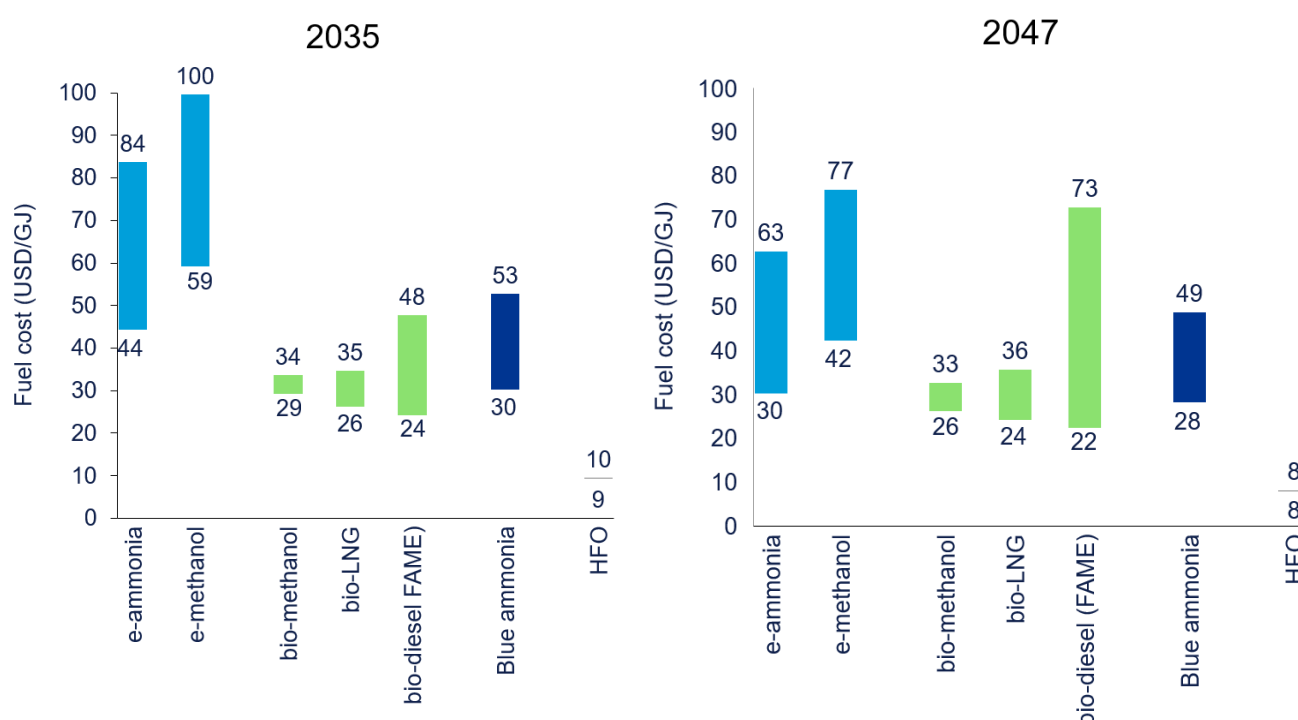


Figure 10: Alternative fuel cost forecast for the regions around India, for 2035 (left) and 2047 (right)

8.4 Required fuel price ranges for India to be competitive

The competitive price ranges for the different alternative fuels in India are illustrated conceptually in Figure 11. For ships already calling at Indian ports, the total fuel price (including taxes, logistics costs and port dues) must match the total fuel price in other visited ports on the route. For ships sailing past India, the total fuel price must be equal to the price in ports on the route minus the additional costs of route deviation. See the case study in chapter 9. for details on required price difference for a ship to deviate from their normal route to bunker in India.

Since we expect alternative fuel supplied in the competing hubs to be produced in locations able to meet the lower end of the cost ranges, the price range in India must be below or in the lower end of the regional cost ranges, illustrated conceptually by the green ranges in Figure 11. It must be highlighted that cost and price forecasting involve significant uncertainties, so focus should be on the indicative ranges and not on specific numbers. For illustrational purposes all the competitive price ranges have the same size in the figure, but the lower price level is naturally irrelevant.

Note that if assessing India's competitiveness against a specific price point in a competing port, any differences port charges, taxes, logistics and bunkering costs, which all add up to the total fuel price, must be taken into account. There are initiatives of reducing port charges for ships using alternative fuels, both in Singapore and in India (see more details and insights in Appendix A.3.3).

For comparison, a recent renewable ammonia auction in India showed delivery prices of around 30-40 USD/GJ (including subsidies of around 5 USD/GJ for the first three years) – details are shown in Appendix A.3.4. This shows that if ammonia projects are realized on this price level Indian ammonia production is already within the competitive range for 2035 and 2047. Appendix A.3.4 also shows the levelized cost of hydrogen (LCOH) in USD/kg hydrogen behind the e-ammonia and e-methanol price ranges.

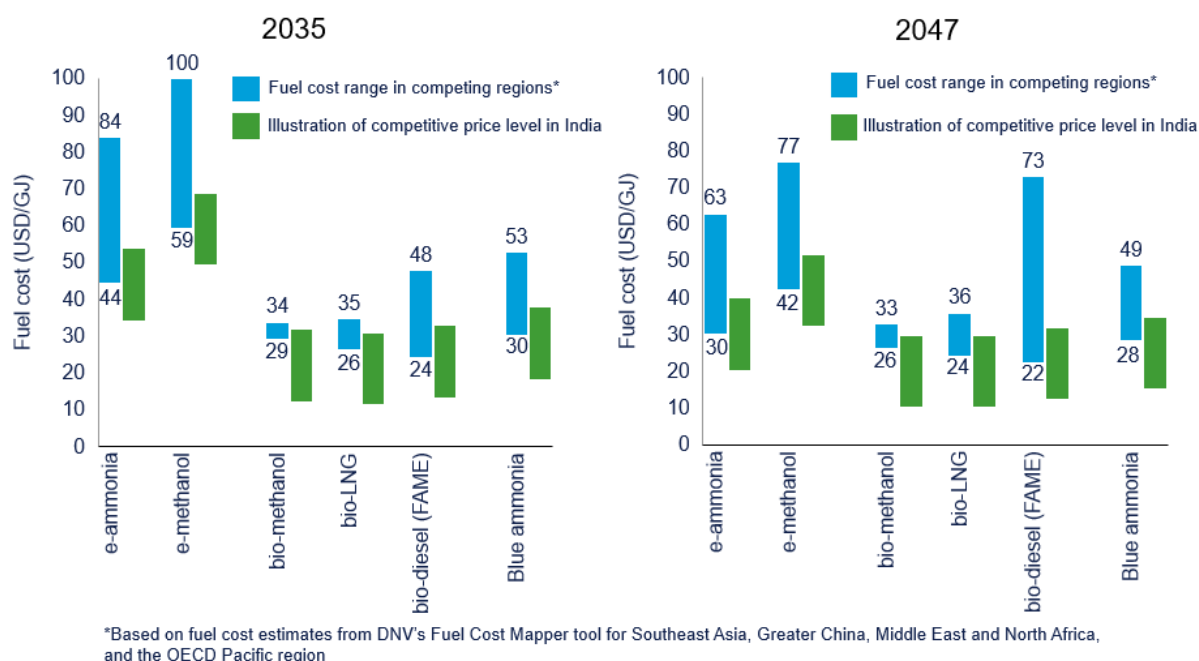


Figure 11: Illustration of competitive fuel price level for the different alternative fuels for India in 2035 (left) and 2047 (right)

9 TOTAL COST OF VOYAGE CASE STUDY

The aim of the total cost of voyage case study is to test what it would cost, in practice, for ships to bunker in India instead of following their usual routes that pass India today. The case study translates the earlier findings on future fuel demand and fuel price ranges into a simple ship-operator question: when does it make financial sense to deviate to an Indian port for bunkering? Two container vessel cases are assessed, reflecting common liner trade patterns: a large ~18,000 TEU vessel on the Far East–West Europe route and a smaller ~3,000 TEU vessel on the Far East–GCC²² / Gulf route. For each case, the analysis compares a “direct” route with deviation options to selected Indian ports and evaluates the resulting change in total voyage cost, including the effects of extra distance, added time, speed adjustments, and additional fuel costs. The results help identify the price and distance conditions under which bunkering in India becomes competitive. Detailed assumptions, vessel inputs, and calculation steps are provided in the Appendix A.4

9.1 Case Selection

The selection of case study vessels is based on the passing vessel traffic analysis conduct in chapter 4. Container vessels are by far the largest segment passing through the defined area south of India, followed by RoRo and LNG vessels. As the container traffic passing India vary in both vessel size and trade routes, two container segments were selected reflecting common liner trade patterns: a large, ~18,000 TEU, vessel on the Far East–West Europe route and a smaller, ~3,000 TEU, vessel on the Far East–GCC/Gulf route.

9.2 Container trades, alternative fuels and bunkering behaviour

Container vessels are generally employed on liner trades, i.e., on fixed trade lanes with multiple fixed port calls for cargo operations. Bunkering while doing cargo operations (SIMOPS) is critical for schedule adherence given the high operating cost of these vessels. While SIMOPS is a standard practice at major global bunkering hubs, its application in Indian ports is currently limited and typically subject to case-by-case approvals, with varying levels of operational readiness across ports. Fuel tank capacity today typically allows at least one full roundtrip on conventional fuels (HFO/MGO), which in most cases provide vessels with several potential bunkering options. The transition to future fuels with lower energy density is expected to increase bunkering frequency, depending on fuel type.

For the container vessel segment, the alternative fuels most prominent in operation and on order are LNG and methanol (see Appendix A.4.2). Ammonia is also considered a potential option. For the two container vessels used in the case studies, methanol is assumed for the larger vessel and ammonia for the smaller vessel. Table 7 presents the typical sailing range (nautical miles) for the case study vessels on conventional fuel (HFO) and the selected alternative fuels, based on the tank capacities of vessels currently on order²³.

Table 7: Overview of typical distance range (in nm) between bunkering stops for the case study vessels

	Large container ship (~18,000 TEU)	Small container ship (~3,000 TEU)
Typical nm range on HFO ²⁴	~25,000 nm	~12,000 nm
Typical nm range on selected alternative fuel	~12,000 nm (Methanol)	~6,000 nm (Ammonia)

9.3 Cost elements included for total cost of voyage

When defining the total voyage cost, the analysis focuses on the incremental cost impact of deviating to bunker in India compared to the current trade route that passes India. Deviation results in additional sailing distance and port time, and vessels can either increase speed to recover time or maintain speed and accept a longer round trip, the latter reducing annual cargo capacity and freight revenue.

²² Gulf Cooperation Council includes Saudi Arabia, United Arab Emirates (UAE), Kuwait, Qatar, Bahrain and Oman.

²³ Since there are very few ammonia powered container ships currently sailing or on order, the onboard ammonia capacity is based on the Approval in Principle (AiP) from 3,500 TEU Maersk ship. Typical methanol capacity onboard large container ships of around 18,000 TEU is 16,000 cubic meters.

²⁴ Evaluated at ECO speed of 16 knots using the average fuel capacity from the selected vessels.

Both options were assessed for the case study vessels, using representative freight rates to estimate lost revenue and conventional fuel (HFO) to estimate additional fuel costs (see Appendix A.4.3). For both vessels, increasing speed is the lower-cost option, consistent with typical container-segment bunkering behaviour driven by high vessel operating costs and high-value cargo. While the transition to alternative fuels may affect this trade-off due to higher fuel prices, these impacts are expected to be reflected in higher freight rates. Table 8 summarises the cost components and net cost effects of deviation, with detailed assumptions provided in Appendix A.4.

Table 8: Overview of cost effect of deviation to India for bunkering

Impact of deviation	Comment	Effect on the cost of the voyage
Additional sailing distance	The sailing distance from the trade route to the bunker port in India.	The vessel increases its speed before/after calling the Indian port to make up for the time lost. This leads to increased fuel consumption and cost, from both the speed increase and the additional distance sailed.
Additional bunkering time	What should be included as additional deviation cost depends on the specific trade and bunkering behaviour. If the vessel would otherwise bunker whilst doing cargo operations, the bunkering time in India must be accounted as additional deviation time. If the bunker stop in India replaces a bunker port stop located close to the trade lane, the bunkering time should not be counted. Assumptions used in the analysis is presented under the results for each case.	
Bunkering cost in India vs. alternative bunker ports	The cost of bunkering in India for the case study vessel compared to the cost in the alternative bunker ports when passing India. The bunker cost covers both the fuel cost and any additional port costs connected to bunkering. It is based on the fuel price assessment in Chapter 8.3 and A.3	Depends on the price variation between Indian ports and the alternative bunker ports. This is a key parameter for determining the cost of the voyage.

9.4 Results from the analysis

The case study results are presented across two key sensitivity dimensions:

1. **Deviation distance:** Three potential bunker ports are assessed for each vessel, selected as the closest options to the relevant trade route among the eight candidate ports (ref. A.1.3)
2. **Bunkering cost variation:** Three bunker cost deltas are applied, representing the price difference between Indian ports and competing bunker ports for the relevant fuel. These deltas are derived from the future fuel price assessment (ref. sub-chapter 8.3.3), using one representative competing-region price point per case, within the defined ranges for 2035 and 2047.

9.4.1 Case study 1: Large container vessel (~18,000 TEU) on East Asia - West Europe trade

For the selected trade route, Cochin Port, V.O.C. Port, and New Mangalore Port are the closest candidate ports to the main route. The reference trade route and deviation routes are shown in Figure 12.



Figure 12: Map of the trade route for case study 1 and deviation route for the three selected ports

Methanol-fuelled vessels in this segment are typically designed to sail between the Strait of Malacca and West Europe without intermediate bunkering, retaining the option to bunker during cargo operations. Deviation to India is therefore treated as an additional cost, including extra sailing distance, speed increase, and port time.

To assess sensitivity to fuel price competitiveness, three bio-methanol bunker cost deltas are evaluated: (i) no price difference between India and competing ports (0%), (ii) a price level at which deviation to the closest port (Cochin) is cost-neutral (-5.5%), and (iii) a 10% lower bunker price in India. Table 9 summarises the impact of deviation on key operational parameters, while Table 10 presents the resulting change in voyage costs for each port and price scenario (see Appendix A.4 for assumptions).

Table 9: Overview of effect of deviation to India on key operational parameters

Key parameters	V.O.C Port	Cochin Port	New Mangalore Port
Additional distance sailed (nm)	101	78	185
Additional time sailing (hrs)	5	4	10
Additional time port (hrs)	13.5	13.5	13.5
Required speed increase ²⁵ (%)	7.2	6.5	9.8
Increase in fuel consumption (% / GJ) compared to direct route	6.5% / 11,650 GJ	5.8% / 10,297 GJ	9.4% / 16,837 GJ

Table 10: Overview of the change in voyage costs for ports and bunker price variations (KUSD per trip)

Bunker cost delta	V.O.C Port	Cochin Port	New Mangalore Port
0 %	373	329	539
- 5.5%	41	0	198
- 10%	-253	-274	-86

The results indicate that a bunker price advantage of around 5.5% makes deviation to Cochin economically viable, with stronger price competitiveness further improving the case. At a 10% price advantage, deviation to all three ports becomes economically feasible. Voyage cost impacts are highly sensitive to green methanol prices, as large container vessels consume substantial fuel volumes. Based on the future fuel price assessment, bio-methanol costs of USD 30–34/GJ—around four times HSFO—significantly magnify the cost-effect of deviation and speed increase. For illustration, deviation to New Mangalore increases voyage costs by ~USD 150,000 per trip under HSFO pricing (USD 350/ton), compared to ~USD 539,000 per trip under current methanol pricing.

9.4.2 Case study 2: Container vessel (~3,000 TEU) on East Asia – GCC Gulf trade

For the selected trade route, Cochin Port, New Mangalore Port, and V.O.C. Port are the closest candidate ports to the main route. The reference trade route and deviation routes are shown in Figure 13.



Figure 13: Map of the trade route for case study 2 and deviation route for the three selected ports

Ammonia-fuelled vessels in this segment are expected to sail between the Strait of Malacca and the Gulf region without intermediate bunkering, retaining the option to bunker during cargo operations. Deviation to India is therefore treated as an additional cost, including extra sailing distance, speed increase, and port time. However, with a typical nautical mile

²⁵ Speed increase calculated for previous port to next port after bunkering in India.

range on ammonia of around 6000 nm, ammonia-fuelled vessels on this route will need to bunker in the UAE before returning to Singapore.

To assess sensitivity to fuel price competitiveness, three e-ammonia bunker cost deltas are evaluated: (i) no price difference between India and competing ports (0%), (ii) a price level at which deviation to the closest port (Cochin) is cost-neutral (-7%), and (iii) a 10% lower bunker price in India. Table 11 summarises the impact of deviation on key operational parameters, while

Table 12 presents the resulting change in voyage costs for each port and price scenario.

Table 11: Overview of effect of deviation to India on key operational parameters

Key parameters	V.O.C Port	Cochin Port	New Mangalore Port
Additional distance sailed (nm)	69	12	23
Additional time sailing (hrs)	4.6	1.0	1.5
Additional time port (hrs)	13.5	13.5	13.5
Required speed increase (%)	7	4.6	5.1
Increase in fuel consumption (% / GJ) compared to passing vessel	12.5% / 3,636 GJ	7.5% / 2,198 GJ	8.5% / 2,479 GJ

Table 12: Overview of the change in voyage costs for ports and bunker cost variations (kUSD per trip)

Bunker cost delta	V.O.C Port	Cochin Port	New Mangalore Port
0 %	200	120	136
-7%	73	0	14
-10%	19	-51	-37

Based on an e-ammonia price of USD 55/GJ, deviation to India first becomes economically viable at Cochin when bunker prices are at least ~7% lower than competing ports such as Singapore. Deviation distances on the East Asia–Gulf route are smaller than for the Europe trade, as vessels sail closer to India, but the shorter total route length requires a higher speed increase, leading to higher relative fuel consumption. Given that e-ammonia is more expensive than bio-methanol, a larger price advantage is required to offset these effects. Even at a 10% bunker price advantage, deviation to V.O.C. Port remains uneconomic, reflecting its greater distance from the trade lane.

9.5 Key insights

Likelihood of deviation: Alternative fuel price differentials and deviation distance are the key determinants of whether vessels will deviate to bunker. Because bio-methanol and e-ammonia are substantially more expensive than conventional fuels, even small price advantages matter. For bio-methanol, a price advantage of ~5.5% (Case 1) can justify deviation to Indian ports, while e-ammonia requires ~8% or more (Case 2). At higher fuel prices, the cost of additional sailing distance increases sharply, underscoring that competitive pricing at Indian ports is critical to attract bunkering demand.

For container vessels, bunkering decisions largely follow cargo operations. The dominant passing segment comprises liner container vessels on fixed routes. Large methanol-fuelled vessels on the Asia–Europe trade via Suez are typically designed to complete the full Southeast Asia–Europe leg without bunkering, making deviation to non-cargo ports unlikely. Even where bunkering is required, several alternative ports closer to the trade lane reduce the likelihood of deviation to India. On the Asia–Gulf route, bunker options are more limited, and ports in South/West India and Sri Lanka are better positioned; however, given the short sailing distance, vessels are still likely to be designed to complete the voyage between Singapore and the UAE without intermediate bunkering.

Impact on required fuel prices: The results from the case study shows that for a large container vessel, normally sailing past India to deviate from their normal route to bunker in India, the price difference between India and Singapore must be around 5.5% for bio-methanol and 7% for e-ammonia. If the 2030 bio-methanol and e-ammonia price in Singapore is 32 and 55 USD/GJ, respectively, the required price in India must be 30 and 51 USD/GJ for the vessel to choose to deviate from its route to bunker in India (as long as additional costs related to taxes, port dues, logistics and bunkering are similar across the different ports).

10 RECOMMENDATIONS FOR THE DEVELOPMENT OF ALTERNATE FUEL BUNKERING IN INDIA

The recommendations in this chapter are based on the analysis presented in Chapters 4 to 9. This includes route analysis, baseline and future fuel demand assessment, stakeholder insights, fuel price assessment and the total cost of voyage analysis.

Based on this analysis, key findings are identified across different stages of the maritime value chain. These findings are then brought together into a set of key barriers affecting the development of alternative fuel bunkering in India. The barriers are mapped along the alternative fuel bunkering value chain to illustrate where challenges arise and which actors are affected.

The recommendations presented in this chapter aim to address these barriers and support the development of alternative fuel bunkering in India. While some recommendations target specific barriers, others address multiple barriers across different stages of the value chain. Each recommendation therefore indicates the relevant value-chain actors responsible for implementation, as well as the indicative timeline for action.

The recommended actions are organized across three-time horizons: short term (2026–2030), medium term (2030–2035) and long term (2035–2047).

The recommendations are also mapped against the relevant pillars of the National Green Shipping Policy (NGSP)²⁶ draft released by the Government of India.

Further details on the methodology and the mapping of findings to barriers are provided in Appendix.

10.1 The alternate fuel bunkering value chain

When developing recommendations to enable alternative marine fuel bunkering in India, it is important to view bunkering as part of a broader maritime fuel value chain rather than as a standalone port activity. A detailed mapping of stakeholders across each stage of the value chain is provided below in Figure 14. The list is indicative and does not represent an exhaustive inventory.

The value chain framework is used in this study to structure the analysis. Findings from the study were mapped to the different stages of the value chain to identify where challenges occur and which stakeholders are affected. These findings were then consolidated into key barriers, which form the basis for the recommendations presented in this chapter. The value chain therefore helps connect the study findings, the identified barriers, and the recommended actions including assigning the responsible actors for implementation.

Globally, alternative marine fuels are still at an early stage of market development. The emergence of bunkering activity depends on coordinated progress across fuel production, logistics, storage, port infrastructure, vessel readiness and end-user demand.

²⁶ <https://maritimeunionofindia.com/pdf/Draft%20NGSP%20Version%204.pdf>

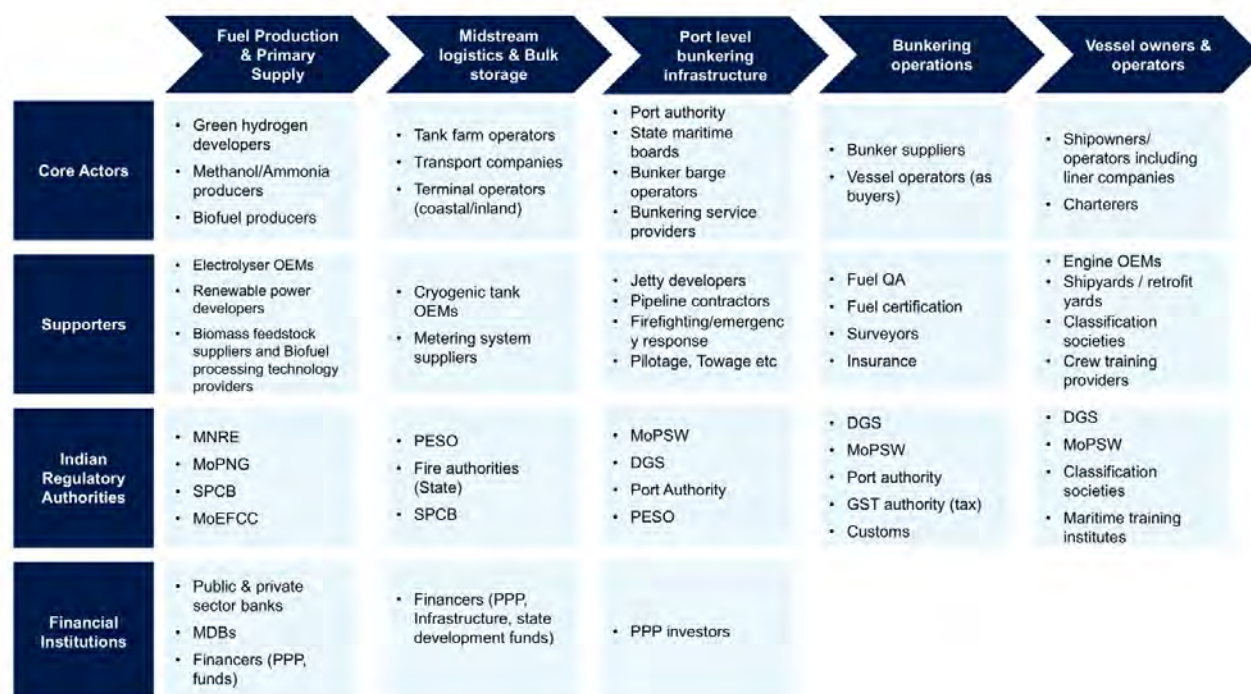


Figure 14: Maritime value chain

10.2 Barriers limiting alternative fuel bunkering development in India

Across the value chain, the study identified a set of barriers that currently limit the development of alternative fuel bunkering in India. These barriers are based on the analysis presented in Chapters 4–9 of this study and also reflect insights gathered through stakeholder consultations with port authorities, bunker suppliers, shipping lines, safety regulators, and fuel producers. In addition, a dedicated multi-stakeholder workshop was conducted to discuss the preliminary findings and understand the perspectives of different actors across the value chain. The value chain framework was used to organise these inputs and identify where the main constraints occur.

The key barriers identified in the study are:

1. **Absence of credible long-term demand commitments**, discouraging investments in fuel production, bunkering infrastructure, and supply chain.
2. **Limited availability of ancillary services alongside bunkering**, reducing the operational attractiveness of Indian ports compared with established bunkering hubs.
3. **Limited policy and institutional coordination for alternative fuel bunkering development in India**, slowing the formation of supply chains and market uptake.
4. **Fragmented approvals and unclear regulatory responsibilities**, involving multiple authorities, leading to delays and project risks.
5. **High infrastructure cost for alternative fuel storage and distribution**, particularly for storage tanks, pipelines, and bunker vessels, increasing investment risk for early infrastructure development.

6. **High production costs (and hence prices) of alternative fuels, especially e-methanol and e-ammonia**, reducing the commercial competitiveness of alternative fuels and slowing the adoption by shipowners.
7. **Higher port-level charges and taxes** compared with major bunkering hubs, increasing the delivered bunker cost and reducing the competitiveness of Indian ports.
8. **Unavailability of operational standards and safety protocols for alternative fuel bunkering**, including SIMOPS clarity, creating operational uncertainty and safety risks for bunkering operations

Figure 15 presents the mapping of barriers across the value chain

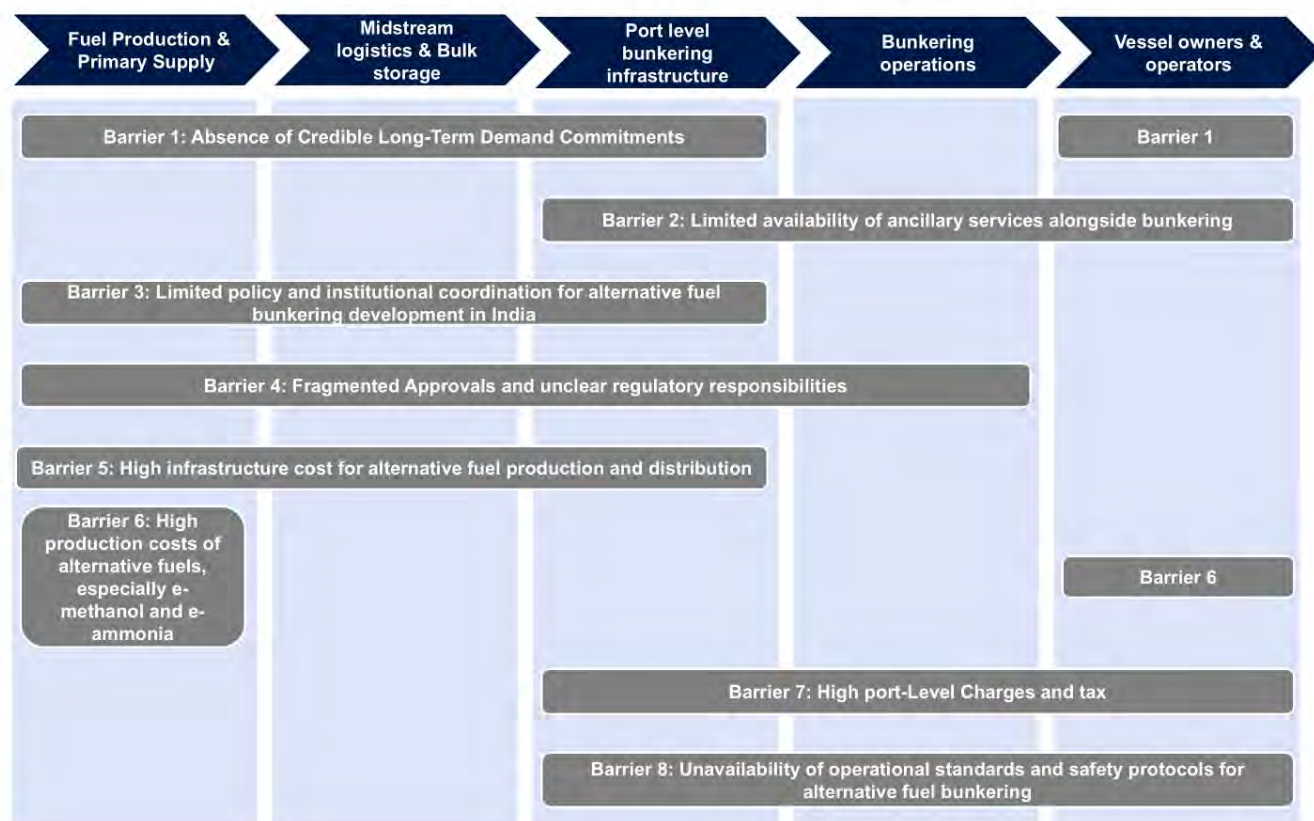


Figure 15: Mapping of barriers along value chain

Many of the barriers are interconnected. For example, uncertain demand discourages investment in fuel production and bunkering infrastructure, while high production costs increase the delivered fuel price at the vessel. Higher fuel prices, in turn, reduce the willingness of shipowners to bunker alternative fuels, further weakening demand. Addressing these barriers therefore requires coordinated action across several actors in the value chain.

10.3 Recommendations for developing alternative fuel bunkering in India

Based on the barriers identified across the alternative fuel bunkering value chain, the following recommendations are proposed to support the development of alternative-fuel bunkering in India. The actions are sequenced across three time horizons: short term (2026–2030), medium term (2030–2035) and long term (2035–2047).

Figure 16 below provides the list of recommendations along different time horizons mapped as per their impact in value chain.

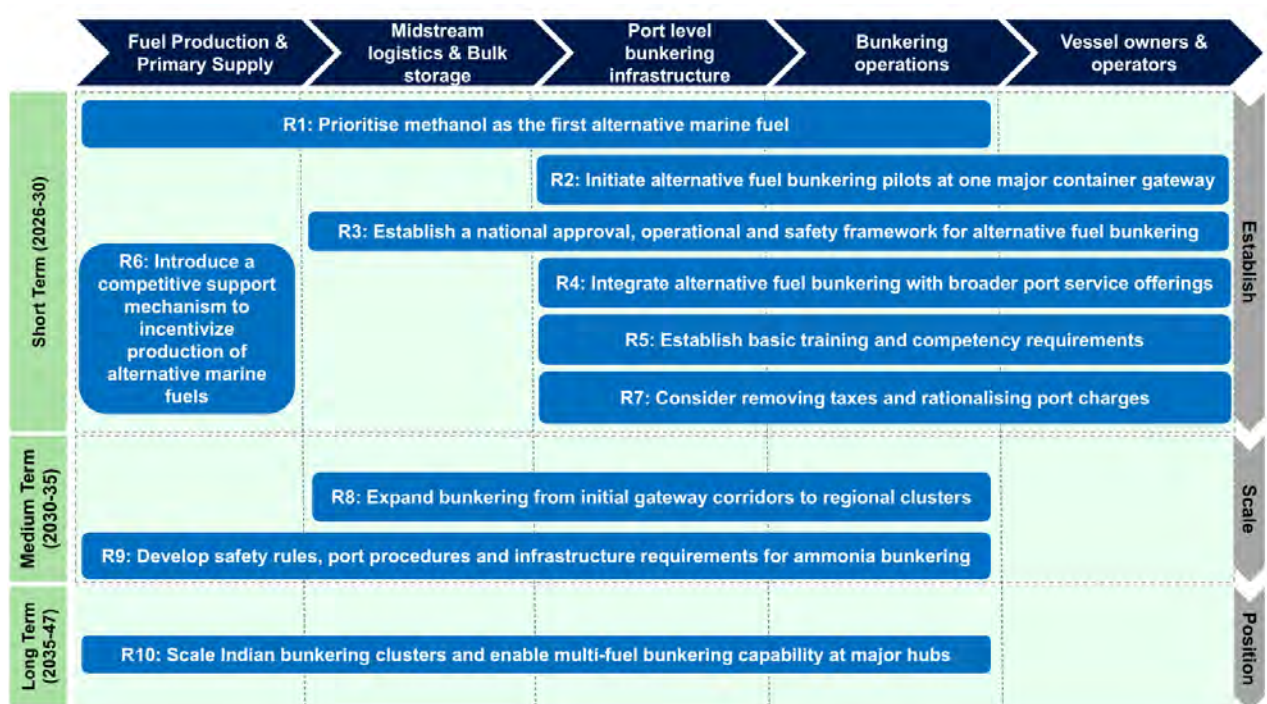


Figure 16 : Recommendations along value chain

10.3.1 Short Term (2026-30) Recommendations: Establish

The first phase focuses on creating the basic conditions for reliable alternative fuel bunkering. This entails anchoring demand at a few selected container gateways, prioritising methanol as the initial fuel pathway, introducing tax and port charge neutrality, clarifying approvals and establishing operational standards. Infrastructure development during this phase should remain flexible and limited to designated hubs. The objective of this phase is to initiate pilot bunkering operations and establish the conditions required for repeatable bunkering services.

R1: Prioritise methanol as the first alternative marine fuel and develop supply chains linking production with the identified early bunkering ports

Background:

The current global order book for alternative-fuel vessels indicates that early uptake of alternative marine fuels is likely to be driven by methanol before ammonia, particularly during the 2026–2030 period. This trend is also reflected in the demand analysis conducted in this study (Chapters 6 and 8). Scenario results show that early fuel demand is expected to be dominated by fuels such as bio-methanol and biodiesel, before e-methanol and e-ammonia scale in later years. The analysis also identifies international container liners as the most likely early demand segment, due to predictable schedules and the growing number of methanol-capable vessels entering service.

International experience shows that ports that signal priority fuels and align infrastructure accordingly have progressed faster. For example, Singapore's Maritime Decarbonisation Blueprint and methanol bunkering framework, as well as Rotterdam's staged fuel readiness approach, demonstrate how fuel prioritisation combined with targeted pilot projects can reduce market uncertainty and support the development of bunkering supply chains.

Barriers addressed:

Barrier 1,3 and 6

Actions:

- MoPSW and DGS to prioritise methanol as the first alternative marine fuel pathway for bunkering operations in India, reflecting the growing number of methanol-capable container vessels entering service globally.
- MoPSW and the Ministry of Petroleum and Natural Gas, to engage domestic methanol producers and assess the availability of reliable supply that could support marine bunkering demand.
- Deendayal Port Authority (Kandla) and V.O. Chidambaranar Port Authority (Tuticorin) to assess how their existing chemical cargo handling capabilities and designation as National Green Hydrogen Mission hubs can support future alternative fuel bunkering supply chains.
- Fuel producers, terminal operators and bunker suppliers to evaluate logistics required for supplying methanol to the ports of Mundra, JNPT, Chennai and Tuticorin, including bunker barges, coastal transport, storage and transfer infrastructure.
- Port authorities, bunker suppliers and terminal operators to evaluate the requirement for dedicated methanol bunker vessels to support regular bunkering operations at these ports.
- Pilot projects may also include other low-carbon fuels such as biofuels or bio-LNG where supply is available, allowing ports and operators to build operational experience while the methanol supply chain is developed.

Responsible Authorities: Ministry of Ports, Shipping and Waterways (MoPSW), Directorate General of Shipping (DGS), Ministry of Petroleum and Natural Gas, Deendayal Port Authority (Kandla), Adani Ports and Special Economic Zone – Mundra, Jawaharlal Nehru Port Authority (JNPA), Chennai Port Authority, V.O. Chidambaranar Port Authority (Tuticorin)

R2: Initiate alternative fuel bunkering pilots at one major container gateway (Mundra) and develop hub-and-spoke supply across key Indian container corridors

Background:

Route analysis and baseline demand assessment indicate that international container vessels represent the most concentrated demand segment for alternative fuel bunkering at Indian ports (Ch.4–5). AIS-based port profiling shows that Mundra and JNPT function as India's primary container gateways with the highest liner coverage and cargo throughput. Logistics analysis further indicates that these ports can be supplied from designated National Green Hydrogen Mission hubs with the Deendayal (Kandla) hub located approximately 75 km from Mundra, enabling feasible fuel supply logistics (Ch.6.3, Table 5). These findings support a phased development approach in which initial bunkering operations are established at a single major gateway, before expanding to additional ports through hub-and-spoke logistics once operational experience is established.

Barrier Addressed:

Barrier 1,3 and 5

Actions:

- MoPSW to initiate the first alternative-fuel bunkering pilot at Mundra Port, reflecting its position as one of India's largest container gateways and its proximity to the Deendayal (Kandla) Green Hydrogen hub, which could support fuel supply logistics.

- Adani Ports (Mundra) and Deen Daya Port Authority (Kandla) together with bunker suppliers and terminal operators to evaluate the infrastructure required for pilot bunkering operations, including storage arrangements, transfer systems and bunker vessel deployment.
- Following initial operational experience, MoPSW and port authorities to extend bunkering capability to JNPT, allowing the Mundra–JNPT corridor to function as the primary west-coast bunkering gateway for container traffic. Port authorities and bunker suppliers to apply a hub-and-spoke supply model, where bunker vessels or coastal fuel transport can serve vessels calling Mundra and JNPT without requiring identical infrastructure at both ports.
- As operations stabilise, MoPSW and port authorities to prepare the southern container corridor (Chennai–Tuticorin) for subsequent bunkering deployment, supported by supply chains linked to the V.O. Chidambaranar Green Hydrogen hub.
- MoPSW and port authorities to engage major container shipping lines already calling these ports—including Maersk, MSC and CMA CGM—to identify services where alternative fuel vessels are deployed or expected.
- MoPSW to prioritise early Green Shipping Corridor discussions linking these ports with major regional hubs in Europe, the Middle East Gulf and South-East Asia, where alternative fuel vessel deployment is expected to increase.
- MoPSW and port authorities to initiate Green Shipping Corridor discussions linked to the proposed pilot bunkering ports, focusing on major trade routes where deployment of alternative-fuel vessels is expected to increase.

Initial corridor development could focus on routes connecting Indian container gateways with:

- Middle East Gulf hubs
- South-East Asian transshipment hubs
- Selected European ports engaged in alternative-fuel shipping initiatives

India has already begun exploring several Green Shipping Corridor initiatives which could provide a foundation for further development. Examples include:

- Rotterdam–India–Singapore corridor discussions, involving ports such as V.O. Chidambaranar and Deendayal Port (Kandla)
- Coastal Green Shipping Corridor initiative, with the Kandla–Tuticorin corridor identified as an initial domestic pilot in partnership with Shipping Corporation of India, Deendayal Port Authority and V.O. Chidambaranar Port Authority²⁷
- Singapore–India Green and Digital Shipping Corridor (GDSC)²⁸

Responsible Authorities: Ministry of Ports, Shipping and Waterways (MoPSW), Directorate General of Shipping (DGS), Deendayal Port Authority (Kandla), Adani Ports and Special Economic Zone – Mundra, Jawaharlal Nehru Port Authority (JNPA), Chennai Port Authority, V.O. Chidambaranar Port Authority (Tuticorin)

²⁷ [Press Release: Press Information Bureau](#)

²⁸ [Singapore and India Formalise Collaboration on Green and Digital Shipping Corridor | Maritime and Port Authority of Singapore](#)

R3: Establish a national approval, operational and safety framework for alternative fuel bunkering

Background:

Stakeholder consultations and policy assessment conducted in this study highlight that India currently lacks national approval and operational framework for alternative fuel bunkering (Chapter 1; Appendix A.2.3). While programmes such as Sagarmala, Maritime India Vision 2030 and the National Green Hydrogen Mission support port modernisation and future fuel infrastructure, regulatory pathways for fuel storage, handling, bunkering operations and safety approvals remain fragmented across multiple agencies. This creates uncertainty for project developers and shipowners considering bunkering investments. International practice shows that early-stage alternative fuel deployment is typically supported by clear national licensing and operational frameworks. For example, Singapore's Maritime and Port Authority introduced a unified methanol bunkering framework supported by the TR-129 standard, which defines operational procedures, safety requirements, SIMOPS conditions, and training obligations. Similarly, the Port of Rotterdam operates a structured bunkering licensing system supported by standardised operational guidelines and coordinated safety frameworks developed with industry stakeholders. Establishing a comparable national framework in India would provide regulatory clarity, reduce project-approval uncertainty, and enable consistent bunkering operations across ports.

Barrier Addressed:

Barrier 4 and 8

Actions:

Approval Framework

- MoPSW, DGS and PESO to define a clear national approval process for alternative-fuel bunkering projects, covering infrastructure development, bunker vessels and operational licensing.
- Port authorities (Mundra, JNPT, Chennai and Tuticorin) to apply this approval process when evaluating early bunkering projects.

Operational and Safety Framework

- MoPSW and DGSGS to establish national operational guidance for alternative fuel bunkering covering fuel handling procedures, emergency response arrangements and allocation of responsibilities between port authorities, bunker suppliers and vessels.
- DGS and PESO to define safety requirements for bunkering operations and bunkering infrastructure, drawing on international practices such as IMO guidance and industry standards including TR-129 for methanol bunkering
- The framework should define SIMOPS conditions, including when alternative-fuel bunkering may occur alongside cargo operations or other port activities.

Responsible authorities: Ministry of Ports, Shipping and Waterways (MoPSW), Directorate General of Shipping (DGS), Petroleum and Explosives Safety Organization (PESO), State Maritime Boards, Port Authorities

R4: Integrate alternative fuel bunkering with broader port service offerings to make Indian port calls commercially attractive

Background:

Stakeholder consultations (Chapter 1) and the total cost-of-voyage analysis conducted in this study (Chapter 9) shows that container vessels are unlikely to deviate from their normal trade routes solely to bunker fuel, particularly on major liner routes such as Asia–Europe. Bunkering decisions therefore tend to follow existing cargo calls and port services, where vessels already stop for loading, unloading or operational services. The study further indicates that shipowners prefer ports where multiple activities—such as cargo handling, crew change, repairs and supplies—can be completed during a single call, reducing operational disruption and overall voyage cost. Integrating alternative-fuel bunkering into this broader port service ecosystem can therefore improve the attractiveness of Indian ports as bunkering locations

Barrier Addressed:

Barrier 2

Actions:

- Port authorities to position alternative-fuel bunkering as part of a broader port service package combining bunkering with transshipment, crew change, ship repairs and other marine services, allowing container liners to combine multiple activities during a single port call.
- Port authorities and bunker suppliers to ensure that fuel testing, sampling and sustainability certification services are available to support bunkering of alternative fuels supplied to vessels.

Responsible authorities: Port Authorities (Mundra, JNPT, Chennai, Tuticorin)

R5: Establish basic training and competency requirements for alternative fuel bunkering operations

Background:

Stakeholder consultations conducted as part of this study (Chapter 1) highlight that training and operational readiness for handling alternative marine fuels remain limited across Indian ports. While regulatory frameworks and technical standards are developing globally, safe bunkering operations also depend on trained personnel capable of managing fuel transfer procedures, emergency response, and coordination between port authorities, bunker suppliers, and vessels. Building basic competency among operational staff during the early phase of bunkering deployment can therefore reduce operational risk and support the reliable implementation of pilot projects.

Barrier Addressed

Barrier 8

Actions:

- DGS and MoPSW to define minimum competency requirements for personnel involved in alternative-fuel bunkering operations, including port officials, bunker operators and emergency response teams
- DGS and maritime training institutes to incorporate alternative fuel handling modules into existing maritime training and certification programmes
- Port authorities and bunker suppliers to use bunkering pilots as practical training opportunities for port staff and operational personnel.

Responsible authorities: DGS, MoPSW, Maritime Training Institutes, Port Authorities (Mundra, JNPT, Chennai, Tuticorin)

R6: Introduce a competitive support mechanism to incentivise production of alternative marine fuels

Background:

The study's fuel price assessment (Chapter 8 and Appendix A.1) shows that while India has strong long-term advantages for producing alternative fuels due to favourable renewable energy potential, these fuels remain significantly more expensive than conventional marine fuels. The study notes specifically the high costs of producing renewable hydrogen-derived fuels such as e-methanol and e-ammonia, mainly due to high electricity costs and investment costs. In this context, financial support to early movers in alternative fuel production can help bridge the cost gap and accelerate early market development. Competitive auctions or investment support can be an effective way to provide such support while maintaining cost discipline. Examples include the EU Hydrogen Bank auctions, where projects compete for the lowest subsidy per unit of fuel produced, and India's own SECI ammonia auctions, which demonstrate that this model is already familiar in the Indian context.

Barrier Addressed:

Barrier 5 and 6

Actions:

- MNRE and the Ministry of Petroleum and Natural Gas to introduce a competitive support mechanism, publicly funded during the initial phase to support the production of alternative fuels intended for marine bunkering and reduce the cost gap to fossil fuels.
- The support mechanism can either be auction-based operational support per unit of fuel produced, or coordinated investment support across the value chain. If both mechanisms are offered it is important to make sure the same projects are not double financed
- Alternative 1: Auction-based support mechanism:
 - Fuel producers participate in the auction with a bid price representing for the lowest level of financial support they need per unit of fuel produced to make the project viable. The lowest bids win, until the auction budget is exhausted.
 - Auction winners receive a fixed premium for a certain time period (such as 10 years), linked to certified fuel production volumes and clear delivery milestones.
 - Eligibility for auction participation to be conditional on non-binding offtake agreements or expressions of interest from fuel offtakers.
 - The design of the auction system can be modelled based on international programmes such as the EU Hydrogen Bank auctions, which provide competitive support for hydrogen and hydrogen-based fuel production.
- Alternative 2: Coordinated investment support:
 - Another competitive support mechanism is coordinated investment support across production facilities, bunkering infrastructure and vessels, where project developers compete for the lowest support required per installed capacity. Similar programmes have been implemented in Norway to establish early hydrogen and ammonia fuel supply chains.

- The program should have a fixed application deadline and coordinated timelines across the supply and vessel side.
- To align with India's early bunkering strategy, prioritise support for methanol production for marine bunkering during 2026–2030, while broader fuel diversification can be considered as demand visibility improves.
- Allocate a defined share of domestic production achieved through support mechanisms for domestic bunkering at designated ports, ensuring that supported production contributes to the development of domestic bunkering.

Responsible authorities: MoPSW, Ministry of New and Renewable Energy (MNRE), Ministry of Petroleum and Natural Gas

R7: Consider removing taxes and rationalising port charges in order to stimulate lower delivery cost of alternative marine fuels

Background:

The study's assessment of bunkering competitiveness (Chapter 8 and Appendix A.3) shows that bunkering in India is currently more expensive than in major global hubs such as Singapore, Fujairah, and Rotterdam. The analysis finds that bunker fuel prices at Indian ports are significantly higher than at major global hubs, and that this gap widens further when GST, port dues, pilotage, towage, and other operational charges are included. Stakeholder consultations also confirmed that these charges are not always transparent or consistent across ports, which creates uncertainty for bunker suppliers and ship operators. The study therefore indicates that improving competitiveness will require not only lower fuel production costs, but also tax neutrality and more transparent, rationalised port charging structures. International practice supports this approach: for example, Singapore applies zero GST to bunker fuel supplied to foreign-going vessels, while ports such as Rotterdam use targeted port-fee incentives to support uptake of cleaner fuels.

Barrier Addressed:

Barrier 6

Actions:

- Ministry of Finance and MoPSW to ensure that alternative marine fuels supplied to vessels, both domestic and foreign going are not subject to taxes that increase the bunker price, including GST, excise duties or customs duties. Exemptions or refund mechanisms should be introduced where these apply.
- Port authorities to review port dues, pilotage, towage, and berth hire charges associated with bunkering operations and assess whether temporary reductions can be offered to vessels using alternative fuels during the early market development phase. Also, these charges should be consistent across ports, reducing uncertainty for bunker suppliers and vessel operators.
- Any reductions in port charges can be time-limited and subject to review after three to four years, allowing authorities to assess utilisation levels, impact on bunkering activity, and benchmark competitiveness against other regional ports

Responsible authorities: MoPSW, Ministry of Finance, Port Authorities, DGS

10.3.2 Medium-Term (2030-35) Recommendations: Scale

In the medium term, India should build on the lessons from the initial bunkering supply chains and focus on scaling them further. Infrastructure expansion should follow proven demand and reliable operations. Storage and supply infrastructure can be expanded where volumes justify the investment.

Preparation for ammonia and other next-generation fuels can also progress during this phase, provided appropriate safety systems are in place and demand is sufficient to avoid underused infrastructure.

As commercial viability improves, public financial support can gradually be reduced, with a larger share of investment coming from private operators.

The aim of this phase is to stabilise operations, reduce costs, and move from early pilots to stable commercial operations

R8: Expand bunkering from initial gateway corridors to regional clusters as demand stabilises

Background:

As discussed in the short term recommendations (R2), the initial development of alternative fuel bunkering in India should focus on a limited number of gateway ports and container corridors, beginning with a pilot at Mundra, followed by expansion along the Mundra–JNPT corridor and subsequently the Chennai–Tuticorin corridor. This phased approach allows operational experience, supply chains, and early demand to develop in a controlled manner. As bunkering volumes grow and operational procedures become established, expansion to additional nearby ports may be considered through a regional cluster approach, where ports share fuel supply logistics, storage infrastructure, and bunker vessels. Unlike some global bunkering hubs such as Singapore, where activity is concentrated in a single port, India's maritime traffic is distributed across multiple coastal gateways. A cluster model therefore provides a practical way to expand bunkering services while maintaining economies of scale and operational efficiency.

Barrier Addressed:

Barrier 1,3 and 5

Actions:

- Extend the Mundra–JNPT corridor to a West Coast bunkering cluster, including Deendayal Port (Kandla) and nearby ports where shared fuel supply logistics are feasible.
- Extend the Chennai–Tuticorin hub to an East Coast cluster, potentially including Paradip and Visakhapatnam to serve bulk and non-container segments.
- Develop permanent storage and fuel-handling facilities at the primary gateway ports (Mundra, JNPT, Chennai, and Tuticorin). As demand grows, selectively replicate storage infrastructure at additional cluster ports where utilisation levels justify investment.

Responsible Authorities: Ministry of Ports, Shipping and Waterways (MoPSW), Port Authorities, Terminal Operators, Bunker Suppliers

R9: Develop safety rules, port procedures, and infrastructure requirements for ammonia bunkering at selected pilot ports

Background:

As described in the short-term recommendations (R1), the study identifies methanol as the most likely early alternative marine fuel for bunkering in India during the initial development phase (2026–2030). However, scenario analysis also indicates that ammonia may become an important marine fuel in later years, particularly as e-ammonia production scales and ammonia-capable vessels enter service. Compared with methanol, ammonia presents more complex safety and handling requirements, including toxicity risks, specialised transfer procedures, and stricter operational safety measures. International experience shows that ports typically begin preparing for ammonia bunkering several years before commercial operations begin, through safety studies, pilot projects, and interim operational guidance. Early preparation allows authorities to define infrastructure requirements, safety procedures, and approval conditions before the industry proposes projects.

Barrier Addressed:

Barrier 4 and 8

Actions:

- DGS with input from PESO and other relevant safety bodies to issue interim ammonia bunkering safety and operational guidelines, applicable for 2-3 pilot ports. It should cover minimum safety distances, SIMOPS restrictions, emergency response arrangements, and allocation of responsibilities between ports, bunker suppliers, and vessels.
- Selected port authorities to undertake port-specific safety and feasibility studies for ammonia bunkering, assessing berth configuration, safety zones, transfer arrangements, and emergency response capability.
- Based on these studies, port authorities to define infrastructure requirements and approval conditions for future ammonia bunkering projects, including storage, transfer systems, and operational procedures.

Responsible Authorities: Ministry of Ports, Shipping and Waterways (MoPSW), Directorate General of Shipping (DGS), PESO, Port Authorities

10.3.3 Long-term (2035-47) Recommendations: Position

The final phase focuses on strengthening India's long-term position in alternative fuel bunkering and green shipping. By this stage, the earlier phases of pilot projects, corridor development, and cost competitiveness are expected to have established operational experience and stable demand at selected Indian ports. The focus therefore shifts from early adoption to scaling bunkering activity and integrating India into regional green shipping networks. Expansion to additional ports should remain demand-driven and commercially justified, building on the regional bunkering clusters developed in earlier phases.

R10: Scale Indian bunkering clusters and enable multi-fuel bunkering capability at major hubs

Background:

As described in the short- and medium-term recommendations (R1 and R8), India's alternative-fuel bunkering system is expected to develop initially through gateway pilots and regional clusters along the west and south coasts. In the long term, if these clusters achieve stable demand and competitive fuel supply, selected ports may evolve into regional bunkering hubs serving major Indian Ocean trade routes. As the alternative fuel market matures, different fuel pathways—such as methanol, ammonia, and other emerging fuels—may coexist. Ports with sufficient demand and

operational capability may therefore develop the infrastructure required to safely handle more than one fuel type. The objective of the long-term phase is to allow India's bunkering clusters to scale in response to market demand while maintaining safe and reliable operations.

Barrier Addressed:

Barrier 1,3, 5, and 6

Actions:

- Scale alternative fuel bunkering infrastructure at Indian ports where sustained demand has been demonstrated, building on the gateway ports and clusters developed during earlier phases.
- Strengthen fuel supply chains, storage infrastructure, and terminal operations within established west-coast and east-coast bunkering clusters.
- Allow major bunkering ports to handle multiple alternative fuels (e.g. methanol, ammonia, and other emerging fuels) where demand and safety frameworks support their use.
- Support the commercial operation of green shipping corridors linking Indian bunkering hubs with major regional trading partners in the Middle East, South-East Asia and East Asia.

Responsible Authorities: Ministry of Ports, Shipping and Waterways (MoPSW), DGS, Port Authorities, International Partner Ports

10.4 Alignment with National Green Shipping Policy (NGSP)

India's National Green Shipping Policy (NGSP) provides a framework for reducing greenhouse gas emissions from the maritime sector and supporting the transition to low- and zero-emission shipping. The policy outlines a set of strategic pillars covering infrastructure development, fuel transition, financing mechanisms, workforce development, and regulatory measures required to support maritime decarbonisation.

The recommendations presented in this study have been developed with the objective of supporting India's long-term ambition to become a competitive and environmentally sustainable maritime nation. To ensure consistency with national policy priorities, each recommendation has been mapped to the relevant NGSP strategic pillars.

The NGSP identifies seven key pillars supporting India's maritime decarbonisation pathway:

- **Green Ports:** Development of port infrastructure, logistics systems, and operational practices that support low-emission shipping and enable alternative fuel bunkering and energy-efficient port operations.
- **Green Fuel:** Promotion of low-carbon and zero-carbon marine fuels such as methanol, ammonia, hydrogen, and biofuels, including the development of production, storage and supply chains.
- **Green Shipping:** Encouragement of low- and zero-emission vessels, operational efficiency improvements, and adoption of technologies that reduce emissions from shipping activities.
- **Green Finance:** Mobilisation of financial mechanisms, incentives and investment frameworks to support maritime decarbonisation, including support for fuel production, infrastructure development and low-emission vessels.
- **Green Skill Development and Human Resources:** Development of training programs and workforce capabilities required for safe handling of new fuels, operation of new technologies, and implementation of decarbonisation measures across the maritime sector.

- **Green Technology and Innovation:** Promotion of research, development, and demonstration of new maritime technologies, including alternative propulsion systems, fuel production pathways, and digital solutions supporting emission reduction.
- **Green Ship Recycling:** Promotion of environmentally sound ship recycling practices aligned with international conventions and sustainability principles.

10.4.1 Mapping of Recommendations with NGSP Pillars

The recommendations proposed in this study support several of the strategic objectives outlined in the National Green Shipping Policy. Table 13 summarises how the recommendations align with the NGSP pillars²⁹. The table below shows how the recommendations in this study support the different pillars of the National Green Shipping Policy. The recommendations translate the policy objectives into practical actions that can be implemented by ports, regulators, and industry stakeholders. Some recommendations contribute to more than one pillar because developing alternative fuel bunkering requires coordinated progress across infrastructure, fuel supply, regulation, and workforce capability.

Table 13: Mapping of recommendations with NGSP Pillars

Recommendation	Green Ports	Green Fuel	Green Shipping	Green Finance	Green Skills & HR	Green Technology & Innovation
R1	✓	✓				✓
R2	✓	✓				
R3	✓		✓			
R4	✓					
R5:					✓	
R6	✓	✓		✓		
R7	✓		✓	✓		
R8	✓	✓	✓		✓	✓
R9	✓	✓	✓	✓		✓
R10	✓	✓	✓	✓	✓	✓



Primary NGSP pillar to which the recommendation is aligned



Secondary NGSP pillar linkages

The mapping illustrates that the study recommendations collectively support all major pillars of the National Green Shipping Policy. Infrastructure-related measures primarily contribute to the **Green Ports** pillar, while fuel pathway

²⁹ Green Ship Recycling has been removed intentionally from the table, as our current study does not cover Ship Recycling at all



prioritisation and production support mechanisms align with the **Green Fuel** pillar. Financial competitiveness measures—including tax neutrality and production support—contribute to **Green Finance**, while workforce capability initiatives support **Green Skill Development and Human Resources**. Finally, several recommendations directly support the **Green Shipping** pillar by enabling the deployment of alternative-fuel vessels and the development of green shipping corridors. Taken together, the recommendations provide a phased pathway that translates the strategic objectives of the NGSP into practical actions for ports, fuel suppliers, and shipping operators.

APPENDIX A: DETAILED METHODOLOGY AND SUPPORTING ANALYSIS

A.1 ROUTE ANALYSIS

A.1.1 Passing traffic – Methodology

To evaluate the potential for attracting passing vessels for bunkering services, the study divides the maritime area into three zones—A, B, and C based on proximity to India and the likelihood of vessels considering Indian ports for bunkering. This zoning approach ensures a structured analysis of trade patterns along busy international routes and diversion feasibility. Zone A has been delineated based on observed vessel traffic patterns rather than a uniform coastal distance. Heat map analysis in Figure A 1 shows that vessels transiting India without calling at Indian ports predominantly pass south of the India, forming a concentrated traffic corridor in this region. While all such vessels are effectively captured in the southern part of India, the western side experiences significantly higher density due to major international shipping lanes linking the Middle East, Africa, and Europe with Southeast Asia and the Far East.

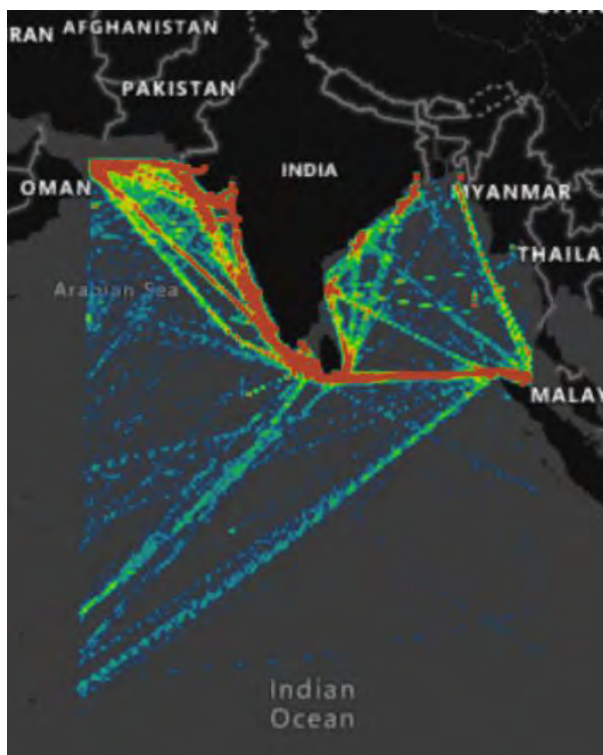


Figure A 1: Heat map showing vessel traffic density around India

Zone A, although smaller, has a wider extension on the western side compared to the east. This design is intentional and based on operational considerations: the western Arabian Sea near the Indian coast experiences higher vessel density, while the eastern side has relatively lower traffic. Furthermore, if a voyage passes through Zone C and subsequently enters Zone A within the same voyage segment during the defined period, Zone A is assigned as the priority zone for that segment. From the southernmost shoreline of India to the outer limit of each designated zone, the distances are as follows: Zone A extends approximately 170 nautical miles, Zone B reaches up to 483 nautical miles, and Zone C spans a significantly larger distance of 1,908 nautical miles. The considerable size of Zone C is due to its inclusion of vessels and voyages transiting through major international maritime routes such as the Suez Canal and the Cape of Good Hope, which are critical corridors for global trade connecting Europe, Asia, and Africa.

Table A 1 : Number of vessels (average from 1st October 2022 to 30th September 2025) and their voyage across zones

Zones	Number of vessels	Number of voyages
Zone A	1555	2975
Zone B	172	300
Zone C	358	561

Example cases:

Zone A (Closest) - Example Case: A container vessel travelling from Jebel Ali (Middle East) to Port Klang (Malaysia) passes through Zone A. Its route alignment means diverting to an Indian port adds negligible distance, making India an attractive option if competitive pricing and fuel availability are ensured.

Zone B (Intermediate) - Example Case: A bulk carrier enroute from Mombasa (East Africa) to Shanghai (China) crosses Zone B. While bunkering in India would require some deviation, favourable fuel pricing and efficient port services could incentivize the vessel to choose India over other regional alternatives.

Zone C (Farthest) - Example Case: A tanker travelling from Ras Tanura (Persian Gulf) to Yokohama (Japan) passes through Zone C. Given its trajectory toward Singapore, a globally recognised bunkering hub, the likelihood of diverting to India is low unless India offers exceptional cost advantages or strategic incentives.

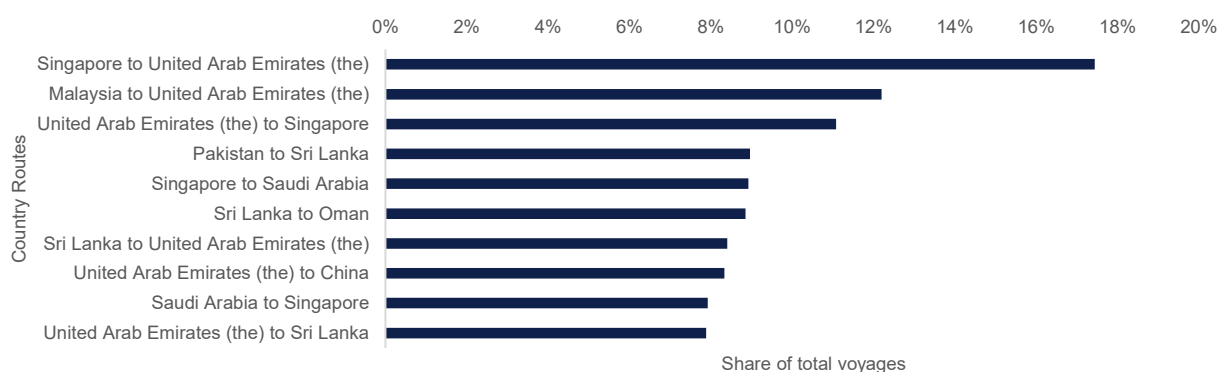


Figure A 2: Top 10 busiest maritime country routes by % of distinct voyages - Zone A for the period October 2022 to September 2025

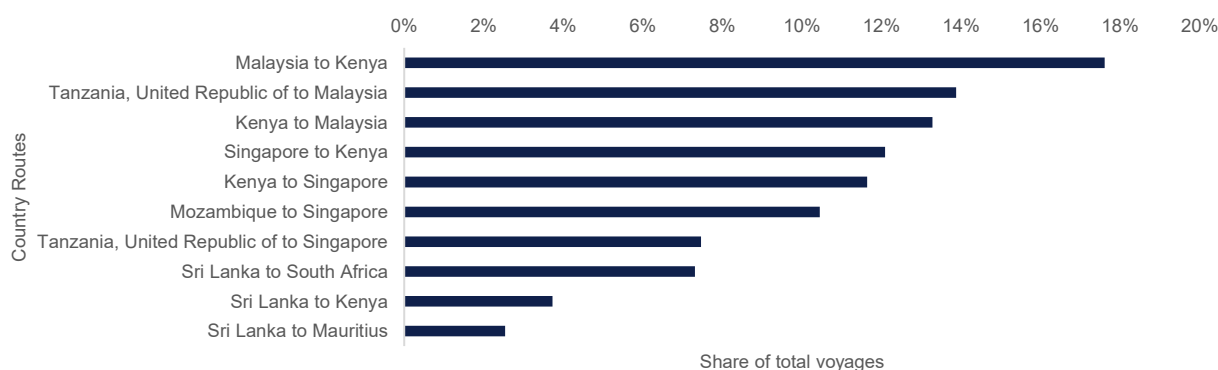


Figure A 3: Top 10 busiest maritime country routes by % of distinct voyages – Zone B for the period October 2022 to September 2025

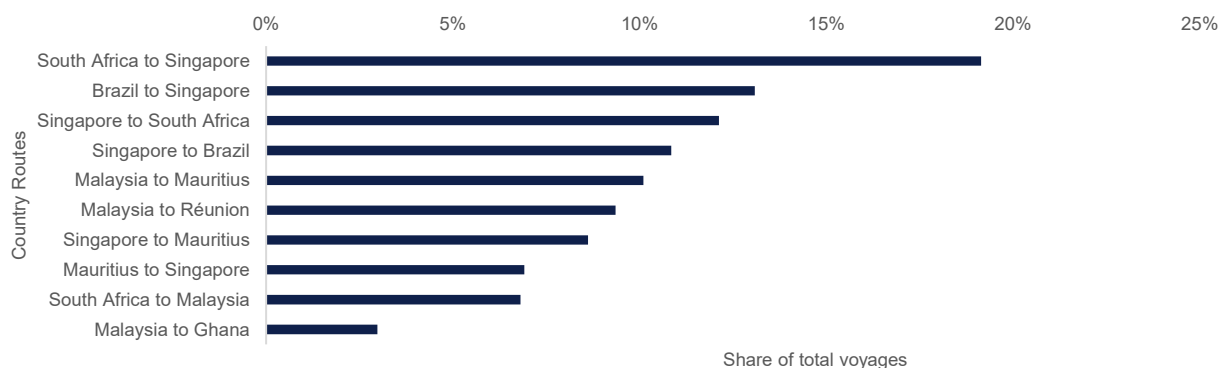


Figure A 4: Top 10 busiest maritime country routes by % of distinct voyages – Zone C for the period October 2022 to September 2025

A.1.2 Passing traffic - supporting analysis

Table A 2 : Number of Voyages by Primary Energy Carrier Type and Zones for the period October 2022 to September 2025

Primary Energy Carrier Type	Zone_A	Zone_B	Zone_C	Grand Total
BATTERY	1			1
FO	50	4	8	62
HFO	2692	303	530	3525
LFO	2			2
LNG	374	7	64	445
MGO	222	6	81	309
RMF	3562	136	529	4227
ULSFO-RM	210	22	52	284
VLSFO-RM	1812	423	418	2653
Grand Total	8925	901	1682	11508

Table A 3 : Number of Voyages by GT and Zones for the period October 2022 to September 2025

GT Range	Number of unique vessels	Total number of voyages	Voyage Segment %
20,000–49,999	1298	3763	32.7%
50,000–99,999	1195	4057	35.3%
100,000–199,999	853	2645	23.0%
10,000–19,999	321	560	4.9%
5,000–9,999	124	239	2.1%
>200,000	91	214	1.9%
1,000–4,999	27	30	0.3%
Grand Total	3909	11508	100%

A.1.3 Port profiling

This section provides a detailed breakdown of port profiling of the eight selected candidate ports, which are potentially suitable for future bunkering operations, by vessel type, primary energy carrier, and GT range to support subsequent analytical steps. The accompanying figure highlights the eight candidate ports selected for further profiling.

Mumbai

Figure A 5 illustrates the number of port calls at Mumbai by ship type across three periods³⁰. The top three ship types are General Cargo, Container, and Passenger vessels. General Cargo dominates with an average of 5,595 port calls across the three periods, highlighting its critical role in Mumbai's port operations. Container ships follow with a steady upward trend, reflecting Mumbai's importance in containerized trade. Passenger, oil, and chemical vessels maintain moderate but consistent activity, underscoring the port's role in supporting specialized cargo handling.

³⁰ Assessment periods are defined as follows: Period 1 (1 October 2022 – 30 September 2023), Period 2 (1 October 2023 – 30 September 2024), and Period 3 (1 October 2024 – 30 September 2025).

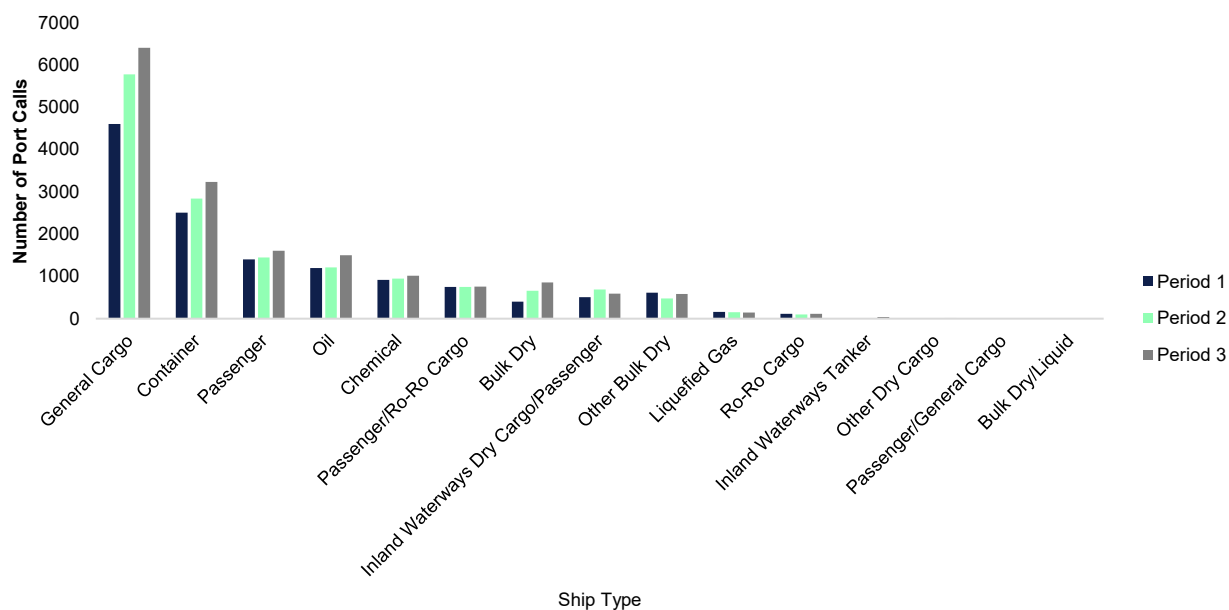


Figure A 5: Number of port calls by Ship Type and period – Mumbai for the period October 2022 to September 2025

Figure A 6 presents port calls by primary energy carrier type and period. The top three fuel types are ULSFO-RM, MGO, and VLSFO-RM. ULSFO-RM leads significantly, exceeding 8,000 port calls in the latest period, showing strong compliance with low-sulfur fuel regulations. MGO and VLSFO-RM follow as major contributors.

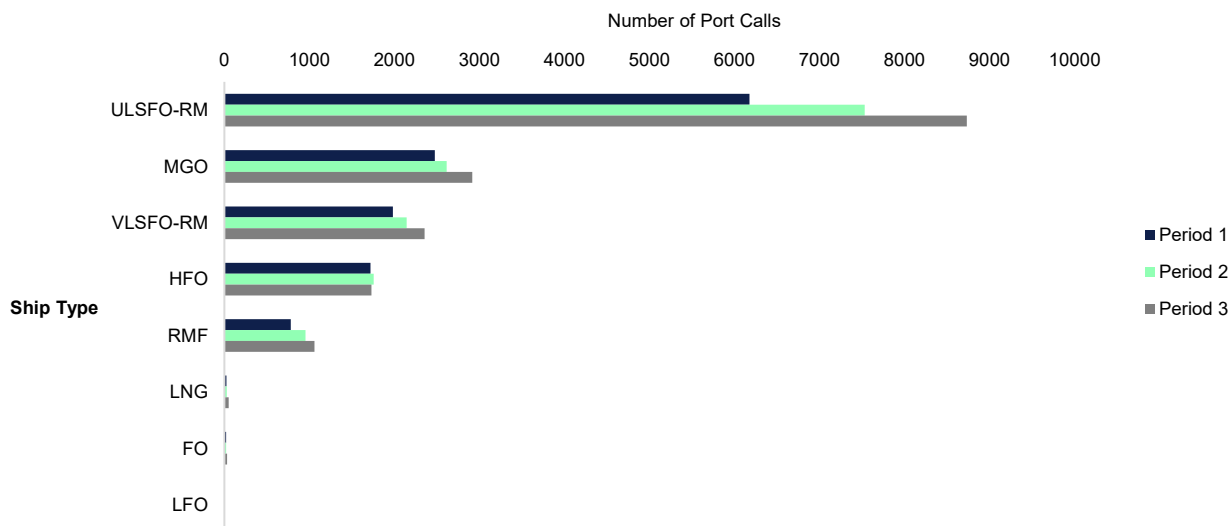


Figure A 6: Number of port calls by primary energy carrier type and period – Mumbai for the period October 2022 to September 2025

Figure A 7 categorizes port calls by vessel gross tonnage (GT) range. The top three ranges are 1,000–4,999 GT, 20,000–49,999 GT, and 5,000–9,999 GT. The smallest range (1,000–4,999 GT) dominates with nearly 7,000 calls in the latest period, while the mid-sized range (20,000–49,999 GT) ranks second, and 5,000–9,999 GT comes third.

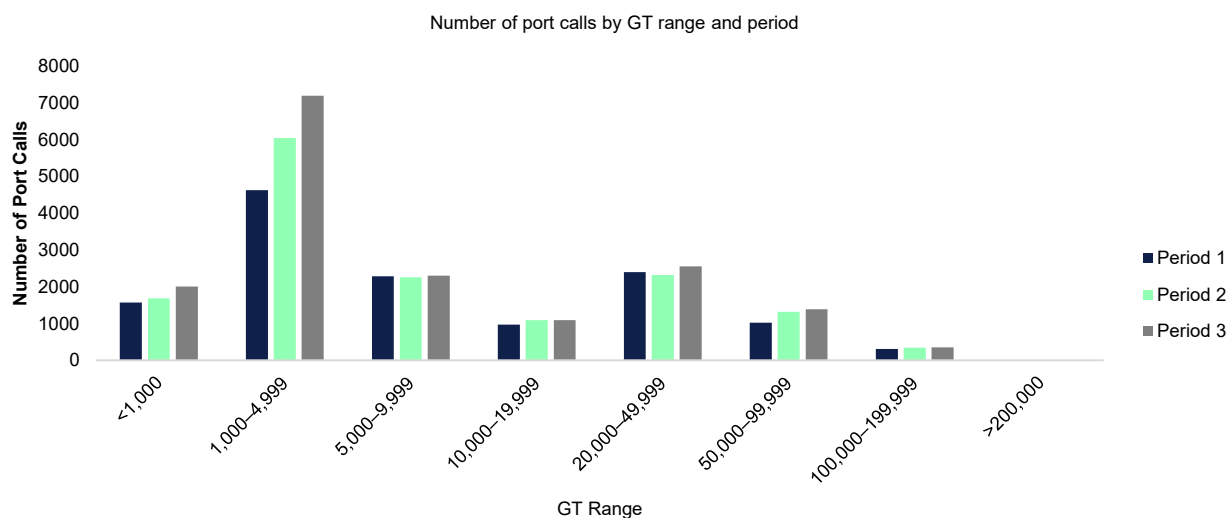


Figure A 7: Number of port calls by GT range and period – Mumbai for the period October 2022 to September 2025

Mundra:

Figure A 8 illustrates the number of port calls at Mundra by ship type across three periods. The top three ship types are Container, Bulk Dry, and Oil vessels. Container ships dominate with more than 3,000 calls in the latest period. Bulk Dry vessels rank second, showing steady activity, while Oil carriers come third, maintaining moderate but consistent operations that highlight the port's role in energy trade.

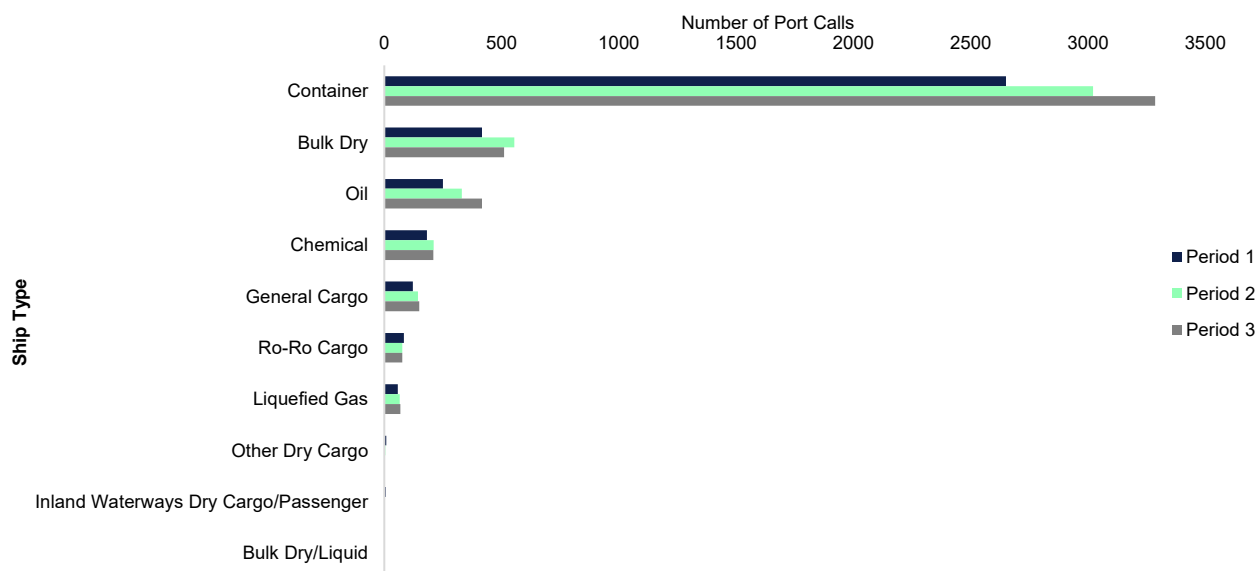


Figure A 8: Number of port calls by Ship Type and period – Mundra for the period October 2022 to September 2025

Figure A 9 presents port calls by primary energy carrier type and period. The top three fuel types are VLSFO-RM, HFO, and RMF. VLSFO-RM leads with the highest number of calls, reflecting compliance with low-sulfur fuel regulations. HFO follows closely, indicating continued reliance on traditional fuels, while RMF ranks third.

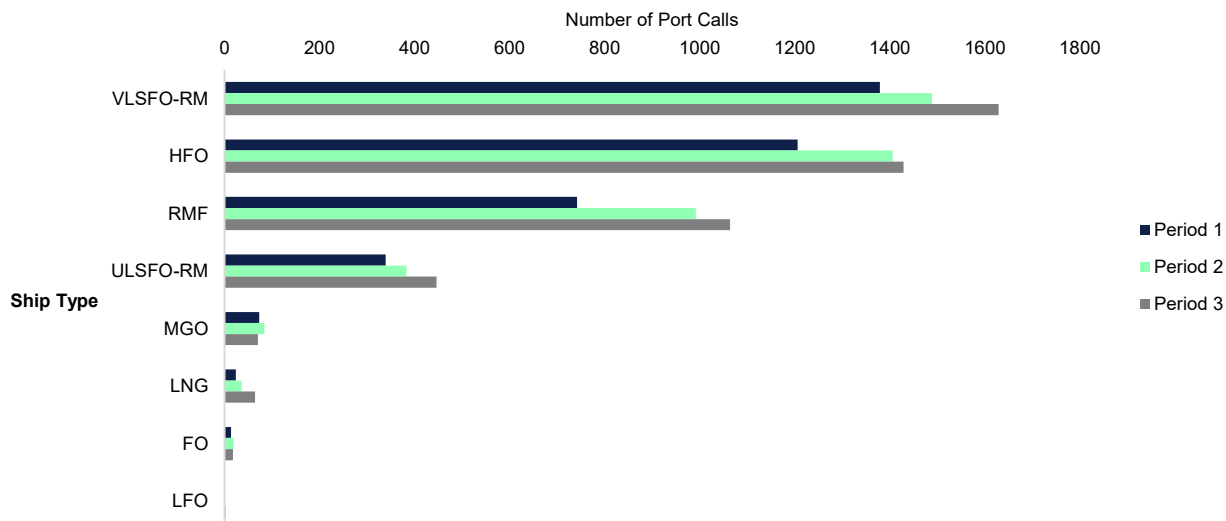


Figure A 9: Number of port calls by primary energy carrier type and period – Mundra for the period October 2022 to September 2025

Figure A 10 categorizes port calls by vessel gross tonnage (GT) range. The top three ranges are 20,000–49,999 GT, 50,000–99,999 GT, and 10,000–19,999 GT. The 20,000–49,999 GT range dominates with over 2,000 calls in the latest period, followed by 50,000–99,999 GT, and then 10,000–19,999 GT. This distribution indicates that Mundra primarily handles medium to large-sized vessels.

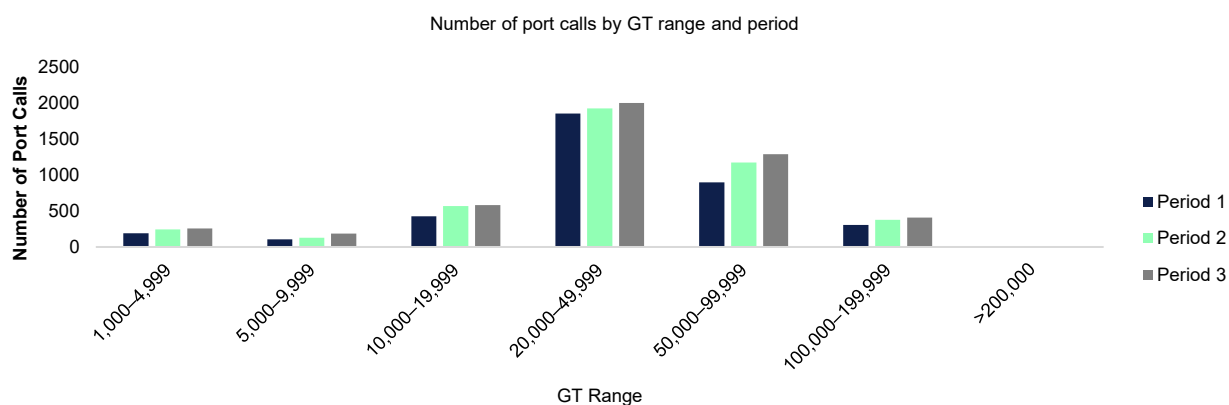


Figure A 10: Number of port calls by GT range and period – Mundra for the period October 2022 to September 2025

Mormugao:

Figure A 11 illustrates the distribution of port calls at Mormugao by ship type across three observed periods. The leading categories are Bulk Dry, Chemical, and General Cargo vessels. Bulk Dry carriers dominate with the highest number of calls, reflecting the port's strong role in iron ore and coal exports.

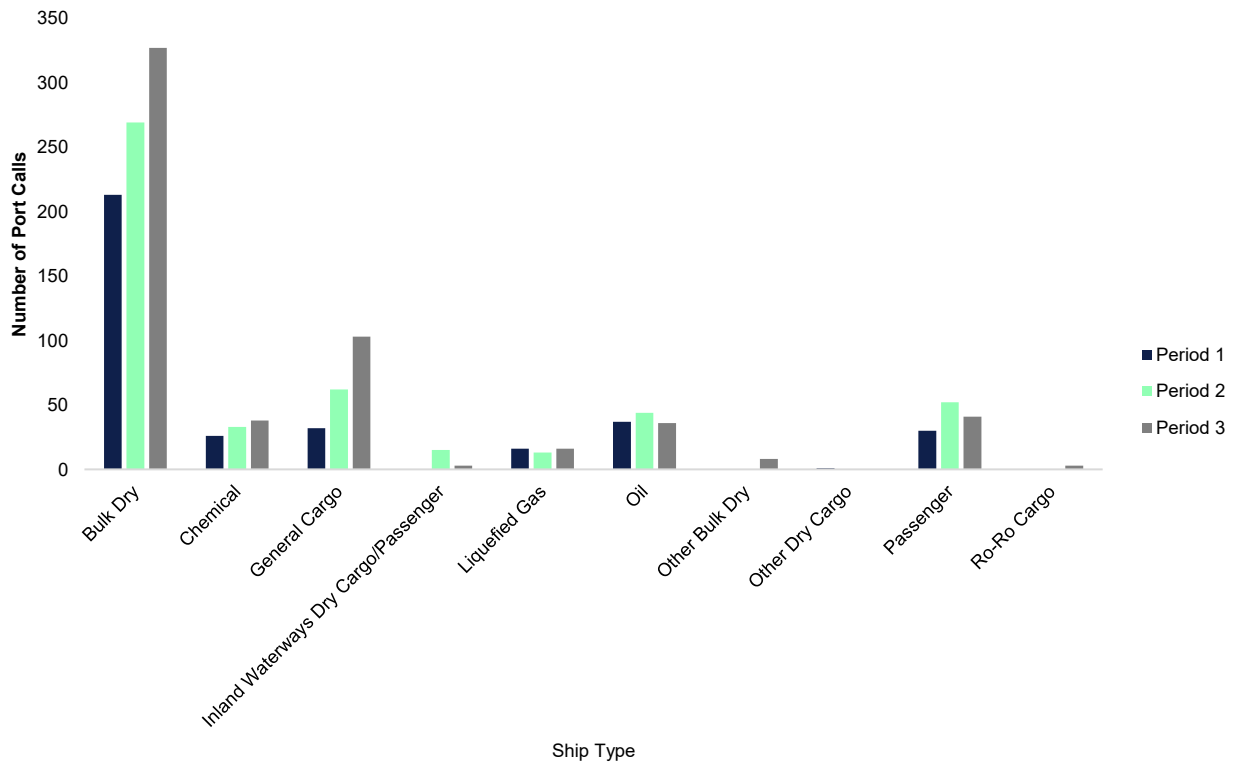


Figure A 11: : Number of port calls by Ship Type and period – Mormugao for the period October 2022 to September 2025

Figure A 12 presents port calls by primary energy carrier type and period. The top three fuel types are VLSFO-RM, HFO, and ULSFO-RM. VLSFO-RM leads with the highest number of calls, around 291 in the latest period, indicating compliance with low-sulfur fuel regulations. HFO follows closely, while ULSFO-RM ranks third.

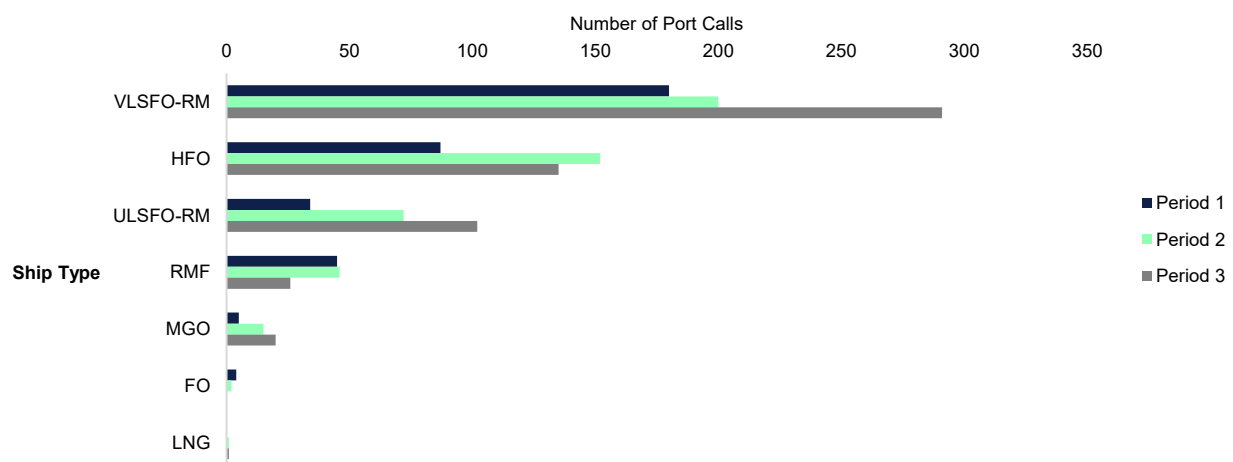


Figure A 12: Number of port calls by primary energy carrier type and period – Mormugao for the period October 2022 to September 2025

Figure A 13 categorizes port calls by vessel gross tonnage (GT) range. The top three ranges are 20,000–49,999 GT, 50,000–99,999 GT, and 1,000–4,999 GT. The 20,000–49,999 GT range dominates with over 390 calls in the latest year, followed by 50,000–99,999 GT, and 1,000–4,999 GT with 40 and 67 port calls, respectively.

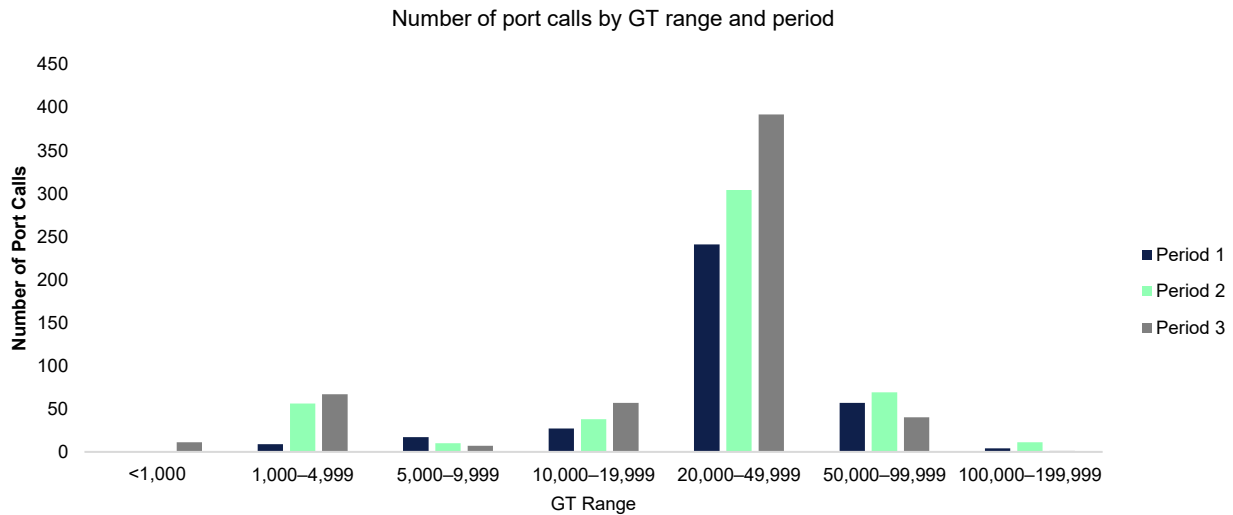


Figure A 13: Number of port calls by GT range and period – Mormugao for the period October 2022 to September 2025

Cochin:

Figure A 14 shows the number of port calls at Cochin by ship type across three periods. The top three ship types are Oil, Container, and Passenger/General Cargo. Oil vessels recorded the highest activity, exceeding 2,000 calls in the latest period. Container ships follow with approximately 1,800 calls in total, while Passenger/General Cargo vessels rank third with around 600 calls.

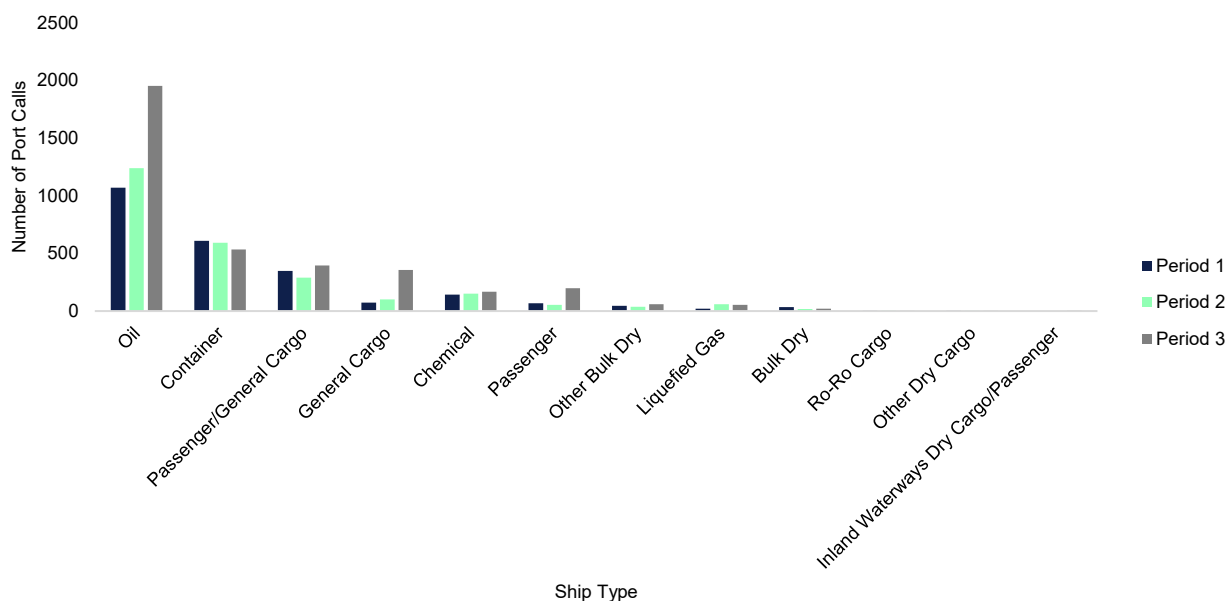


Figure A 14: Number of port calls by Ship Type and period – Cochin for the period October 2022 to September 2025

Figure A 15 displays port calls by primary energy carrier type and period. The top three fuel types are ULSFO-RM, VLSFO-RM, and MGO. ULSFO-RM leads with about 2,200 calls, VLSFO-RM follows with roughly 1,000 calls, and MGO accounts for approximately 500 calls.

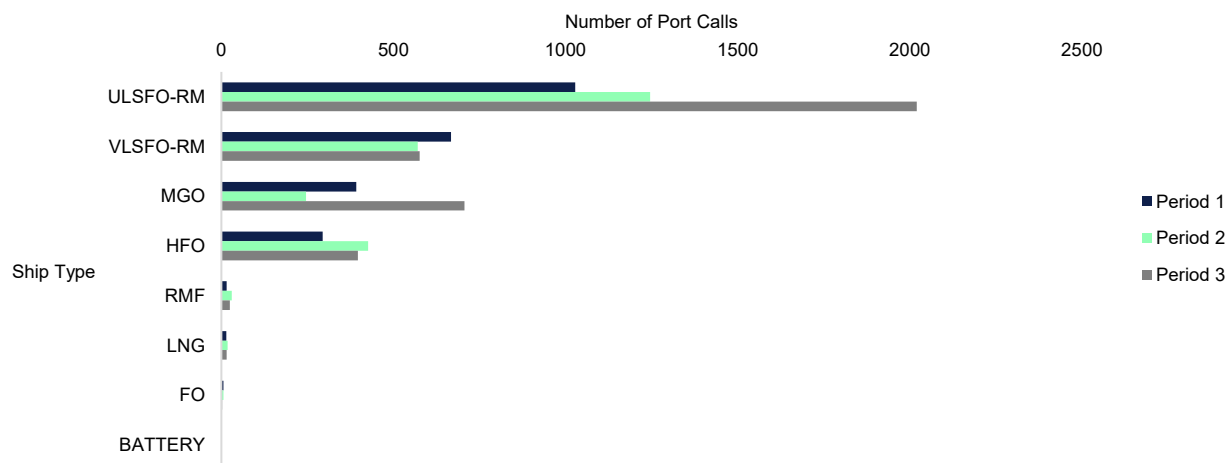


Figure A 15: Number of port calls by primary energy carrier type and period – Cochin for the period October 2022 to September 2025

Figure A 16 categorizes port calls by vessel gross tonnage (GT) range. The top three ranges are 1,000–4,999 GT, 20,000–49,999 GT, and 10,000–19,999 GT. The 1,000–4,999 GT range recorded over 2,300 calls, 20,000–49,999 GT had around 1,200 calls, and 10,000–19,999 GT accounted for about 600 calls.

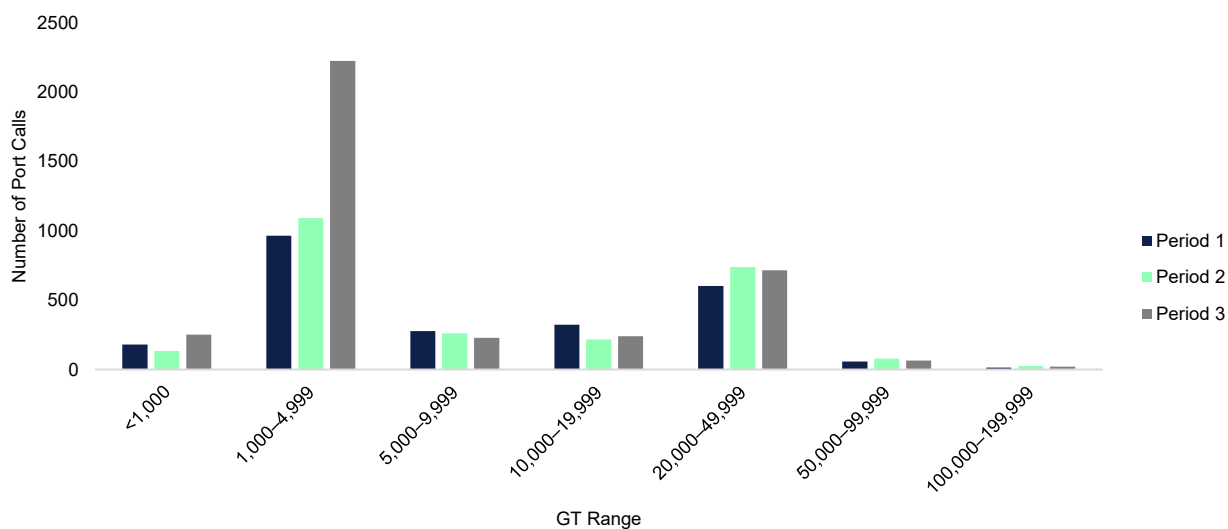


Figure A 16: Number of port calls by GT range and period – Cochin for the period October 2022 to September 2025

Chennai:

Figure A 17 shows the number of port calls at Chennai by ship type across three periods. The top three ship types are Container, Bulk Dry, and General Cargo. Container vessels recorded approximately 1,200 port calls in the latest period, Bulk Dry vessels had around 800 port calls, and General Cargo accounted for about 600 port calls.

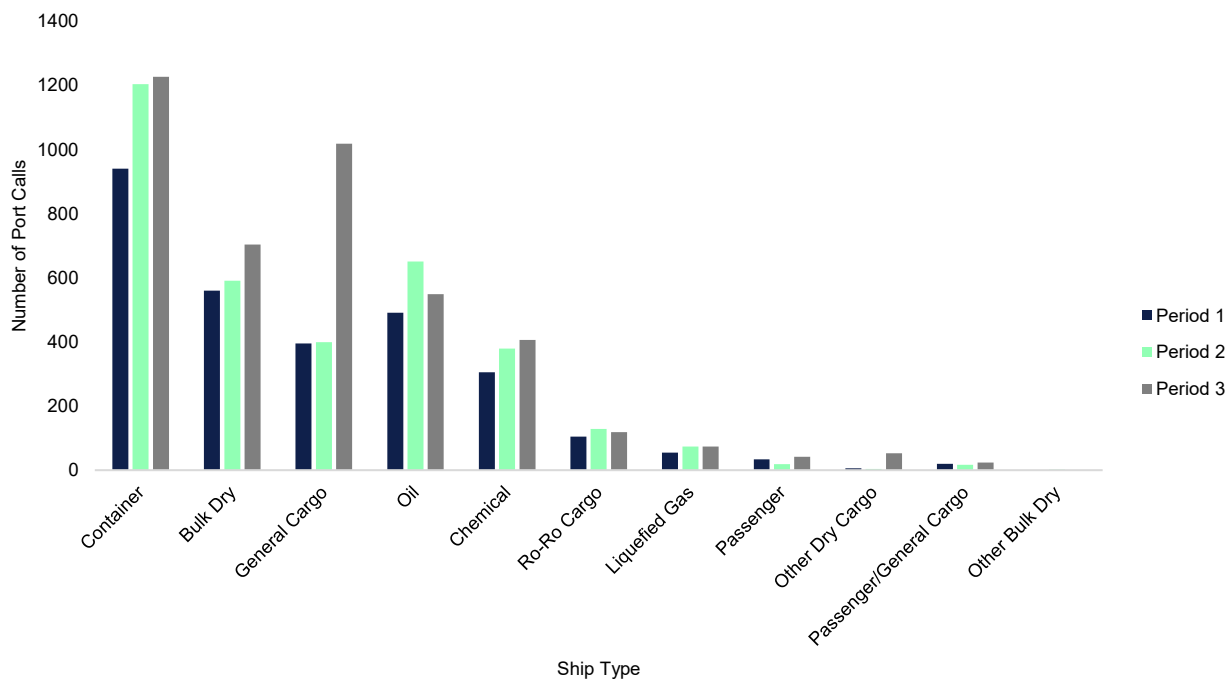


Figure A 17: Number of port calls by Ship Type and period – Chennai for the period October 2022 to September 2025

Figure A 18 displays port calls by primary energy carrier type and period. The top three fuel types are VLSFO-RM, HFO, and ULSFO-RM. VLSFO-RM leads with roughly 1,400 port calls, HFO follows with about 1,078 port calls, and ULSFO-RM accounts for 1,113 port calls in the latest year.

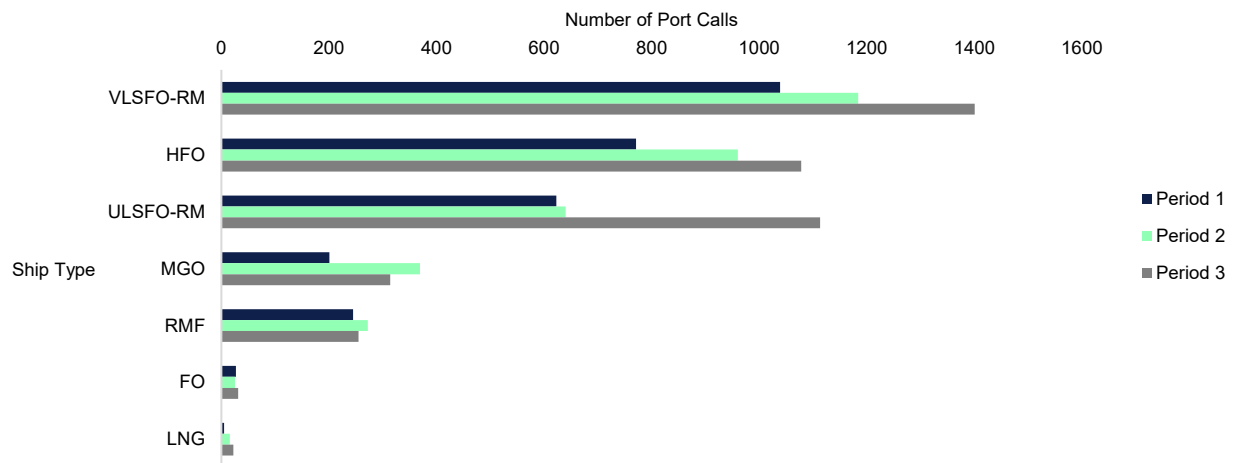


Figure A 18: Number of port calls by primary energy carrier type and period – Chennai for the period October 2022 to September 2025

Figure A 19 categorizes port calls in Chennai by vessel gross tonnage (GT) range and period. The top three ranges are 20,000–49,999 GT, 1,000–4,999 GT, and 5,000–9,999 GT. The 20,000–49,999 GT range recorded around 1,800 port calls, 1,000–4,999 GT had about 1,200 port calls, and 5,000–9,999 GT accounted for roughly 600 port calls in the last year.

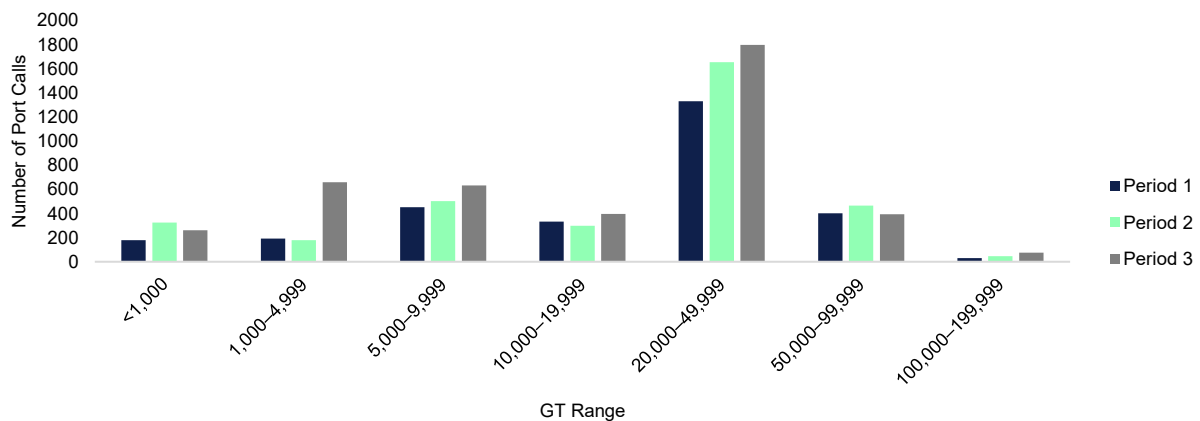


Figure A 19: Number of port calls by GT range and period – Chennai for the period October 2022 to September 2025

Tuticorin:

Figure A 20 shows the number of port calls at Tuticorin by ship type across three periods. The top three ship types are Bulk Dry, Container, and General Cargo. Bulk Dry vessels recorded around 600 port calls in the latest period, Container vessels had around 500 port calls, and General Cargo accounted for about 300 port calls.

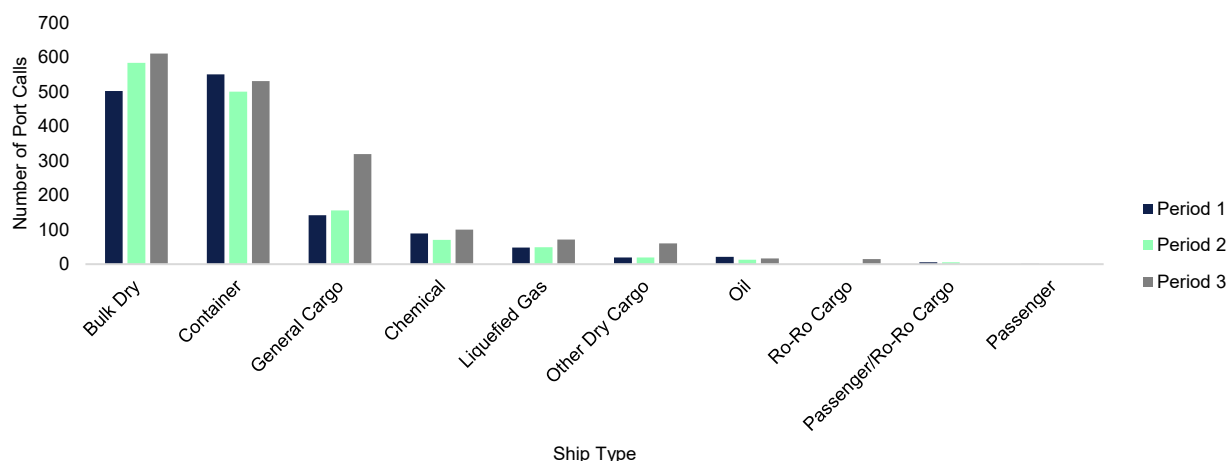


Figure A 20: Number of port calls by Ship Type and period – Tuticorin for the period October 2022 to September 2025

Figure A 21 displays port calls by primary energy carrier type and period. The top three fuel types are VLSFO-RM, ULSFO-RM, and HFO. VLSFO-RM leads with roughly 850 port calls, ULSFO-RM follows with about 450 port calls, and HFO accounts for approximately 350 port calls.

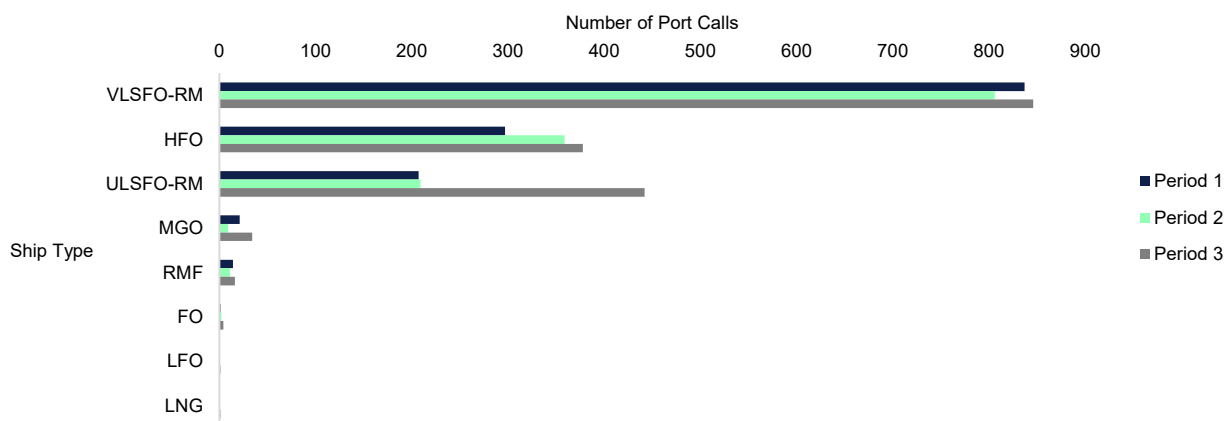


Figure A 21: Number of port calls by primary energy carrier type and period – Tuticorin for the period October 2022 to September 2025

Figure A 22 categorizes port calls by vessel gross tonnage (GT) range. The top three ranges are 20,000–49,999 GT, 10,000–19,999 GT, and 5,000–9,999 GT. The 20,000–49,999 GT range recorded around 850 port calls, 10,000–19,999 GT had about 520 port calls, and 5,000–9,999 GT accounted for roughly 220 port calls in the latest period.

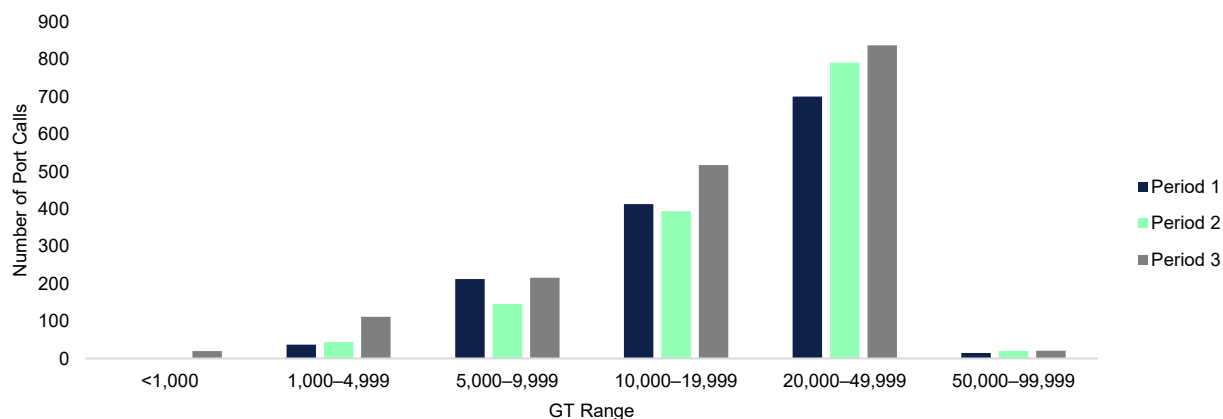


Figure A 22: Number of port calls by GT range and period – Tuticorin for the period October 2022 to September 2025

Visakhapatnam:

Figure A 23 shows the number of port calls at Visakhapatnam by ship type across three periods. The top three ship types are Bulk Dry, Container, and Oil. Bulk Dry vessels recorded 1634 port calls in the latest period, Container vessels had 482 port calls, and Oil accounted for 277 port calls.

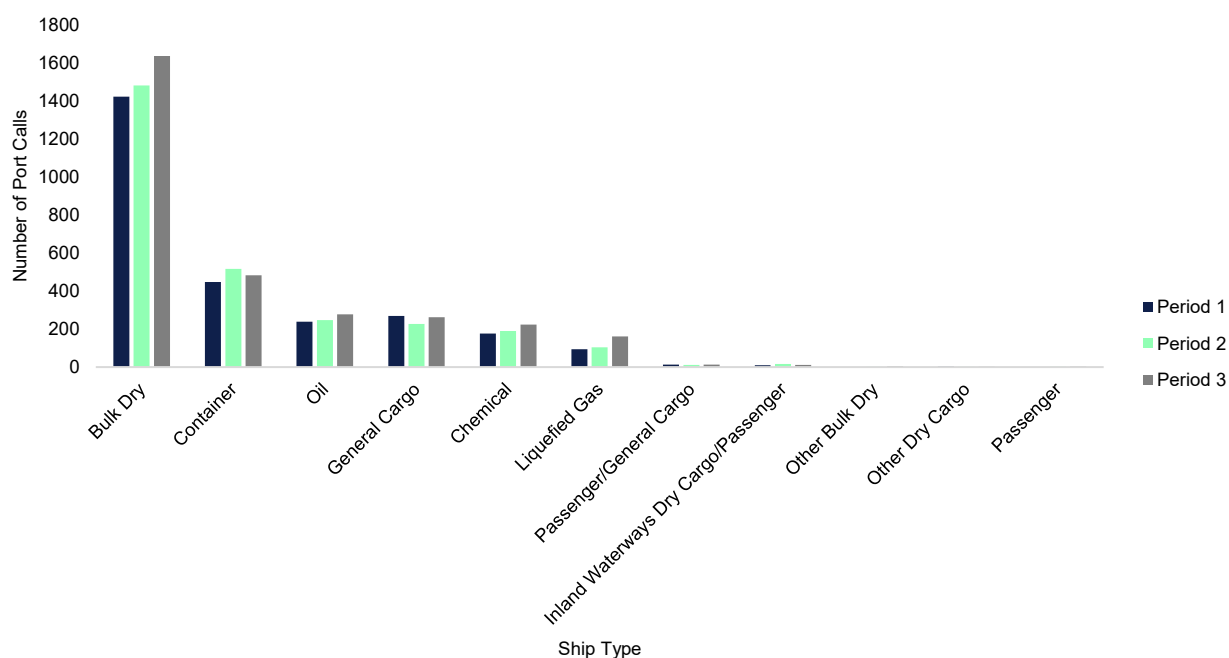


Figure A 23: Number of port calls by Ship Type and period – Visakhapatnam for the period October 2022 to September 2025

Figure A 24 displays port calls by primary energy carrier type and period. The top three fuel types are VLSFO-RM, HFO, and ULSFO-RM. VLSFO-RM leads with 1708 port calls, HFO follows with 708 port calls, and ULSFO-RM accounts for approximately 398 port calls in the latest years.

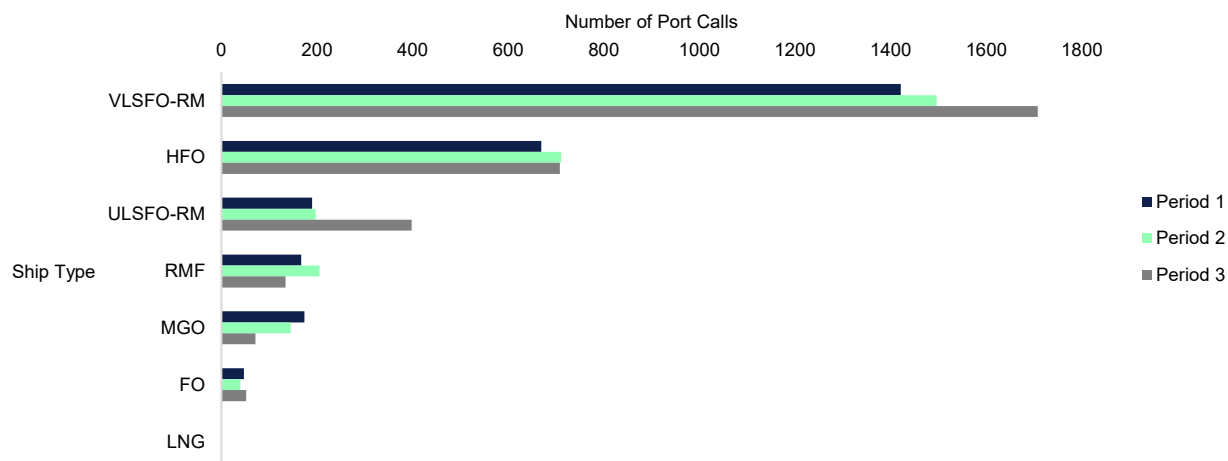


Figure A 24: Number of port calls by primary energy carrier type and period – Visakhapatnam for the period October 2022 to September 2025

Figure A 25 categorizes port calls by vessel gross tonnage (GT) range. The top three ranges are 20,000–49,999 GT, 10,000–19,999 GT, and 50,000–99,999 GT. The 20,000–49,999 GT range recorded 2,125 port calls, 10,000–19,999 GT had 360 port calls, and 50,000–99,999 GT accounted for roughly 209 port calls.

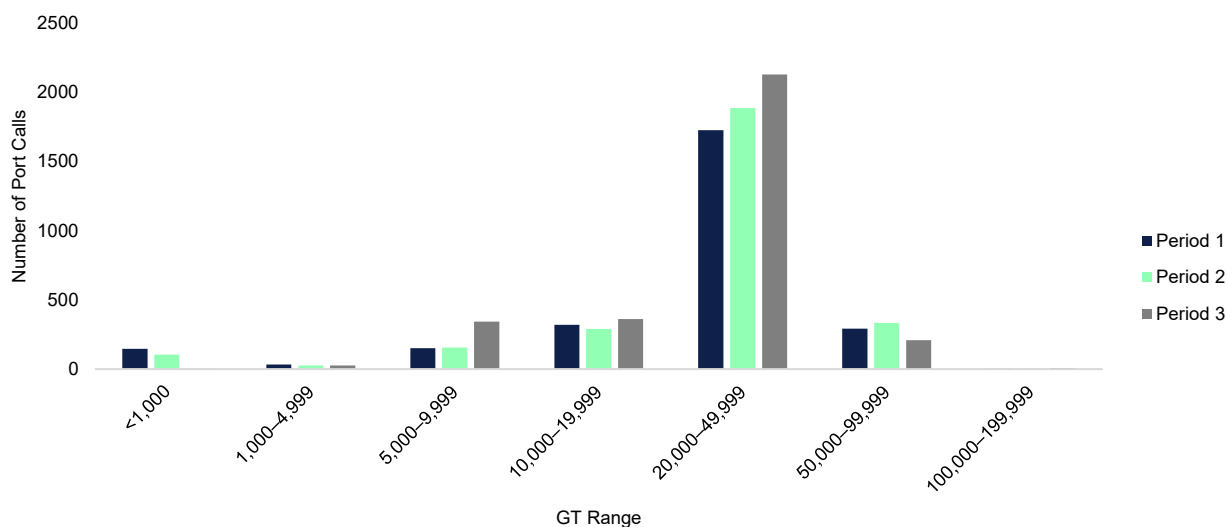


Figure A 25: Number of port calls by GT range and period – Visakhapatnam for the period October 2022 to September 2025

Paradip:

Figure A 26 shows the number of port calls at Paradip by ship type for the latest period. The top three ship types are Bulk Dry, General Cargo, and Oil. Bulk Dry vessels recorded 1791 port calls in the latest period which is slightly lower than period 2, General Cargo vessels had 543 port calls, and Oil vessels accounted for 380 port calls in the latest period both have seen considerable increase than the previous periods.

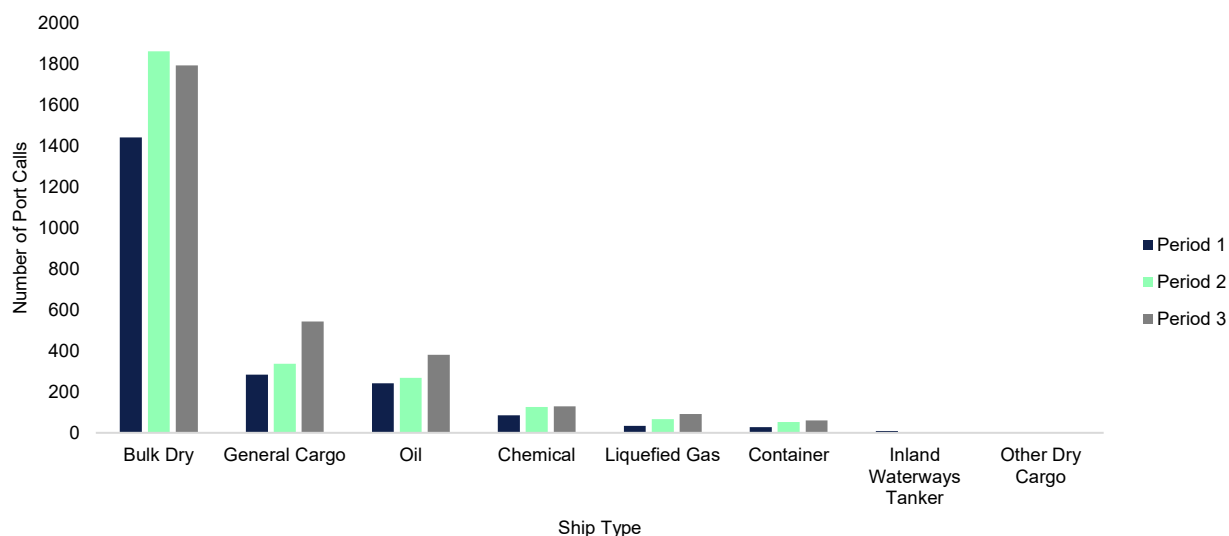


Figure A 26: Number of port calls by Ship Type and period – Paradip for the period October 2022 to September 2025

Figure A 27 displays port calls by primary energy carrier type for the latest period. The top three fuel types are VLSFO-RM, HFO, and ULSFO-RM. VLSFO-RM recorded 1537 port calls, HFO had 570 port calls, and ULSFO-RM accounted for 588 port calls.

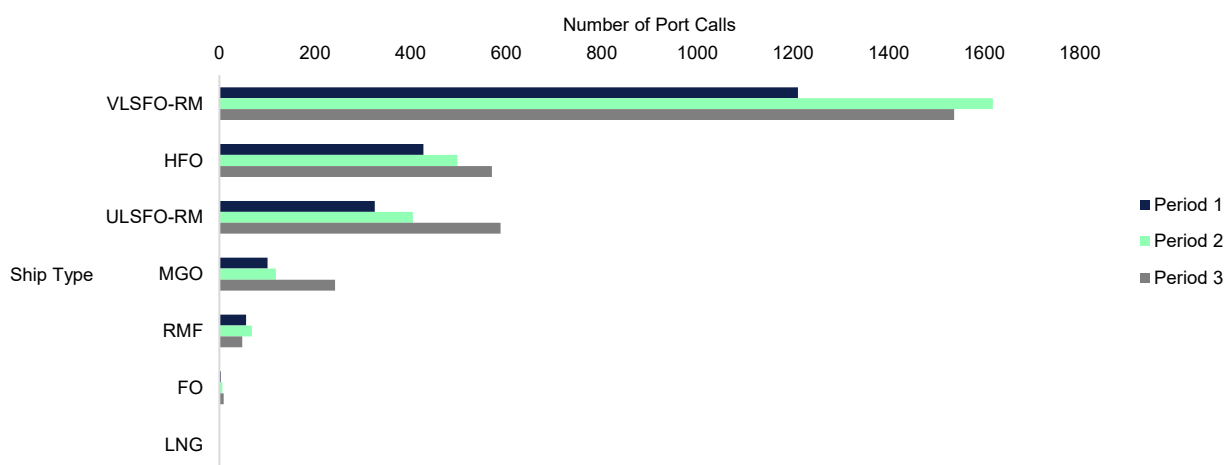


Figure A 27: Number of port calls by primary energy carrier type and period – Paradip for the period October 2022 to September 2025

Figure A 28 categorizes port calls by vessel gross tonnage (GT) range for the latest period. The top three ranges are 20,000–49,999 GT, 1,000–4,999 GT, and 5,000–9,999 GT. The 20,000–49,999 GT range recorded 2,000 port calls, the 1,000–4,999 GT range had 264 port calls, and the 5,000–9,999 GT range accounted for 260 port calls in the latest period with slight increase than the previous periods.

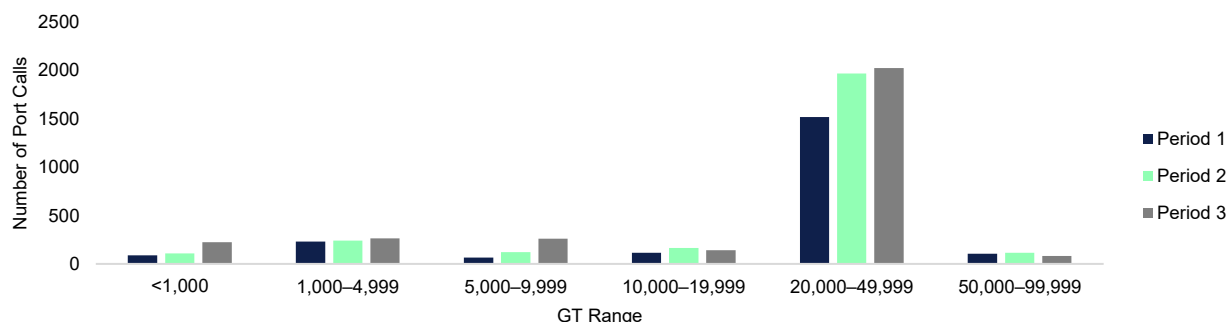


Figure A 28: Number of port calls by GT range and period – Paradip for the period October 2022 to September 2025

A.1.4 Port selection criteria and detailed rationale

The purpose of selecting candidate bunkering ports was to identify locations that collectively represent India's most credible near- to long-term opportunities for conventional and alternative marine fuel bunkering. The selection supports subsequent analysis of fuel demand scenarios, infrastructure phasing, and delivered fuel cost competitiveness.

Ports were selected based on a combination of operational relevance, strategic positioning, and future readiness. Specifically, each selected port meets one or more of the following criteria:

1. Established or emerging role in bunkering
 - Existing conventional fuel bunkering activity, or
 - Demonstrated plans or commitments to develop LNG, methanol, hydrogen, or ammonia bunkering infrastructure.
2. AIS-based vessel traffic significance
 - High absolute vessel calls, or
 - Strategic vessel types (container liners, bulk carriers, tankers, passenger vessels) relevant to bunkering demand.
3. Strategic location along major trade lanes
 - Proximity to the Suez–East Asia and Middle East Gulf–East Asia corridors, enabling bunkering with limited route deviation.
4. Alignment with national and international policy frameworks
 - Maritime India Vision 2030
 - National Green Hydrogen Mission
 - Harit Sagar Green Port Guidelines
 - IMO GHG Strategy
5. Collective fuel coverage and network balance
 - Ensuring coverage across LNG, methanol, hydrogen, and ammonia,
 - Balanced representation of west coast, east coast, hub, and bulk-centric ports.

AIS data indicate that Mumbai (JNPA) leads with the highest vessel calls (16,877 in the latest period), handling a diverse mix of general cargo, container, and passenger vessels. Mundra (4,722 calls) stands out as a modern, high-throughput container port, while Chennai (4,214 calls) functions as the principal container gateway on the east coast. Cochin (3,741 calls) is notable for oil and passenger/general cargo traffic, whereas Visakhapatnam (3,072 calls) and Paradip (2,995 calls)

are primarily bulk dry cargo ports. Tuticorin (1,722 calls) and Mormugao (591 calls) serve more specialised regional and bulk markets.

The analysis of movement of cargo through major Indian ports over the period, April 2023 to March 2024 to establish which ports have handled highest volume of cargo was also conducted. The following Figure A 29 displays Net Registered Tonnage (NRT) for ships that have either “entered” (ships arrived at the port) or “cleared” (ships departed from the port) with cargo in foreign trade.

Ports such as Mundra, JNPT, Kandla handle the highest NRT, highlighting their prominence in foreign trade cargo flows. Figure A 30 shows that JNPT handled the highest net registered tonnage for both entered and cleared coastal cargoes between April 2023 and March 2024, followed by Hazira and Mundra. The distribution across ports reveals that a handful of ports dominate cargo flows, while many others handle relatively smaller volumes, helping to identify strategic hubs for infrastructure planning and resource allocation.

The cargo flow assessment is used to identify ports where vessels already call for cargo operations in significant volumes, as these ports offer the most practical opportunities for bunkering. In reality bunkering—particularly for alternative fuels—typically takes place at ports where ships are already loading or discharging cargo, rather than at ports that vessels only pass.

The analysis reviews cargo movements through major Indian ports for the period April 2023 to March 2024, based on Net Registered Tonnage (NRT) of vessels that have either *entered* (arrived with cargo) or *cleared* (departed with cargo) the port. Ports such as Mundra, JNPT, and Kandla record the highest cargo volumes in foreign trade, while JNPT, Hazira, and Mundra dominate coastal cargo flows. This concentration indicates where vessel calls are most frequent and operationally anchored.

These findings support the identification of strategic ports for bunkering development and provide operational context for the baseline energy demand, future fuel demand, pricing, and total cost of voyage analyses presented in subsequent sections. Supporting data and assumptions are provided in the Appendix.

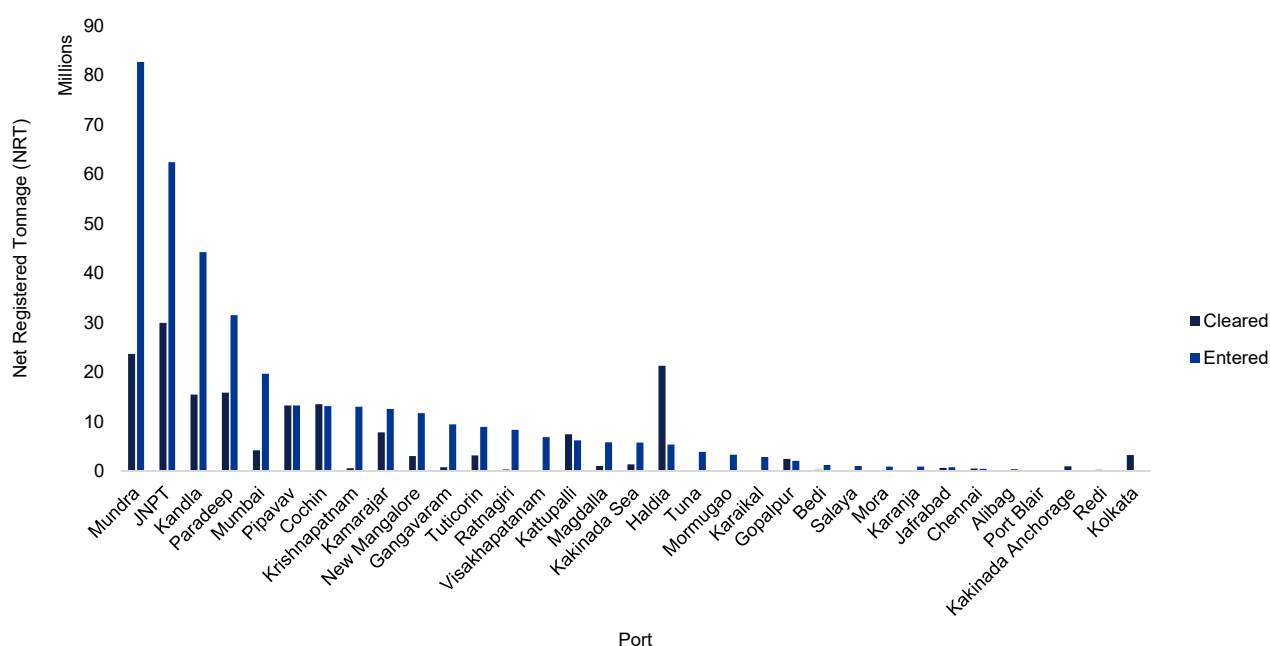


Figure A 29: Net Registered Tonnage that entered and cleared with Cargoes in Foreign Trade during April 2023 to March 2024

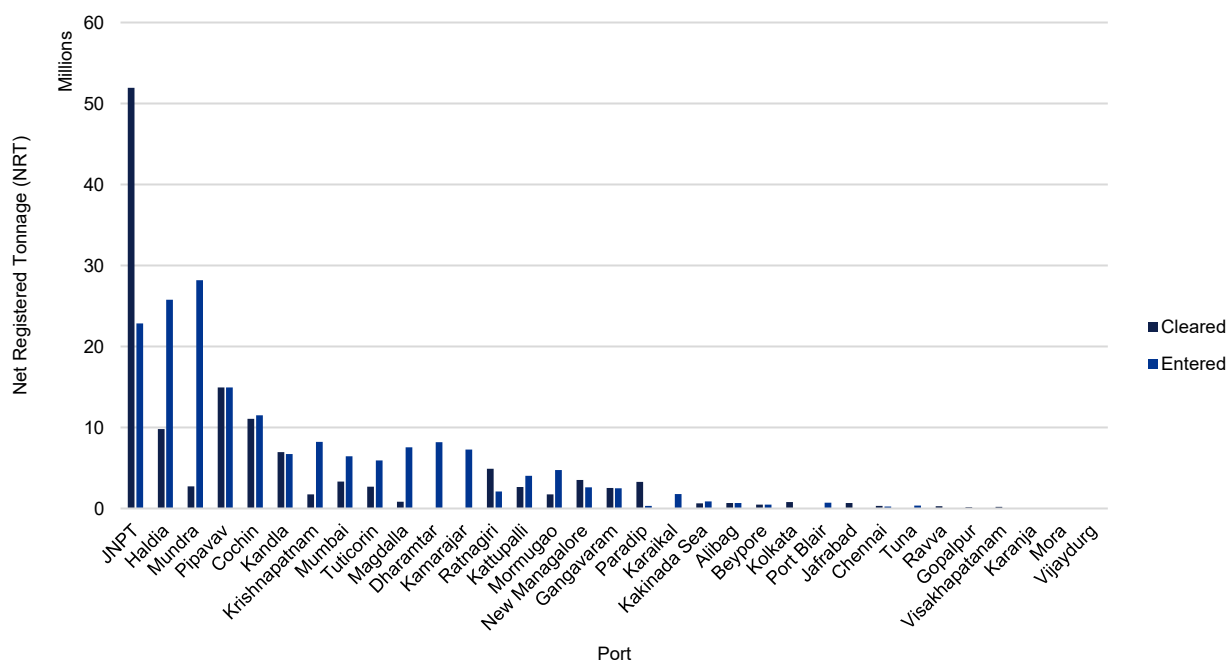


Figure A 30: Net Registered Tonnage that entered and cleared with Cargoes in Coastal Trade during April 2023 to March, 2024

The data for this assessment was sourced from the Directorate General of Commercial Intelligence and Statistics (DGCIS) portal: https://www.dgciskol.gov.in/pub_cargo.aspx.

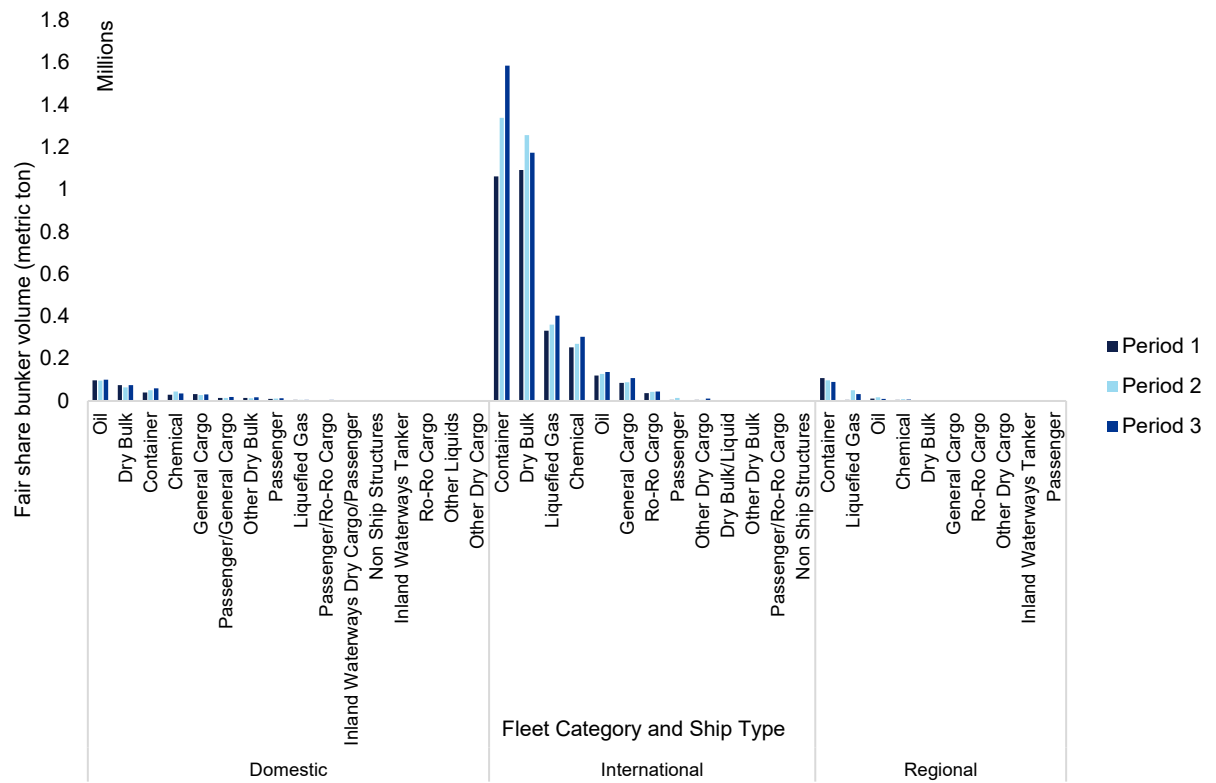


Figure A 31: Fair share bunker volume by Fleet category and Ship Type for the period October 2022 to September 2025

A.2 FUTURE FUEL DEMAND FORECASTING

This section presents the scenario-based approach used to estimate India's future demand for alternative marine fuels between 2027 and 2047. Building on baseline energy demand and fleet insights from earlier sections, the analysis explores how different growth trajectories, technology adoption patterns, and policy signals could shape India's role as a regional bunkering hub. The scenarios provide a structured view of potential demand evolution across vessel segments and fuel types, offering key input for assessing supply feasibility and competitiveness.

A.2.1 Scenario development and key drivers for the different scenarios

This section outlines the scenario framework for bunkering uptake in India, organised into three layers: **Energy Demand**, **Fuel Pathway**, and **Bunker Uptake**. Each layer represents a set of drivers shaping the future landscape, with a focus on areas where India can exert influence.

The layers represent different categories of drivers

India's future bunker potential depends on both direct and indirect drivers. Energy demand influences the size of the addressable market—how much fuel ships calling Indian ports consume. The fuel pathway describes shipowners' investment decisions and compliance strategies regarding emissions regulations, thereby determining which fuels will be in demand. Finally, bunker uptake represents the most immediate drivers—those that directly influence whether decision-makers choose India as a bunkering location. These layers interact, but the key points of intervention for India lie in the third layer, where infrastructure, pricing, and policy clarity can make or break competitiveness.



Figure A 32: The scenario analysis applies a three-layered approach, with adjustable parameters across Energy Demand, Fuel Pathway, and Bunker Uptake, each projected toward 2047

A.2.2 Qualitative assessment of drivers and barriers across layers

In the following subsections, we qualitatively assess the key drivers and barriers within each layer. In the following section we discuss and highlight where India is naturally advantaged, where structural challenges remain, and where emerging opportunities could be accelerated.

Layer 1 – Energy demand (addressable market)

This layer captures the indirect, macro-level drivers that determine the overall scale of bunker demand in Indian ports.

Example drivers:

- **Growth in seaborne trade:** The expansion of global and regional trade, particularly containerised and bulk cargo, increases the addressable market for marine fuels. India's projected economic expansion and integration into global supply chains reinforce this upward trend.
- **Modal shift to coastal shipping:** Ongoing efforts to shift cargo from road to coastal shipping can create more intra-regional maritime activity, increase domestic fuel demand and strengthen India's role in regional flows.
- **Port-led trade growth and transshipment hub ambition (e.g., Sagarmala):** Upgraded ports, deep-water facilities, improved connectivity and transshipment ambitions attract more container and cargo traffic — increasing the baseline volume of ships calling Indian ports.
- **Fleet modernisation and efficiency:** The renewal of the fleet with more energy-efficient vessels, as well as operational measures such as speed optimisation and digitalisation, can reduce overall fuel consumption per tonne-mile, but may also increase the competitiveness of Indian ports if they offer efficient turnaround and value-added services.

Example barriers:

- **Uncertainty in trade growth:** Geopolitical disruptions, supply chain reconfigurations, and economic volatility can dampen or unpredictably shift demand, making infrastructure investment riskier.
- **Competition from established hubs:** Major regional hubs already serve dense trade corridors (such as Fujairah, Singapore and Rotterdam/Antwerp, and competitive pressures may limit India's share of bunkering traffic unless differentiators emerge.
- **Uncertainty around emerging hubs:** Potential development of alternative bunkering hubs (e.g., Egypt, Colombo, Oman) creates competitive ambiguity and complicates long-term planning.

India's Leverage:

India can influence this layer indirectly by promoting coastal shipping, improving logistics connectivity, and streamlining port and customs processes. India can also boost export–import volumes by supporting industrial growth and manufacturing competitiveness in sectors with high trade intensity, strengthening trade agreements, and enhancing India's role in global value chains. In addition, modernising port governance and landlord models to foster private investment, promoting India as a regional transshipment alternative, and ensuring competitive port tariffs can further increase India's attractiveness as a node within regional and international shipping networks.

Layer 2 – Fuel pathways (technology and compliance by shipowners)

This layer describes what fuels will be relevant in the future, depending on shipowners' decarbonisation strategies, IMO/EU regulations, and fleet renewal cycles.

Example drivers:

- **Technology readiness and availability:** The maturity of dual-fuel engines, fuel cells, and retrofitting solutions for methanol, ammonia, LNG, and biofuels is increasing, with a growing share of the order book featuring alternative fuel capability.
- **Regulatory and market incentives:** The IMO Net-Zero Framework, (FuelEU Maritime), and national schemes are setting clear trajectories for well-to-wake GHG intensity, incentivising investment in alternative fuels and abatement technologies.
- **Cargo owner and financial pressure:** Charterers and financiers are increasingly demanding decarbonisation, with green corridors, ESG reporting, and green financing becoming mainstream.
- **Early emergence of green corridors:** Bilateral and regional green corridor initiatives—particularly in Europe, the Middle East, and East Asia—provide strong signals about expected future fuels along major trade routes, potentially influencing shipowner investment strategies globally.

Example barriers:

- **Fuel availability and cost:** Low-carbon fuels remain expensive and in constrained supply, with shipping competing against aviation, steel, fertilisers, and chemicals for the same molecules. Cost uncertainty and supply variability reduce shipowner confidence.
- **Infrastructure gaps:** Few major ports can currently supply methanol, ammonia, or hydrogen safely and at scale. This creates route dependency risk, making shipowners hesitant to commit to new fuel types without assured availability along trade corridors.
- **Safety and Regulatory Uncertainty:** Prescriptive regulatory frameworks for ammonia and hydrogen bunkering are still emerging globally. The absence of mature safety codes, combined with the need for extensive workforce upskilling, increases operational risk.
- **Slow fleet turnover:** With vessel lifespans of 20–30 years, transitions in fuel pathways occur slowly, creating long periods of uncertainty during which multiple pathways may coexist.
- **Lifecycle emissions concerns:** Lack of global alignment on well-to-wake accounting, particularly for fuels such as biofuels or blue hydrogen/ammonia, can complicate adoption and investment decisions.
- **OCCS adoption** could significantly reduce demand for low-GHG fuels.

India's leverage:

India's influence in this layer is primarily strategic: it can reduce uncertainty by clearly signalling which fuels are likely to be available in the future, supporting pilot and demonstration projects to build operational experience, and providing transparent and predictable guidance on safety and certification processes. By articulating credible long-term plans for fuel production, handling, and port-side readiness, India can shape market expectations and strengthen its position within emerging multi-fuel trade networks.

Layer 3 – Bunker uptake (Direct drivers at the point of choice)

This layer captures the immediate factors that determine whether a vessel chooses to bunker in a particular port. Unlike the previous layers, where India's influence is indirect or strategic, here India has the clearest and most direct ability to shape outcomes.

Example drivers:

- **Competitive bunker pricing:** Attractive fuel pricing supported by efficient supply chains, transparent pricing mechanisms, and predictable cost structures.
- **Geographical positioning on key routes:** Ports located on major east–west or regional trade lanes enjoy structural visibility for bunkering decisions. These could potentially develop into regional transshipment hubs for container lines that are currently sailing past India.
- **Port infrastructure readiness:** Ports with multi-fuel bunkering capability, robust digital and physical infrastructure, and efficient customs and safety procedures are more attractive to shipowners.
- **Efficient operational performance:** Availability of modern terminal equipment, efficient berthing and pilotage services, reliable scheduling, and minimised waiting times.
- **Digitalisation and process transparency:** Use of integrated port community systems, digital documentation, real-time communication, and simplified pre-arrival procedures improves trust and reduces operational uncertainty.
- **High-quality ancillary:** Crew change facilities, ship repair and maintenance services, waste reception, freshwater supply, and logistics support can make a port more attractive as a one-stop operational location.
- **Safety and reliability track record:** Demonstrated ability to handle different fuels safely, with low incident rates and strong emergency response capabilities.
- **Predictable regulatory environment:** Clear operational rules, consistent enforcement, and transparent communication from port authorities reduce risk for shipowners.
- **Policy clarity and communication:** Transparent, predictable policies and proactive communication reduce uncertainty for decision-makers, building trust in the reliability and efficiency of Indian ports.

Example barriers:

- **High capital and operational costs:** Large investment requirements for new fuel storage, transfer systems, and safety infrastructure—combined with uncertainty in fuel demand—may delay development.
- **Uncertain fuel demand across fuels:** Shipowners' hesitation to commit to one fuel pathway makes it difficult for suppliers to size or justify infrastructure investments.
- **Procedural and bureaucratic delays:** Inconsistency in customs, safety inspections, and documentation processes increases turnaround time and undermines competitiveness.
- **Fuel quality assurance concerns:** Perceived or real inconsistencies in fuel quality, sampling integrity, or supply reliability discourage bunkering decisions.
- **Safety risks and public acceptance issues:** Concerns around handling hazardous fuels (ammonia, hydrogen, methanol) may complicate permitting processes or limit suitable sites within port areas.
- **Limited availability of ancillary services:** If essential marine services are fragmented or unavailable, shipowners may prefer ports offering integrated service packages.
- **Competition from established hubs:** Existing hubs benefit from economies of scale, established supply chains, and reputation, making it challenging for emerging ports to attract initial demand.
- **Land-use constraints:** Port areas with competing commercial pressures may struggle to allocate secure, appropriately zoned space for new fuel infrastructure.

- **Lack of deep-water berths:** Limited capacity to accommodate large container vessels restricts a port's ability to serve as a regional transshipment hub.

India's leverage:

India's influence in this layer is substantial. By enhancing port infrastructure, creating efficient and predictable operational environments, improving digital systems, and ensuring transparency in safety and quality standards, India can meaningfully increase its attractiveness as a bunkering location. Consistent and streamlined port procedures, integrated ancillary services, and credible long-term plans for fuel availability further strengthen India's position. These areas of influence directly shape day-to-day decision-making by shipowners and form the basis for several policy themes.

A.2.3 National Strategy and Policy Assessment for India's Alternative-Fuel Bunkering Ecosystem

This section provides a high-level assessment of how India's national strategies, policies, and regulatory frameworks intersect with the three scenario layers—energy demand, fuel pathway, and bunker uptake—to shape the country's competitiveness as a future-ready alternative fuel bunkering hub. The focus is not on restating India's renewable energy or biomass potential (which is addressed in Section A.3.2), but rather on identifying where policy support currently strengthens India's positioning, where structural barriers remain, and what near-term actions could close critical gaps. This synthesis bridges the scenario analysis with a forward-looking strategy and serves as a foundation for the recommendations.

Current strengths and strategic alignment

India's policies supporting port-led economic growth, trade facilitation, and coastal shipping contribute positively to expanding the addressable bunkering market. Flagship programmes such as Sagarmala and Maritime India Vision 2030 are modernising port infrastructure, enhancing multimodal connectivity, and enabling greater cargo throughput—structural factors that increase vessel calls and, by extension, marine fuel demand. The Green Port (Harit Sagar) Guidelines also set decarbonisation targets for ports and mandate future bunkering capabilities for green fuels, reinforcing the integration of energy demand considerations into long-term planning.

The National Green Hydrogen Mission provides funding for green hydrogen and derivative production, along with financial support for port-side infrastructure such as pipelines, storage tanks, and bunkering systems. Three ports—Kandla, Tuticorin, and Paradip—have already been designated as hydrogen hubs, and the presence of LNG terminals and chemical-handling experience at major ports strengthens India's baseline readiness for a multi-fuel future.

Structural gaps and barriers

However, despite this momentum, there is currently no national-level policy or fiscal mechanism to stimulate early demand for alternative fuels in shipping. Unlike other transport sectors, marine bunkering remains outside the scope of demand-side pricing incentives or duty exemptions. Furthermore, while several ports are being upgraded, India lacks a phased implementation roadmap or port-wise prioritisation for alternative fuel uptake.

Downstream regulatory frameworks for fuel handling, storage, and transfer—particularly for methanol and ammonia—are still underdeveloped. India has issued bunkering guidelines for LNG and, more recently, biofuels, but equivalent standards for methanol and ammonia bunkering are not yet in place. There is also limited zoning for future fuel infrastructure in port master plans, and workforce training for safe fuel handling remains at a nascent stage. These regulatory and operational gaps introduce uncertainty for investors and shipowners.

Operationally, inconsistency in customs procedures, a lack of service-level agreements for bunkering, and limited availability of bunkering-ready berths or barges may delay uptake. In addition, limited transparency around fuel quality and readiness across ports creates a trust barrier. India's current policy environment does not yet offer sufficient commercial incentives or service guarantees to make alternative fuel bunkering reliably competitive in the short term. There are no port-user rebates or fuel-cost adjustment mechanisms to close the price gap with fossil bunkers.

Opportunities for immediate action

In the short term, there is an opportunity to bridge these gaps by issuing port-specific bunkering readiness plans, aligning trade and maritime development strategies, and exploring fiscal mechanisms such as GST waivers or offtake guarantees to create early demand signals. Publishing interim guidelines for methanol and ammonia, reserving land for future fuel terminals, and establishing cross-agency coordination to align port, energy, and environment regulations would substantially reduce friction.

Short-term measures such as priority berthing for low-carbon fuel vessels, real-time publication of bunkering readiness, fuel availability dashboards, and clear turnaround standards could substantially improve India's value proposition as a bunkering location.

A.2.4 Fixing parameters for scenario analysis

To ensure clarity and comparability in the scenario analysis, certain parameters have been fixed while others are varied. This approach reduces complexity and allows the analysis to focus on the drivers most relevant to India's bunkering potential. Fixing parameters ensures that differences between scenarios can be attributed to the selected variables rather than multiple overlapping changes.

Two options were considered for structuring the scenarios:

- **Option 1 – Market capture:** Vary the total volume of carbon-neutral energy demand (low, medium, high) and India's bunkering uptake under different market development scenarios (e.g., trade growth, port development, competitiveness), while keeping the fuel pathway fixed under a net-zero framework.
- **Option 2 Future fuel resilience:** Vary the fuel mix—exploring pathways where methanol, ammonia, biofuels, or e-fuels dominate—while keeping total energy demand constant.

Following discussions with the project partners and IMO, option 1 was selected.

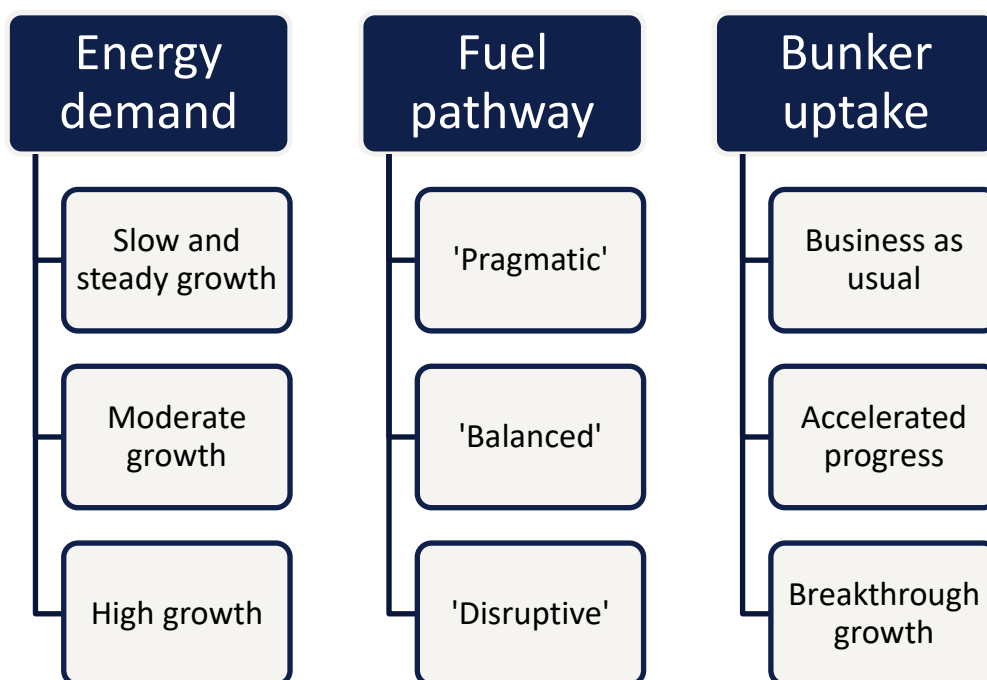


Figure A 33: The scenario analysis applies a three-layered approach, fixing the fuel pathway under a net-zero framework while varying energy demand and bunker uptake to illustrate India's market capture potential.

Final scenario setup used for the demand analysis

The demand model has the ability to treat the domestic, regional, international and passing fleet independently. However, there are some demand drivers that are similar across the different fleet groups. One such driver is the net annual fleet growth between the four demand categories listed in the first part of this paragraph. The project has used DNV's Maritime Forecast to 2050 (2025 edition) to model the fleet development in Scenario 1. For scenario 2 and 3, an "uplift" to the forecast of 0.5% and 1.5% annually, respectively, is applied to reflect that India's share in global shipping is growing faster compared to the global forecast used. This results in an annual growth rate (CAGR) for the fleet from 0.16% in Scenario 1 to 1.66% in Scenario 3, in line with other credible outlooks for fleet growth towards 2050. Note that these growth rates are inclusive of energy efficiency gains forecasted in the same period.

Decarbonisation rate is the primary driver of alternative fuel demand and remains constant across scenarios, aligned with IMO's 2023 Revised GHG Strategy. The IMO Net-Zero Framework (NZF) is not yet formally adopted; however, its 2050 net-zero ambition is used here as an analytical reference pathway for demand projections. Since the NZF does not specify annual GFI targets for all years, linear interpolation was applied between known milestones. Domestic and regional fleets are assumed to decarbonise at the same pace for transparency, despite potential for faster domestic adoption.

Current bunkering demand benchmarks are drawn from section 5 and allocated across fleet categories using the "fair share principle." This method tends to overestimate demand in emerging bunkering regions, as it assumes equal distribution based on port calls. To correct this, international fleet demand was adjusted downward to align with external sources for actual bunkering volumes in India. According to the port call data analysed in this report, India has a high number of port calls with low bunkering volumes as ships prefer to bunker elsewhere. This is why the "bunkering uptake factor" for international ships has been adjusted to align with S&P estimated bunker volumes. The bunkering uptake factor is increased in Scenario 2 and 3 to reflect that India captures more of their fair share demand in line with the leading bunkering hubs such as Singapore as India becomes more competitive.

The passing fleet is modelled differently, as it currently does not bunker in India. Scenarios 2 and 3 introduce probabilities for capturing demand from vessels deviating to India for competitive pricing or strategic advantages. In Scenario 2, 50% of container ships calling Colombo and small shares of vessels passing Zones B and C are redirected to India. Scenario 3 assumes 80% of Colombo traffic shifts to India, reflecting successful transshipment relocation. While these shifts increase demand, their overall contribution remains modest.

The last layer, the "bunkering uptake factor" aims to quantify how India develops compared to competing bunkering hubs regionally between 2027 to 2047:

- **Scenario 1:** Alternative fuels are available in ports, but supply constraints and weak price competitiveness limit adoption. Bunkering is driven more by necessity than strategic preference. The allocation factor rises gradually from 0.55 (aligned with S&P-estimated bunker volumes) in 2024 to 0.60 by 2040, stabilising at 0.65 by 2047—reflecting organic growth but no major competitiveness improvements.
- **Scenario 2:** Moderate port development, improved reliability, and targeted operational enhancements lead to better availability and pricing of alternative fuels. India captures a greater share of regional bunker demand, with the allocation factor rising to 0.70 used for emerging bunkering hubs by 2040 and stabilising at 0.85 by 2047—equivalent to about 85% of India's expected fair share based on trade flows.
- **Scenario 3:** India develops world-class maritime hubs through aggressive investment in alternative fuel infrastructure, regulatory incentives, and strong private-sector participation. The uptake factor rises rapidly, reaching 0.9 by 2040 and 1.20 by 2047—meaning India captures roughly 20% more than its expected fair share of regional bunker demand as India in this Scenario becomes a leading bunkering hub for alternative fuels.

Finally, net fleet growth, current bunkering demand, the rate of decarbonisation, and the application of the bunkering uptake factor drive demand for alternative fuels across the three scenarios

A.2.5 Results from growth and fuel demands analysis

Scenario 1 – Slow and Steady Growth

Scenario 1 represents the most pessimistic demand forecast of the three Scenarios. Current bunkering demand including fossil fuels is about 100,000 TJ. The same demand for alternative fuel demand is in this Scenario reached in 2045 and is equivalent to 5 million tons methanol, 5.4 million tons of ammonia or 833,000 tons of hydrogen³¹.

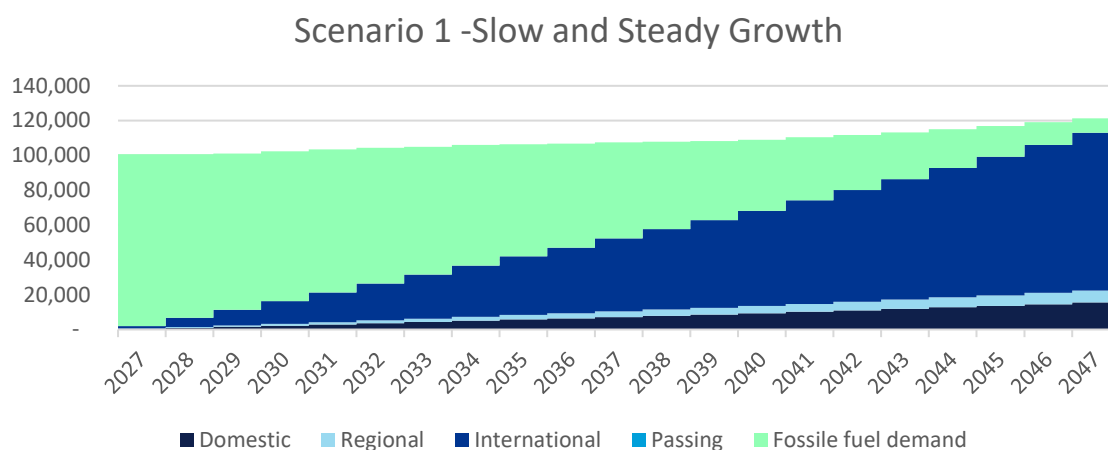


Figure A 34: Scenario 1 -Slow and Steady Growth

The fuel quantities shown in the tables below represent a hypothetical scenario where 100% of the energy demand is met by a single fuel type. In practice, the market will likely adopt a combination of different fuels, so these figures should be viewed as illustrative rather than definitive.

Table A 4 : Fuel quantities (Scenario 1)

Fuel type, metric tons	Equivalent demand in 2035, mt	Equivalent demand in 2047, mt
Methanol (19.9 GJ/ton)	2,109,642	5,680,352
Ammonia (18.6 GJ/ton)	2,257,090	6,077,366
Hydrogen (120 GJ/ton)	349,849	941,992

Scenario 2 – Accelerated progress

Scenario 2 assumes that India is partially successful in establishing itself a container transshipment hub that moves about half of the container transshipment currently performed in Sri Lanka over to mainland India. Furthermore, the quality of service and reliability is increased to capture about 15% more (bunkering uptake factor) of the bunkering volumes that is currently lost to other regions compared to scenario 1. 100% of the domestic demand is still supplied by Indian ports.

³¹ Methanol: 19.9 GJ/ton, Ammonia: 18.6 GJ/ton, Hydrogen: 120 GJ/ton

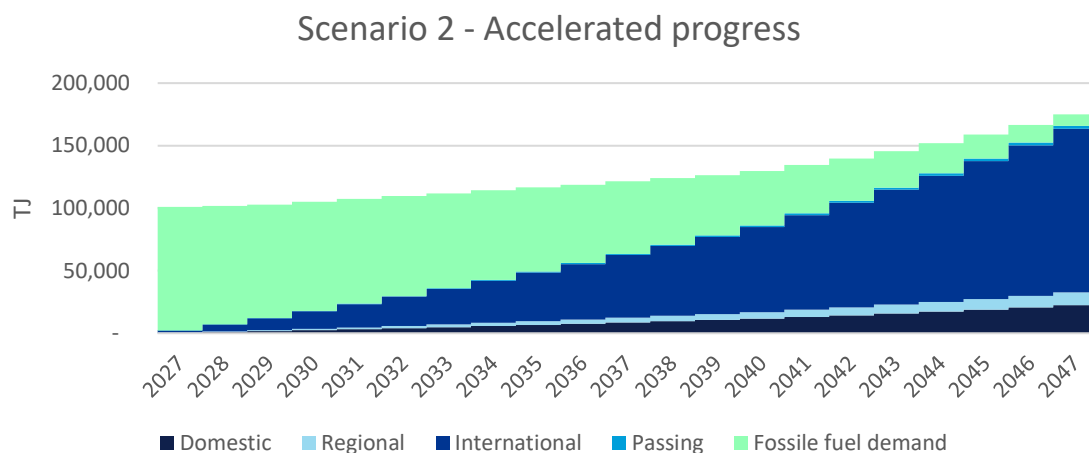


Figure A 35: Scenario 2 - Accelerated progress

Table A 5 : Fuel Quantities (Scenario 2)

Fuel type, metric tons	Equivalent demand in 2035, mt	Equivalent demand in 2047, mt
Methanol (19.9 GJ/ton)	2,479,714	8,338,103
Ammonia (18.6 GJ/ton)	2,653,027	8,920,873
Hydrogen (120 GJ/ton)	411,219	1,382,735

Scenario 3 – Breakthrough growth

Scenario 3 assumes that India becomes a leading alternative fuel bunkering hub and is successful in attracting 20% more demand than their fair share. This is achieved by being both highly competitive on price and the quality of the fuels and services provided. This will result in a potential demand of around 3.5 million tons of ammonia in 2035 which is approximately the same amount of energy bunkered in India in 2024.

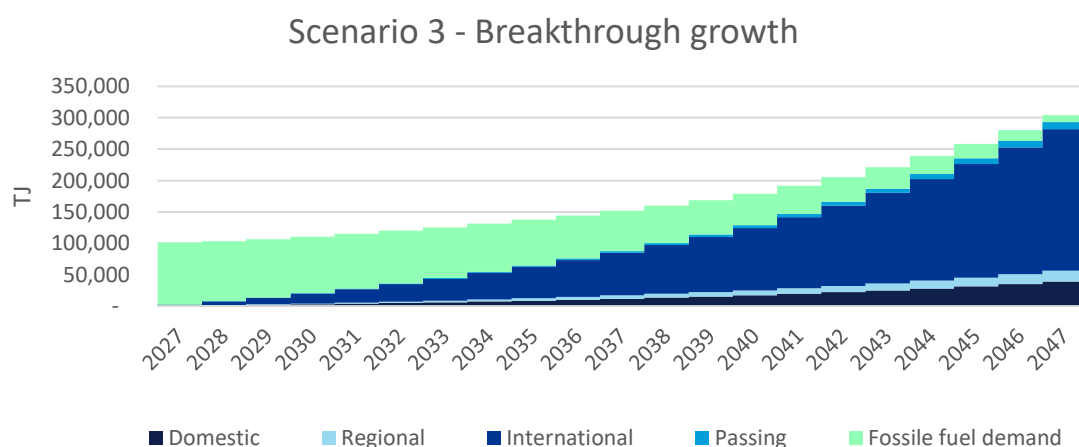


Figure A 36: Scenario 3 - Breakthrough growth

Table A 6 : Fuel Quantities (Scenario 3)

Fuel type, metric tons	Equivalent demand in 2035, mt	Equivalent demand in 2047, mt
Methanol (19.9 GJ/ton)	3,254,404	14,737,661
Ammonia (18.6 GJ/ton)	3,481,862	15,767,713
Hydrogen (120 GJ/ton)	539,689	2,443,996

A.3 FUTURE FUEL PRICING ASSESSMENT

A.3.1 Bunkering behaviour and fuel market

Current bunkering behaviour

International shipping operates in an intensely cost-competitive environment, where fuel price is the dominant determinant of bunkering decisions once availability, quality, and operational reliability are assured. Consistent with global practice, ship operators adopt an opportunistic bunkering strategy, concentrating fuel purchases at ports offering the lowest total delivered cost—defined as the combined effect of fuel price, port charges, and operational bunkering costs—and taking only minimal quantities at higher-cost locations.

To assess India's competitiveness relative to established global bunkering hubs, a comparative analysis was undertaken covering fuel prices, port-related charges, and operational bunkering costs at selected major hubs and Indian ports, using heavy fuel oil (HFO) as a common reference fuel. Table A 7 presents the underlying cost components, including quoted fuel prices, port fees per call, operational bunkering charges, and applicable taxes.

The results show that India is currently uncompetitive relative to major hubs such as Singapore, Fujairah, and Rotterdam. Quoted HFO prices at Indian ports are approximately 54% higher than Singapore and more than 50% higher than Fujairah, even before accounting for port fees, operational charges, or taxation. When these additional cost elements are included, the total delivered bunker cost differential widens further, reinforcing the limited attractiveness of Indian ports for discretionary bunkering.

These findings align with observed bunkering behaviour. The global bunkering market remains dominated by large, integrated hubs such as Singapore, Rotterdam, and Fujairah, which benefit from competitive fuel pricing driven by scale and market liquidity. These hubs also offer streamlined operations, including high pumping rates, minimal waiting times, reliable bunkering-at-anchor arrangements, and a mature marine services ecosystem, all of which reduce vessel turnaround time and operational risk.

The materially higher fuel prices observed at Indian ports reflect structural characteristics of the Indian bunkering market rather than short-term price distortions. Bunkering demand is relatively limited and fragmented across ports, resulting in lower turnover and higher per-tonne supplier margins. In parallel, Indian refineries are increasingly optimised to maximise distillate production for domestic consumption rather than residual fuel streams for the international bunkering market, increasing the opportunity cost of supplying HFO to foreign-going vessels.

Port-related and operational factors further amplify this disadvantage. Indian ports typically face higher port dues, pilotage, and tug requirements, alongside slower pumping rates, limited availability of compliant bunkering barges, and more fragmented service arrangements. India is also the only region in the comparison where a 5% GST (Goods and Service Tax) is applied to bunker fuel supplied to foreign-going vessels, further increasing the total delivered cost relative to competing hubs.

Stakeholder interviews support these findings. While some operators initially perceive a modest fuel price difference when considering headline prices alone, most acknowledge that once port fees and operational costs are included, the effective cost differential aligns with the larger gap identified in the comparative dataset. Operators also highlighted non-cost factors—such as variable documentation processes, inconsistent bunkering-at-anchor availability, uncertain fuel availability and tidal or scheduling constraints—that reduce predictability and increase the perceived operational risk of bunkering in India.

Taken together, the quantitative evidence and stakeholder feedback explain why vessels on international routes rarely divert to Indian ports solely for bunkering and instead concentrate bunkering activity in established low-cost hubs. While fuel supplied at Indian ports is generally regarded as high quality and reliably compliant, this strength does not currently outweigh the combined disadvantages of higher fuel prices, higher port and operational costs, and lower operational efficiency that shape global bunkering choices.

Table A 7 : Fuel Prices, Port Fees and Bunkering/Operational Charges along Major Bunkering Hubs during December 2025.

Ports/Region	Fuel Price (USD/tonne) <i>Includes commodity price and supplier margin (if any).</i>	Port Fee (USD/call) <i>Includes port dues, pilotage, anchorage, berth hire, and any statutory charges incurred when entering the port.</i>	Bunkering/Operational Charges <i>Includes barge hire, pumping charges, manpower, documentation, and service-related costs directly tied to fuel delivery.</i>	Tax (GST/VAT)
Singapore ^{32 33 34}	353	700 - 900	2,000 – 4,000	0
Fujairah ^{35 36}	322	1,800 – 2,200	1,500 – 3,000	0
Rotterdam ^{37 38}	347	5,400 – 6,000	3,000 – 5,000	0
India ^{39 40 41}	545	9,500 – 10,500	2,500 – 4,000	5%

To illustrate how the different cost elements add up in USD/tonne, we have assumed a 5,000-tonne HFO bunker stem at each location, shown in Figure A 37. Each bar aggregates the four cost components: (i) fuel price (USD/tonne), (ii) port fees, allocated on a per-tonne basis by spreading per-call charges across the assumed bunker volume, (iii) operational bunkering charges, similarly normalised to USD/tonne, and (iv) applicable taxes where relevant. Mid-point values have been used where cost ranges are provided for port fees and operational charges, and all values have been converted to USD for consistency. The figure shows that for a 5,000-tonne bunker stem, fuel price is the dominant cost component across all locations, with GST further increasing the delivered cost in India. Port fees and operational charges represent a smaller share on a per-tonne basis at this scale; however, they remain relevant in absolute terms for operators when evaluating bunkering decisions. For smaller bunker stems, these per-call charges are distributed over lower volumes, increasing their per-tonne impact and making them more material—particularly in India where baseline fuel costs are already higher.

³² [Port Dues Concessions | Maritime & Port Authority of Singapore \(MPA\)](#)

³³ [APAC-EVNT-PRO-2025-06-27-SIN-BIO-Argus-Biofuels-Forum-Argus Marine Fuels.pdf](#)

³⁴ [Pilotage tariff revision | GAC](#)

³⁵ [Fujairah Marine Fuel Prices - Bunker Costs Live | OilPriceAPI](#)

³⁶ [POF Tariff Book](#)

³⁷ <https://www.oilmonster.com/bunker-fuel-prices/west-northern-europe/rotterdam/133>

³⁸ [Port Of Rotterdam Offers 'Substantial' Port Fee](#)

³⁹ [Mumbai Bunker Fuel Prices Today, IFO 380, IFO 180, MGO Prices per Ton](#)

⁴⁰ [Waiver reinstated at Port of Gangavaram for vessels using green bunker fuels | Manifold Times](#)

⁴¹ [Delivered bunker premiums recover slower than cargoes | Latest Market News](#)

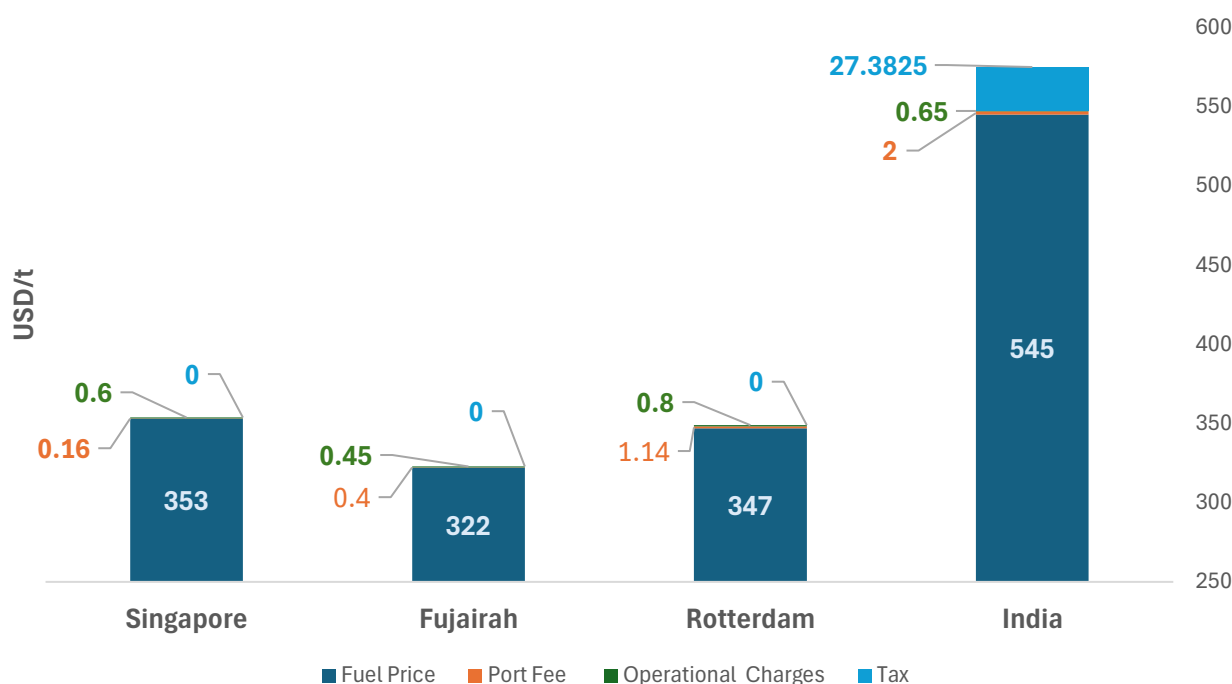


Figure A 37: Total bunkering costs for different ports in USD/t for a 5,000 tonne bunker stem, including fuel price, port fee, operational charges and tax

A.3.2 Current fuel market

The global bunkering market is dominated by a few major hubs strategically located along key shipping routes, as seen in Table A 8. Singapore remains the largest bunkering port worldwide, serving as a critical refuelling point for vessels transiting between Asia and Europe. Rotterdam is the leading hub in Europe, benefiting from its proximity to major trade lanes and strong infrastructure. Fujairah, positioned near the Strait of Hormuz, is a key Middle Eastern hub, offering competitive pricing and accessibility for vessels operating in the Indian Ocean and Persian Gulf.

India's bunkering volumes are significantly lower than those of major global hubs. Singapore recorded 54.92 million tonnes⁴² of bunker fuel sales in 2024, while the Port of Rotterdam bunkered 9.8 million tonnes⁴³ while Indian ports bunkered roughly 2.25 million tonnes⁴⁴ over the same period. This indicates that Indian ports operate at a much smaller scale, reflecting their limited role in international bunkering despite rising vessel calls. The fuel and port fee assessment highlights that higher port charges, limited economies of scale, slower pumping rates, and infrastructural gaps, particularly the limited availability of compliant barges, further erode India's competitiveness relative to the major hubs.

Table A 8 : Bunker volumes by port 2024⁴⁵

Country	Port	2024 Volume (mn t)
Singapore	Singapore	54.92
The Netherlands	Rotterdam	9.39
UAE	Fujairah	7.5
China	Zhoushan	7.26
Belgium	Antwerp-Bruges	6.51

⁴² <https://www.spglobal.com/energy/en/news-research/latest-news/refined-products/011525-singapore-bunker-sales-hit-5492-million-mt-record-in-2024-amid-red-sea-reroutes>

⁴³ <https://bunkermarket.com/rotterdams-2024-bunker-sales-records-9-8m-tonnes-Ing-growth-soars/>

⁴⁴ <https://s7d9.scene7.com/is/image/spglobalcom/121724-india-bunkering-red-sea-diversions-srilanka>

⁴⁵ <https://www.manifoldtimes.com/news/ipecc-2025-top-ten-global-bunkering-ports-and-marine-fuel-suppliers-revealed/>

South Korea	Busan	6.24
China	Hong Kong	5.7
Panama	Panama	5.2
United Kingdom	Gibraltar	4.77
China	Shanghai	4.13
India	Mumbai	<1.0

Fuel prices, as shown in Figure A 38 between these major ports have experienced significant price differences in the past five years, especially for MGO between Fujairah and the two other ports, reaching over 30% at some instances.



Figure A 38: Bunker prices shown in delivered price at the ports of Rotterdam, Singapore and Fujairah, 2020-2024. Source: Clarksons Research Shipping Intelligence Network

A.3.3 India's advantage for alternative fuel production

Electricity cost development

India's renewable potential is among the highest globally, and although coal will remain a major component for decades, the electricity mix is projected to shift significantly toward renewables. According to DNVs Energy Transition Outlook, electricity demand in the Indian Subcontinent will more than double by 2060, driven by population growth and industrialization. Electrification is the cornerstone to both the energy transition and economic development. DNVs electricity demand forecast for the region includes production of hydrogen and hydrogen-derivatives for hard-to-electrify sectors. While coal currently dominates the electricity mix, its share will decline steadily as solar and wind become the backbone of electricity generation. By 2060, renewables (primarily solar and wind) are expected to supply around 70% of electricity, with solar alone contributing nearly 40% and wind about 30%. Coal will fall to roughly 10–15%, while gas and hydro will play smaller roles. The region is forecasted to add ~200 GW of wind capacity by 2040, mostly onshore, and solar will expand even faster due to India's vast solar potential and falling investment costs, see Figure A 39.

The increase in renewables generation will drive down electricity costs in India. As electricity is the main component in production costs for hydrogen and derivatives, this will be a key driver for expected declining costs for these fuels in India. Of the regions assessed in the fuel cost analysis, India is forecasted to have the largest decrease in electricity price, except for Greater China due to a very rapid expansion of renewables capacity.

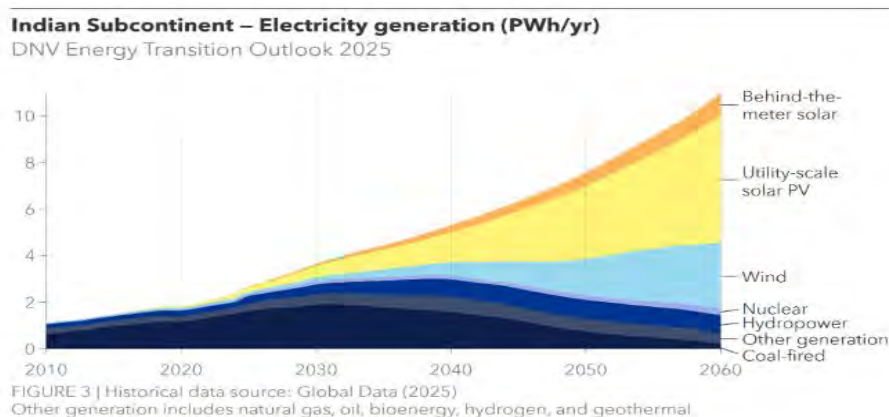


Figure A 39: Forecasted electricity production in Indian Subcontinent (DNV Energy Transition Outlook 2025)

Biomass availability

Biofuel production costs are lower than blue- and e-fuels, but the potential for biofuel production is highly dependent on availability of (sustainable) biomass. Biomass is a limited resource and cannot cover all future demand for alternative fuels.

DNV has done an estimate on global biomass availability based on a bottom-up methodology combining literature review, expert interviews and statistical analysis of public datasets. Strict sustainability criteria were used, aligned with the EU RED II directive, and conservative estimates were applied to avoid overstating potential. These figures account for technical, economic, and sustainability constraints, ensuring realistic and conservative estimates. Global sustainable and economically exploitable biomass potential is estimated at 32.2 EJ in 2020, increasing to 42.0 EJ by 2050. The Indian region, comprised bordering countries (except China and Myanmar), is estimated at 4.3 EJ in 2020 increasing to about 5.3 EJ in 2050 (see Figure A 40).

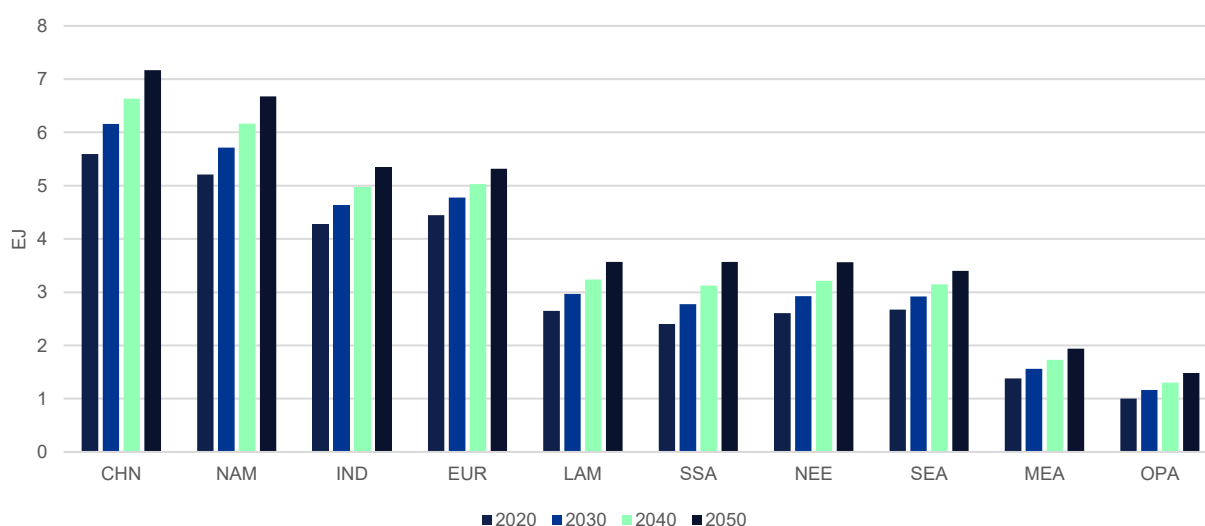


Figure A 40: Energy from sustainable biomass potential per region (Source: DNV analysis)

India's sustainable biomass potential ranks among the world's highest, with the Indian region estimated at approximately 4.3 EJ in 2020, projected to increase to 5.3 EJ by 2050, positioning it as the third-largest biomass-to-energy potential globally after Greater China and North America.

Another study shows that India's annual biomass feedstock availability totals approximately 308 million tonnes, comprising 122.27 MT of rice straw, 109.52 MT of wheat straw, and 51.15 MT of coarse cereals, with additional agricultural residues and forestry by-products⁴⁶. With surplus biomass availability estimated at around 228-230 million metric tonnes annually, India possesses considerable untapped resources, particularly in municipal and industrial waste, and agricultural by-products, which are highly suitable for advanced biofuel production including biodiesels, biomethane, and biomethanol.

India has achieved substantial progress on its ethanol blending mandate—a government requirement mandating that oil marketing companies (OMCs) blend a minimum percentage of ethanol with petrol before retail sale—reaching an average ethanol blending of 19.05% by the end of July 2025⁴⁷. Current biofuel production is economically supported through administered pricing mechanisms, with ethanol procurement prices for ESY 2024-25 established at INR 57.97 per litre (~0.5 USD/l) for C-Heavy molasses-derived ethanol and ₹71.86 per litre (~0.8 USD/l) for maize-derived ethanol⁴⁸. However, second-generation (2G) advanced biofuels face higher production costs due to complex conversion processes and capital-intensive infrastructure. The IOCL's 2G ethanol plant at Panipat required an investment of over Rs. 900 crore (USD 100 million)⁴⁹ with pricing formulas still under government review to incentivize scaling. While biofuel production costs remain comparatively lower than blue and e-fuels, government support mechanisms including capital subsidies up to 30% of project costs, GST exemptions on feedstock, and export flexibility for advanced biofuels remain essential to offset the cost differential between biofuels and conventional fossil fuels.

Ongoing alternative fuel projects in the region

Figure A 41 and Figure A 42 show the project pipeline for ammonia, hydrogen and methanol for India and the surrounding regions (Middle East and Africa (MEA), OECD Pacific (OPA), Greater China (CHN), South East Asia (SEA) and Indian Subcontinent (IND), based on DNVs Alternative Fuel Insights platform. The year represents the announced year for entry into operation.

Projects in MEA are concentrated in Egypt and Morocco, with a strong emphasis on green ammonia production, some targeting European offtake markets. While the number of projects is limited, they are typically large-scale developments, positioning these countries as future exporters of clean fuels.

In OPA, Australia dominates the pipeline, also prioritizing green ammonia. These projects aim to serve both domestic demand and export markets, with potential destinations including Singapore and Japan. Similar to MEA, the region features few but very large projects.

China presents a contrasting profile, with more numerous, smaller projects. The majority focus on biomethanol and e-methanol, accounting for almost half of global bio- and e-methanol capacity in the current pipeline. According to local experts, a majority of the methanol capacity built in China is targeting exports.

In India, the capacity is largely driven by green ammonia projects.

⁴⁶ <https://www.tataconsultingengineers.com/blogs/biomass-powering-indias-sustainable-energy-future/>

⁴⁷ <https://www.pib.gov.in/PressReleasePage.aspx?PRID=2155110®=3&lang=2#:~:text=During%20the%20ongoing%20ESY%202024,for%20the%20ESY%202024%2025.>

⁴⁸ <https://www.thehindubusinessline.com/economy/india-achieved-ethanol-blending-of-192-during-esy-2024-25/article70344516.ece>

⁴⁹ <https://www.pib.gov.in/PressReleasePage.aspx?PRID=1850585®=3&lang=2>

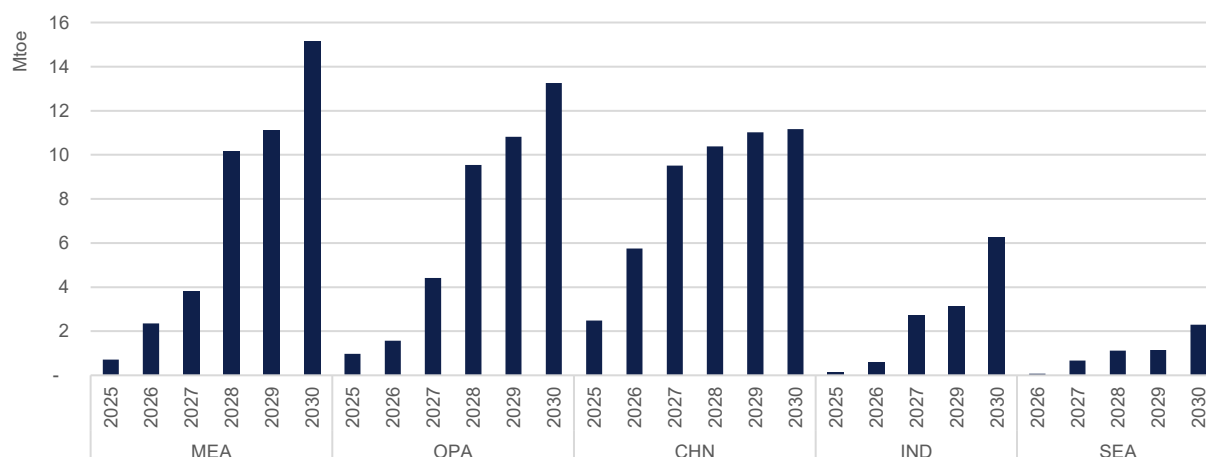


Figure A 41: Project pipeline for Ammonia, Hydrogen and Methanol, by region to 2030 (Source: DNVs Alternative Fuel Insights platform)

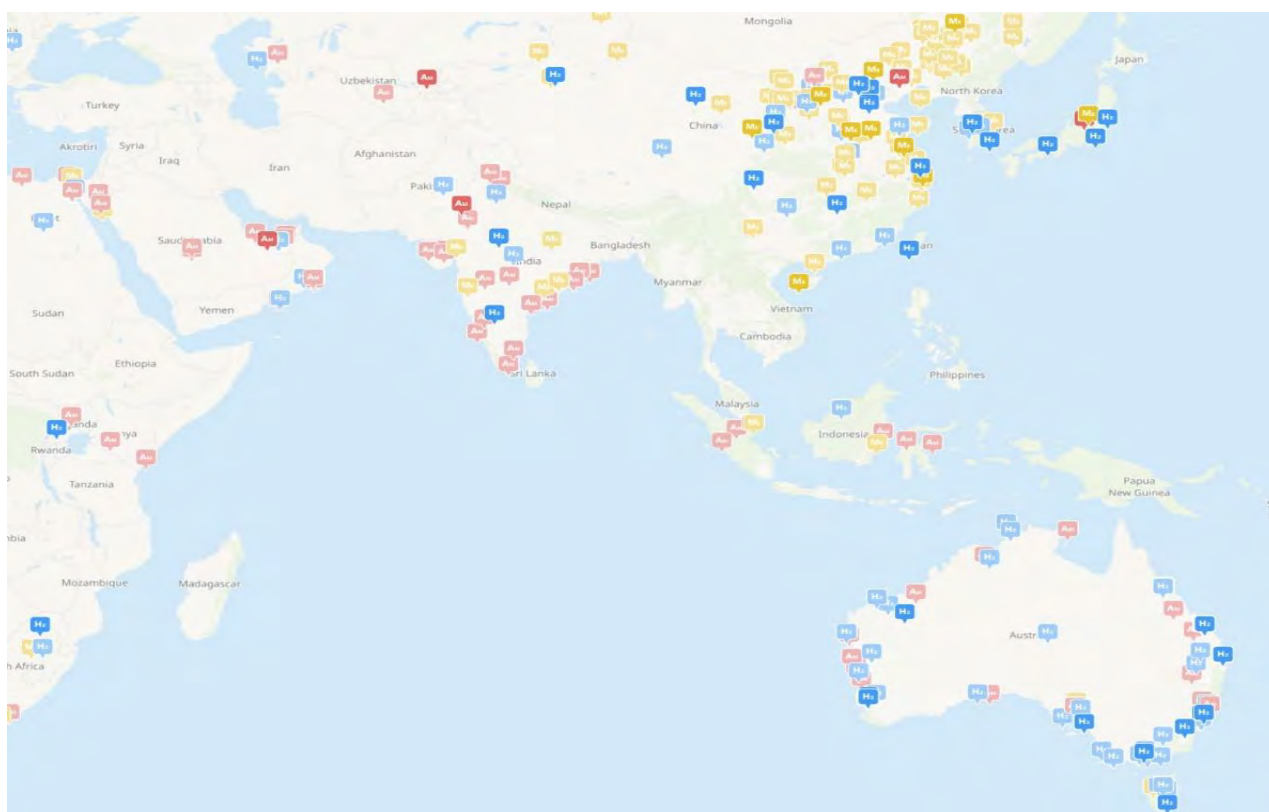


Figure A 42: Map of ongoing ammonia, hydrogen and methanol projects (Source: DNVs Alternative Fuel Insights platform)

A.3.4 Alternative fuel price assessment

Fuel cost vs price

Fuel prices, i.e. what the end user pays for the fuel, can fluctuate significantly even if production costs remain stable. This is because they are influenced by market conditions and policy measures. Prices include profit margins, any taxes and

regulatory compliance costs, logistics/bunkering costs and market dynamics (such as demand-supply imbalances, especially during the early adoption phase).

Regulation impacting fuel transition and willingness to pay

Production costs for alternative fuels are currently significantly higher than those of conventional fuels, and regulatory mechanisms (subsidies or penalties) are necessary to facilitate the transition. National, regional and global regulations are taking shape to enable uptake of alternative fuels and reduce emissions from the maritime sector.

As a general rule, to make the industry transition to alternative fuels the price of alternative fuel must be lower than the price of fossil fuel including any emission and penalty costs. As shown in the Figure A 43 below, the low-GHG fuel supply curve illustrates the production cost of alternative fuels, and shows how these fuels can be priced up to the highest willingness to pay line, just below the fossil plus penalty level. In a perfectly competitive market, fuel prices would converge, as suggested by the low-GHG price range. In reality, transport constraints and varying fuel characteristics create fragmented markets rather than a single unified one. However, from the perspective of shipowners making investment decisions on newbuilds or retrofits, the market initially appears more uniform, alternative fuels compete directly at this decision point. Once a choice is made, segmentation becomes evident, as shipowners are effectively locked into the specific fuel ecosystem they selected.

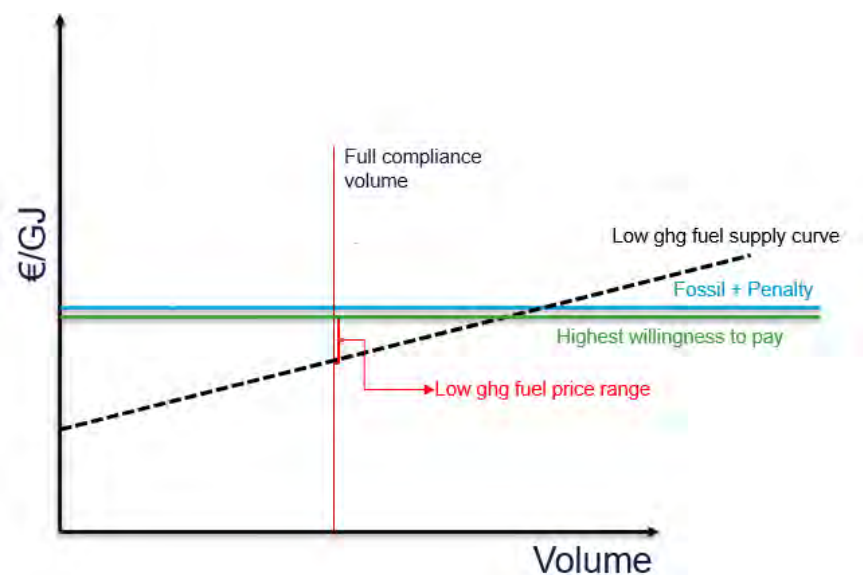


Figure A 43: Price formation and market balance of low-GHG fuels under compliance schemes like the IMO NZF

National regulation

India's national regulations strategically drive the maritime sector's transition to alternative fuels like biofuels (ethanol, biodiesel, bio-CNG), LNG, green hydrogen, ammonia, and methanol by offering targeted financial, tax, and operational incentives. Policies such as the Maritime Amrit Kaal Vision 2047⁵⁰, National Green Hydrogen Mission⁵¹, and Harit Sagar⁵² Green Port Guidelines reduce the cost premium of these fuels, enhancing ship owners', fuel producers', and ports' willingness to invest in cleaner energy solutions amid global decarbonization pressures.

These measures lower upfront and operational costs through subsidies, rebates, and priority access, making alternative fuels more competitive with conventional bunker fuels. By addressing price sensitivity and infrastructure gaps, the

⁵⁰ <https://green-port-shipping.org/resource/reports/maritime-amrit-kaal-vision-2047>

⁵¹ <https://mnre.gov.in/en/notice/the-national-green-hydrogen-mission-13-1-2023-648-kb-pdf/>

⁵² <https://shipmin.gov.in/sites/default/files/Harit%20Sagar%20-%20Green%20Port%20Guidelines%20%28May%202023%29.pdf>

framework accelerates adoption, positions India as a leader in green shipping, and improves energy security while reducing emissions.

Incentives for Ship Owners

Ship owners gain from the Green Shipping Subsidy Program's 30% support for vessels powered by hydrogen, LNG, or biofuels, higher than the 20% for conventional ships. Maritime Amrit Kaal Vision 2047 proposes port dues rebates, tonnage tax reductions, and up to 50% cuts in terminal charges for cleaner fuel users, alongside 30-40% shipbuilding assistance for green retrofits. Harit Sagar Guidelines provide priority berthing and berth dues rebates for ships using LNG, hydrogen, ammonia, or methanol. For comparison with competing hubs, The Maritime Singapore Green Initiative offers reduction in port dues for ships using low- carbon fuels, and greater reductions for zero-carbon fuels such as hydrogen⁵³

Benefits for Fuel Producers

Producers receive administered pricing for ethanol and excise duty waivers under the National Policy on Biofuels 2018 (amended 2022)⁵⁴. Biodiesel benefits from a reduction in GST from 12% to 5%, while the SATAT (Sustainable Alternative Towards Affordable Transportation) Scheme provides capital subsidies and offtake guarantees for bio-CNG. The National Green Hydrogen Mission offers production-linked incentives per kilogram produced, transmission charge waivers, and pilot project funding. Additionally, the Amrit Kaal initiative extends Production-Linked Incentives (PLI) to marine hydrogen fuel cells and ammonia engines.

Support for Ports

Ports developing LNG, hydrogen, ammonia, and methanol bunkering access, Sagarmala⁵⁵ grants, duty exemptions on equipment, green financing, and carbon credits under Harit Sagar Guidelines⁵⁶. Amrit Kaal introduces a Maritime Green Fund to offset revenue losses from reduced dues and offers flexible 99-year land leases, plus capital subsidies for green infrastructure in industrial parks.

Tax and Pricing Mechanisms

LNG and hydrogen in India are priced under the Petroleum and Natural Gas Regulatory Board Act (2006⁵⁷), following a market-driven framework and benchmarked against global indices such as Henry Hub and international LNG spot markets. Recent fiscal reforms have improved the economics of marine fuels: the GST rate on bunker fuel has been reduced from 12% to 5%, significantly lowering procurement costs for ship operators and easing cash-flow constraints. Collectively, these pricing mechanisms and fiscal adjustments help reduce the transition-cost burden associated with adopting LNG, hydrogen, and other low-carbon marine fuels, while strengthening India's competitiveness as an emerging regional bunkering hub.

International regulation

IMO Net Zero Framework

The IMO NZF is still in draft form and not yet adopted, but aims at marking a turning point for global shipping, introducing the first-ever worldwide carbon pricing mechanism and strict greenhouse gas intensity targets for ships. The draft requirements includes that from 2028, vessels over 5,000 GT will need to reduce their well-to-wake GHG fuel intensity (GFI) or face financial penalties, with reduction requirements tightening every year toward net-zero by 2050. Since the IMO decision was delayed for at least one year, it is expected that the start year will also be delayed.

⁵³ DNV 2025, Maritime Forecast to 2050

⁵⁴ <https://mopng.gov.in/en/page/11>

⁵⁵ <https://sagarmala.gov.in/sites/default/files/sagarmala-eng.pdf>

⁵⁶ <https://shipmin.gov.in/sites/default/files/Harit%20Sagar%20-%20Green%20Port%20Guidelines%20.pdf>

⁵⁷ https://www.indiacode.nic.in/bitstream/123456789/2012/1/2006_19.pdf

The regulations include annual GFI reduction targets to 2035, as shown in Figure A 44 below. Two tiers of requirements are set on the annual attained GFI for a ship: a Base target and a Direct Compliance target.



Figure A 44: Net-Zero Framework. Note: the decision to adjourn the adoption of IMO NZF by one year could result in changes to the regulations, including aspects such as timeline

Based on the attained GFI and the targets, each ship will have to determine an annual compliance balance, expressed in tonnes CO₂eq. If a ship has GFI lower than the Direct Compliance target, it will receive surplus units (SUs). If GFI is between Base and Direct it will get a Tier 1 deficit, and if GFI is above Base it will get a Tier 1 + Tier 2 deficit

Ships with deficits must either buy Remedial Units (RUs) from the IMO Net-Zero Fund or use SUs from other ships (only for Tier 2 deficits). The initial RU prices (2028–2030) are \$100 per tonne CO₂eq for Tier 1 and \$380 per tonne CO₂eq for Tier 2. These will be reviewed and defined for the years after 2030.

The regulations are designed in this manner with the intention that most ships will use sufficient low-GHG emission fuels to reach the Base target and then buy Tier 1 RUs. This requires that the IMO sets the Tier 2 RU price higher than the price for low-GHG emission fuels, as explained in chapter A.3.4. Figure A 45 shows the alternative fuel willingness to pay based on IMO NZF avoided penalties (keeping initial RU prices) and potential SU sales income, assuming the alternative fuel is zero emission.

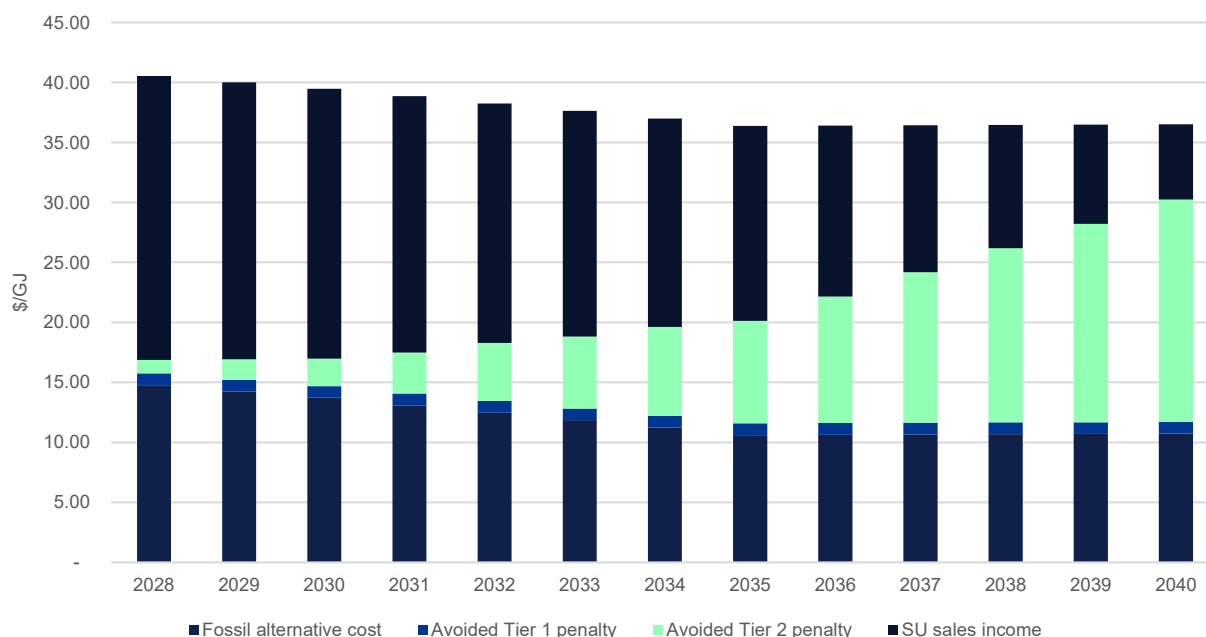


Figure A 45: Alternative fuel willingness to pay, based on IMO NZF penalties

Fuel EU Maritime

In addition to meeting NZF requirements, ships that fall under the EU ETS and FuelEU Maritime regulations must continue to comply with these frameworks until a potential alignment with NZF is established. This means such vessels will need to surrender emission allowances under the EU ETS and may face penalties under FuelEU Maritime for any non-compliance. Notably, FuelEU Maritime uses a metric and mechanism similar to those applied by the NZF. Both under the NSZ and the FuelEU Maritime, the emission factor for the different fuels are highly important in order to be competitive, as it is in the end the overall CO₂ abatement cost for each fuel which determines how competitive the fuel is compared to other fuels, not only the price level alone.

Alongside the specific regulations like NZF and the FuelEU Maritime, there are other more 'commercial' drivers that are and can drive the willingness to pay for low-GHG fuels. As of 2025, the uptake of biofuels is largely driven by commercial service offerings with reduced scope 3 emissions, in return for a higher transport price. Such services are focused on container shipping and car carrier trades, with cargo owners willing to pay a premium for reduced scope 3 GHG emissions.

Methodology for determining future alternative fuel price levels

We have used DNVs Marine Fuel Cost Mapper tool (described below) to estimate future fuel production costs for the relevant regions around India.

The required price range for India must be below or in the lower range of the fuel production cost range for the surrounding regions, including any expected added costs for distribution and bunkering.

DNVs Marine Fuel Cost Mapper

Model description

The Marine Fuel Cost Mapper is a techno-economic cost model developed by DNV Environment Advisory to analyse all elements of the fuel supply chain, including production and distribution to port terminals. The model covers both low GHG

emission fuels and fossil fuels, and its output and scenarios are updated on a regular basis to take into account developments on the global energy markets and methodological improvements.

Cost forecasting will always include a level of uncertainty rooted in estimated input assumptions, such as primary energy costs, scale of production, grid electricity costs, and distribution distances. To address some of these uncertainties, this analysis is performed for two scenarios to provide a cost range that absorbs some of the uncertainties associated with input assumption. The two scenarios include adjustment in the cost of LCOH and biowastes, as illustrated in Figure A 46.

High/low LCOH

LCOH is adjusted +/- 20% from baseline

High/low biowaste costs

Biowaste input costs are adjusted +/- 20% from baseline

Figure A 46: Fuel Cost Scenarios modelled in the Fuel Cost Mapper

To enhance the fuel cost projections, reported fuel prices have been used for 2024 where available. Between 2025 and 2029 the fuel costs are interpolated based on the reported fuel prices in 2024 and the model's projected fuel costs in 2030.

Regions

Annually, DNV presents results from its modelling of the world's energy system in the Energy Transition Outlook (ETO) study. The ETO model divides the world into 10 regions, shown in Figure A 47. The same regions are applied in the Fuel Cost Mapper and is used in this analysis.



Figure A 47: The 10 global regions used in DNVs Energy Transition Outlook and Marine Fuel Cost Mapper

India is part of the region **Indian Subcontinent**. In addition to India, this region consists of Pakistan, Afghanistan, Bangladesh, Sri Lanka, Nepal, Bhutan and the Maldives. The region is the most populous of the 10 regions: 1.9 billion people today, rising to 2.4 billion by 2060. India makes up 80% of the subcontinent's economy, strongly influencing the region's overall energy transition trend.

The regions included in this assessment of competing regions are Southeast Asia, Greater China, Middle East and North Africa and OECD pacific.

Fuel types

Table A 9 Shows the fuel types included in this analysis.

Table A 9 : Fuel types included in the analysis

Initial energy source	Production & processing	Distribution	Final product
Biomass	Biowaste	Transit storage, port storage, and transportation	Bio-LNG
	Forestry/agri. Residues		Bio-LNG
	Used cooking oil		Biodiesel (FAME)
	Forestry/agri. Residues		Bio-methanol
Renewable electricity	Green hydrogen		e-ammonia
	Ammonia synthesis & ammonia liquefaction		e-methanol
Natural Gas	Methanol synthesis		
	Ammonia synthesis & ammonia liquefaction		Blue ammonia

Input assumptions

Table A 10 describes the input assumptions for the fuel cost modelling.

Table A 10 : Input assumption for DNV Marine Fuel Cost Mapper

Item	Description
Hydrogen feedstock cost	We use simulation results from DNV's Energy Transition Outlook (2025-ed.). For e-hydrogen we use the weighted average cost of hydrogen production based on electricity, including: - Grid connected electrolysis - Solar (dedicated solar PV & solar plus storage electrolysis) - Wind (Dedicated onshore, fixed offshore, and floating offshore) with electrolysis - Dedicated nuclear electrolysis For blue hydrogen, we use the levelized cost of hydrogen via methane reforming with CCS.
Grid electricity prices	We use industrial electricity prices from DNV's Energy Transition Outlook (2025-ed.).
Natural gas prices	We use wholesale gas prices from DNV's Energy Transition Outlook (2025-ed.).
Crude oil price	We use a crude oil price trajectory which is decreasing from 81 USD/barrel (2025) to 56 USD/barrel (2050), aligned with DNV's Energy Transition Outlook (2025-ed.).
Biomass feedstock cost	Assumptions on the initial cost of biomass feedstock, is based on various literature. As demand for biomass increases, it is expected that supply costs will also increase, since more expensive sources of biomass need to be utilized. Because of this, we assume that biomass costs increase in the long-run. For 2025, we use biomass costs for biowaste and forestry/agricultural residues based on industry literature sources indicating region-specific prices such as IEA (2025;2020). Used cooking oil, corn, and sugarcane costs are based on recent reported regional reported prices from a wide range of sources, including USDA (2025), news articles (e.g., China Raises Cane Price to Boost 2024/25 Plantings CZ app, What Is The Matter With South Africa's Maize Prices?), and SASA (2025). In the baseline scenario, we assume that biomass costs for all feedstocks increase at an annual rate of 2%, reflecting increased costs for feedstock extraction and distribution.
CO2 feedstock cost	For point source capture, we assume a cost of 60 USD per tonne CO2. For DAC, we assume that capture cost decrease from 600 USD/tonne CO2 (2020) to 100 USD/tonne CO2 (2050) (IEA, 2022). On top of the capture cost, we add a cost of 30 USD/tonne CO2, reflecting distribution costs (European Technology Platform for Zero Emission Fossil Fuel Power Plants, 2021). In the end, we calculate a weighted average cost of CO2 capture, considering both

	DAC and point source capture. We assume that the share of DAC for e-fuel production increases from 0% (2020) to 60% (2050), based on projections from IEA (IEA, 2022).
Conversion costs (feedstock to fuel)	We apply the same CAPEX and fixed OPEX costs for plants of the same type converting feedstock to fuel. Plants producing fuels from immature production pathways, are assumed to have a decreasing unit CAPEX per capacity output towards 2050, due to technological developments and scaling up of plant capacity (economies of scale). Every conversion plant of the same type is assumed to have the same energy use, though energy costs will be different due to different regional energy prices.
Distribution costs	Distribution costs are included in the fuel cost projections. It reflects the cost associated with delivering the fuel from the conversion plant to a ship, including both transportation and bunkering costs.

Alternative fuel cost forecast

Figure A 48 illustrates the estimated cost ranges in 2035 and 2047 for selected fuels across Southeast Asia, Greater China, the Middle East and North Africa, and the OECD Pacific region. The alternative fuel costs are benchmarked against the regional HFO price. Overall, e-fuels are characterized by significant upfront capital requirements and substantial electricity demand, which translates into elevated fuel costs. High electricity prices, especially in the OECD Pacific region, is a key driver for the upper ranges of the production costs.

Further, the cost of captured CO₂ used as feedstock in the production of e-methanol is expected to be very high in the coming years. The model assumes a gradual shift from point source (PS) carbon capture to direct air capture (DAC). With DAC, large fans will draw in air from the atmosphere and capture diluted CO₂ gas, negating the need for direct connection to a flue gas source. This is followed by a separation stage, where electricity is applied in a process where CO₂ is separated from other gases, and then compress the CO₂ to adequate concentrations. This creates an additional operational cost that translates into higher costs for the fuel output. On the flipside, this will allow for more flexibility in terms of where e-fuel production facilities are located.

In general, biofuels are comparatively more affordable than e-fuels, due to low feedstock costs and relatively low energy input to the processing stages. The final cost does, however, largely depend on the fuel output and biowaste input. Biodiesel (FAME) produced from used cooking oil is expected to increase in total production costs due to expected scarcity of used cooking oil. Feedstock costs are expected to increase for most biowaste types in the coming years, due to scarcity and competition from other industrial products, such as food, animal feed, textile, paper, pharmaceuticals etc.

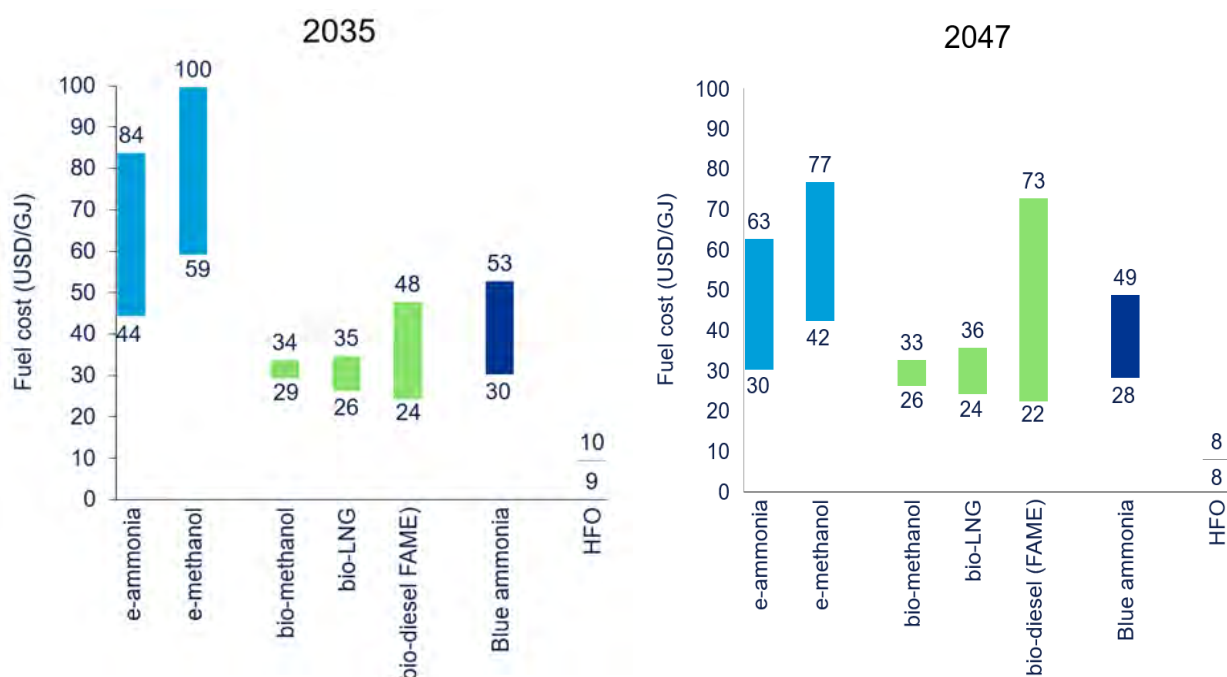


Figure A 48: Alternative fuel cost forecast for the regions around India, for 2035 (left) and 2047 (right)

The figures show that the costs of e-fuels are categorically higher than the other fuel categories for these regions. Whereas biofuels are expected to increase in cost going forward, the electricity costs and are simultaneously expected to decrease for several regions. Yet, the electricity prices are expected to differ a lot between these regions, which explains the large cost range displayed for the e-fuels. Though the costs for most biofuels are expected to either stagnate or even increase in the coming years, they remain cheaper than e-fuels by a decent margin. However, this is very dependent on the expected scarcity of different types of biowastes, which is challenging to predict. By 2047, HFO remains far cheaper than low-carbon alternatives, creating a cost gap that needs to be filled by more stringent regulatory requirements, technology improvements, and other forms of policy support. The decline in HFO price from 2035 to 2047 is due to expected decline in oil demand and crude oil price.

Figure A 49 shows levelized cost of hydrogen (LCOH) behind the cost ranges for e-ammonia and e-methanol. The cost for LCOH is comparable in most of the assessed regions towards 2047, except for Greater China and OECD Pacific, where the cost is significantly lower. This is partly due to efforts to strengthen grid capacities and decreasing learning costs from several hydrogen-based projects that are already in the pipeline.

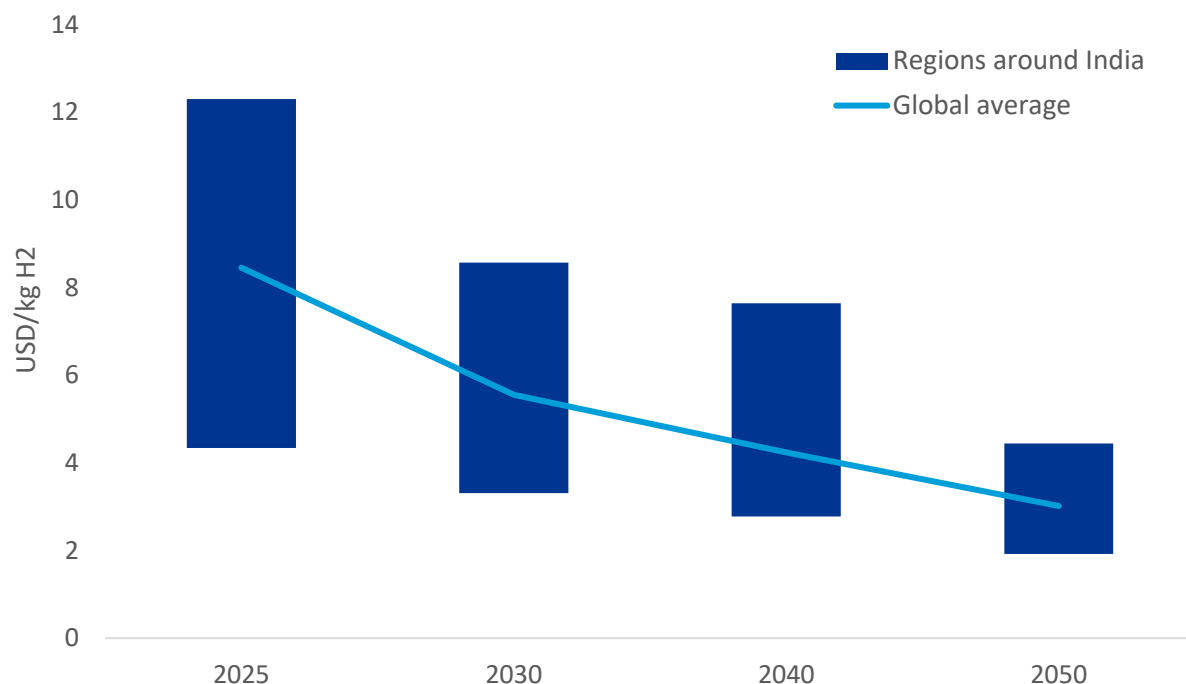


Figure A 49: Levelized cost of hydrogen (LCOH) ranges for the regions around India, compared to global weighted average LCOH

Required fuel price ranges for India to be competitive

Figure A 50 shows an illustration of the fuel price levels required for India to remain competitive with surrounding regions towards 2035 and 2047. The required price ranges for India are visualized as below or in the lower range of the forecasted cost in the competing regions – the ranges are indicative and focus should not be given on specific numbers.

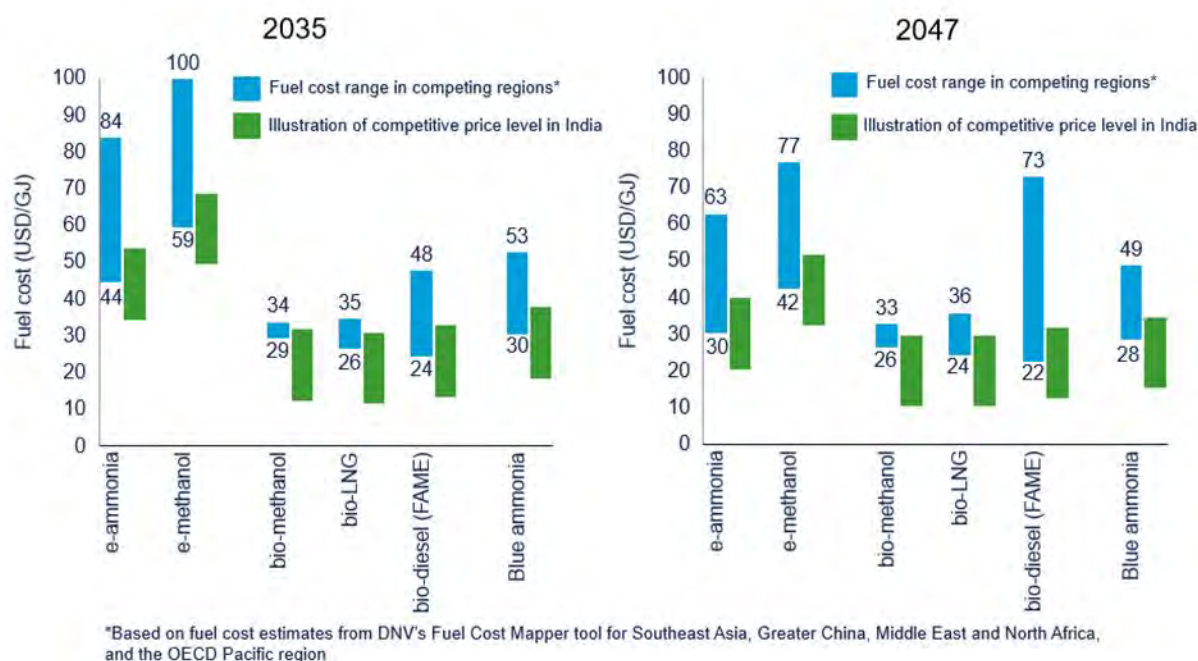


Figure A 50: Illustration of competitive fuel price level for the different alternative fuels for India in 2035 (left) and 2047 (right)

For comparison, Figure A 51 shows the bid prices (in USD/GJ) for delivery of renewable ammonia in India from a recent auction by the Solar Energy Corporation (SECI)⁵⁸. The producers will receive production subsidies for the first three years of a ten-year fixed price delivery contract to fertilizer manufacturers in India (\$106 per ton in year 1, and \$85 per ton in year 2 and 3)⁵⁹. The delivery prices in the figure includes subsidies, which converts into 4,6-5,7 USD/GJ. These prices were described as “record low” – if these projects are realised on this price level, Indian ammonia production is already within the competitive range for 2035.

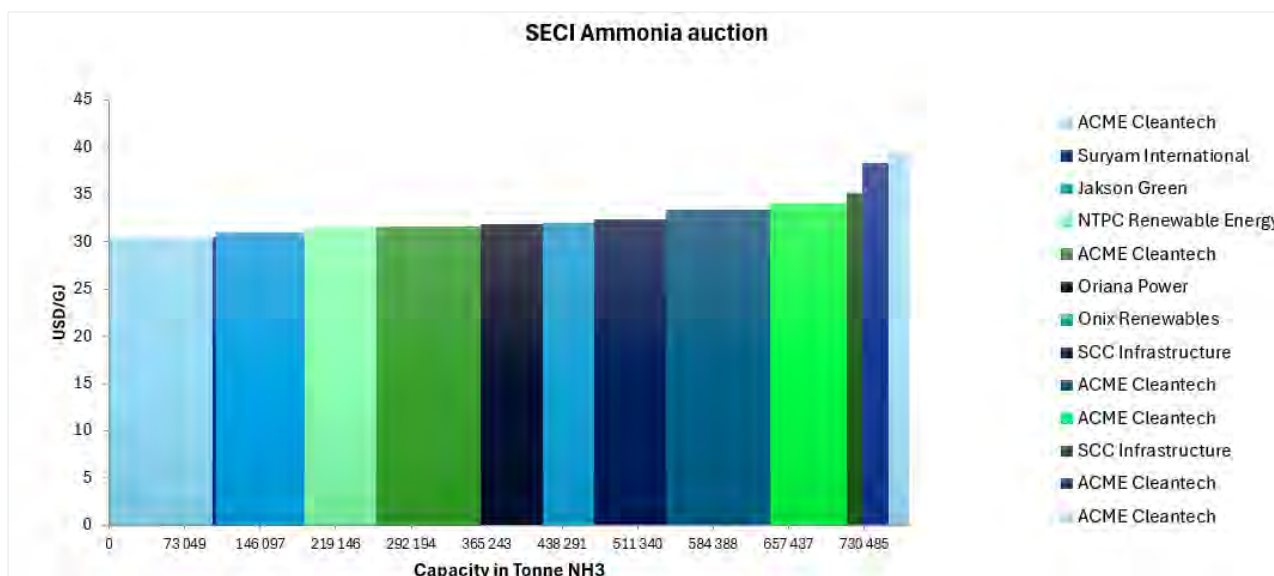


Figure A 51: Results from SECI's green ammonia auction in India

⁵⁸ <https://ammoniaenergy.org/articles/seci-completes-renewable-ammonia-auction-round/>

⁵⁹ <https://ammoniaenergy.org/articles/renewable-ammonia-price-discoveries-a-closer-look-at-the-h2global-and-seci-auctions/>

A.4 TOTAL COST OF VOYAGE COST STUDY

A.4.1 Determining baseline route and deviation distance

After selecting the case routes, the project analysed operational data from 59 container ships (17,000–20,000 TEU), shown in Figure A 52 that passed India in 2022 (before red sea shipping disruption). These vessels form the basis for the technical and operational inputs for case study 1. To account for variations in design, engine type, and sailing distances, averages were applied to smooth differences. Consequently, the “case ship” is defined as the average profile of these 59 vessels rather than a single representative ship. The exact same exercise was performed for the smaller ship in case study 2.

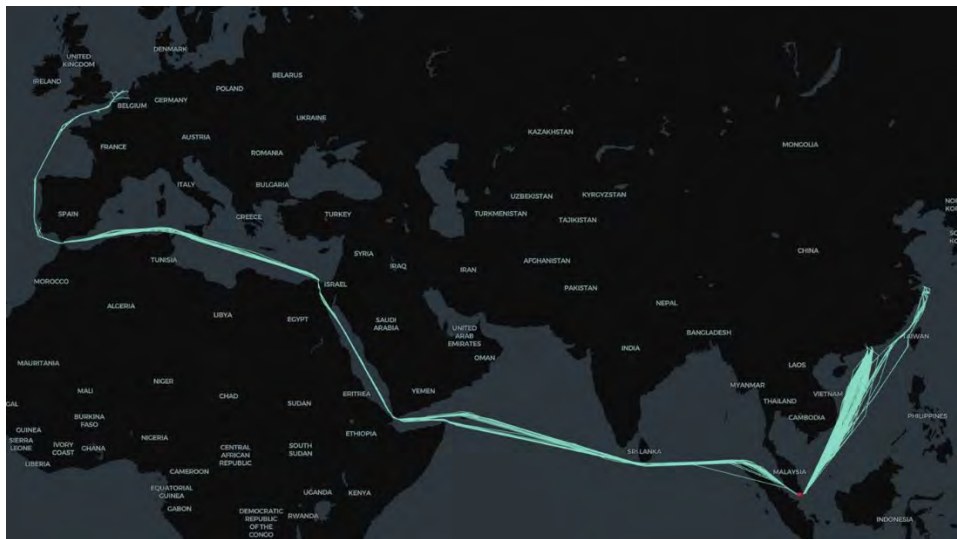


Figure A 52: Large container ships trade route (59 unique ships in 2022)

To calculate the deviation distance to the three selected Indian ports, two fixed reference points were established. For case study 1, these were the south coast of Sri Lanka and the north coast of Somalia. All ships pass these locations regardless of whether they deviate to India, making them suitable for defining the “as-is” route. The direct distance between these points represents the baseline route. For deviation routes, additional waypoints were added to include the selected port, and the difference between the baseline and adjusted distances is referred to as the “deviation distance”. The following figures, Figure A 53 and Figure A 54 show the baseline route for case study 1 and the deviation route to New Mangalore.



Figure A 53: Illustration of baseline route for case study 1

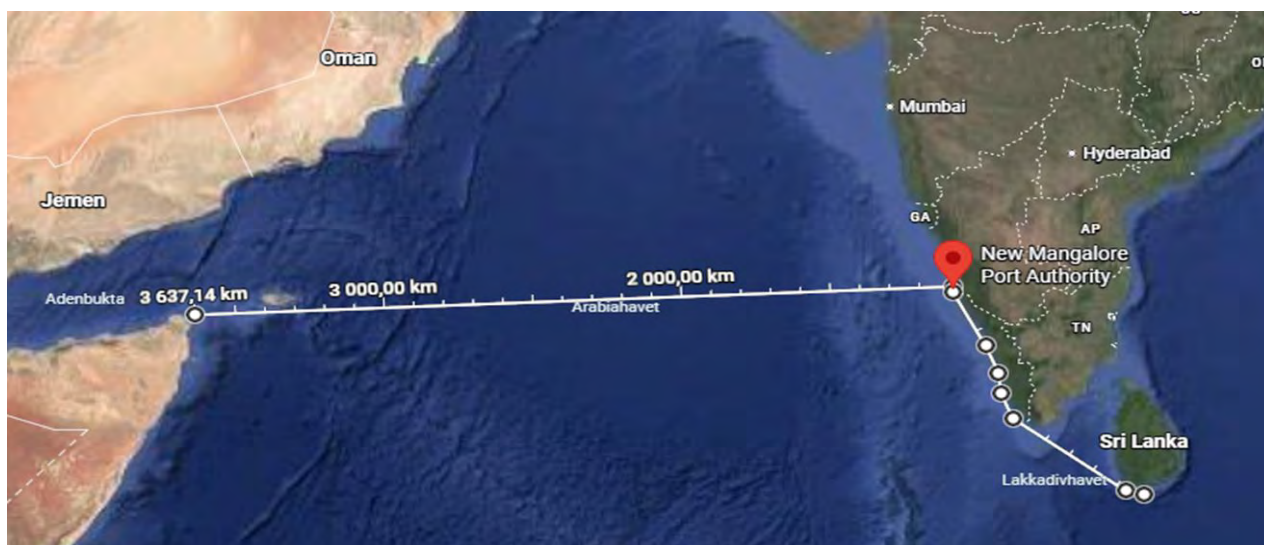


Figure A 54: Illustration of deviation route to New Mangalore for case study 1

A.4.2 Alternate fuel selection for case vessels and operational (nm) range

When determining the future fuels for the case study vessels, we examined the current order book and ships in operation on alternative fuels today.

The following Table A 11 show the current vessels on order and in operation for different alternative fuel types.

Table A 11 : Ships (all types) on order and in operation with alternative fuels (Source: DNV AFI)

Fuel type	Number of ships on order	Number of ships in operation
Ammonia	45	3
Hydrogen	34	8
LNG	624	833
Methanol	353	97

The following Table A 12 shows the current container vessels on order and in operation for different alternative fuel types.

Table A 12 : Container ships on order and in operation with alternative fuels (Source: DNV AFI)

Fuel type	Number of ships on order and in service	Average TEU
Ammonia	1	1,400
Hydrogen	2	730
LNG	598	15,955
Methanol	246	12,852

For case study 1, methanol was selected as the future alternative fuel. This choice reflects recent industry developments, such as Maersk's order of eight 16,200 TEU container ships, each equipped with methanol storage capacity of 16,000 cubic meters. For case study 2, ammonia was chosen as this is a potential future fuel for deep-sea vessels, even though the order book for vessels with ammonia as fuel is currently limited. Since only one 1,400 TEU container ship has been

ordered with ammonia capability, an Approval in Principle (AiP) design for a 3,500 TEU vessel with 4,000 cubic meters of ammonia storage was used as the reference.

To estimate the operational range in nautical miles for these fuels, energy consumption assumptions were aligned with current container ship operations, and fuel loading was set to 95% of available tank capacity. Engine efficiency for methanol and ammonia is assumed to be comparable to modern diesel engines, based on input from DNV subject matter experts.

A.4.3 Breakdown of cost effect and assumptions for calculations

Typical shipping companies can hold several roles in container shipping, including liner operator and tonnage provider, which impacts which perspective to take when analysing voyage costs. It is the liner operator who has operational control of the vessel and typically pays for fuel and port costs. The tonnage provider owns the vessel and provides it to liner operators under charter agreements. Typical container shipping companies often holds both roles. As it is the liner operator who controls the voyage, this is the perspective taken in the total cost of voyage analysis. The Table A 13 below gives a breakdown of the yearly cost effect of deviating to India for the two alternative actions that can be taken by a liner operator (1) increasing speed to make up for lost time, and (2) spending longer on the trade route.

Table A 13 : Breakdown of the effect on voyage cost for a ship bunkering in India compared to the baseline route

Parameter	Description	Alt 1: With speed increase	Alt 2: No speed increase
FREIGHT REVENUE	Revenue per year for a vessel on a typical trade, usually a set freight rate per container per main trade route.	No change (yearly cargo capacity is the same)	Lower revenue per year (due to fewer round trips and reduced cargo capacity)
RELEVANT VOYAGE COST CATEGORIES			
VESSEL CHARTER RATE (incl. OPEX)	Typically covers the day-to-day running costs required to keep the ship operational and capital expenses (excl. voyage related costs). OPEX covers manning, maintenance and repairs, insurance, lubricants and stores, and administrative overheads. The charter rate and OPEX varies with time, e.g. per day/year.	No change (Charter rate for the vessel is constant per year)	No change (Charter rate for the vessel is constant per year)
Fuel cost	Fuel cost is dependent on fuel consumption and fuel price. Fuel consumption varies with distance (per nm sailed) and with speed (higher speeds increase consumption).	Fuel consumption: - Longer distance leads to higher fuel consumption per trip and year. - Higher speed leads to increased fuel consumption for whole leg. Relevant fuel price depends on price variance.	Longer distance leads to higher fuel consumption per year. Relevant fuel price depends on price variance.
Port cost	Port costs typically include berth fees, port dues at loading and discharge ports, pilotage and towage. Port cost varies with number of port calls and depending on the specific port.	An additional port leads to higher port cost per trip and year.	An additional port leads to higher port cost per trip and year.

To determine if a liner operator would either (1) increase speed or (2) spend longer on the route, the cost effect of both options was estimated. The assumptions used are presented in the following sub-chapters.

Methodology and assumptions for calculation of fuel consumption and effect of increasing speed

Fuel consumption is a critical input in the case analysis, as it determines the additional fuel required to complete the deviation.

The first step was to identify vessels of similar size to the case ships operating on the specific routes analysed. For the 18,000 TEU scenario, 55 unique container ships were identified, while 66 vessels of approximately 3,000 TEU were found trading on the Shanghai–Middle East route. A statistical analysis of these ships was conducted to establish a representative “typical” vessel for each size category and trade route.

This process included using DNV’s Master Model to estimate fuel consumption for all identified ships along their respective routes. The model provided detailed information on sailing and port consumption as well as voyage durations. These data points were converted into energy consumption per hour for both sailing and port conditions. Finally, average values were calculated across the 55 large vessels and 66 smaller vessels to derive the input parameters for the 18,000 TEU and 3,000 TEU cases, respectively.

A summary of the case inputs is presented in below in Table A 14

Table A 14 : Case inputs

Category	Unit	3,000 TEU (Shanghai – UAE)	18,000 TEU (Shanghai – Rotterdam)
Sailing energy consumption rate	MJ/hour	66,465	202,111
Port energy consumption rate	MJ/hour	11,101	22,447
Distance, direct route	nm	6,171	11,919
Distance of leg passing India (AIS data for case ship)	nm	5,135	6,927
Sailing duration	hours	411	824
Port duration	hours	183	238
Cruise speed	knots	15.0	19.9
Round trip duration	days	40	99

If the vessel increases speed from the reference value to recover time lost due to deviation and bunkering in India, the sailing energy consumption must also increase. This is because main engine power is approximately proportional to the cube of the vessel's speed, while fuel consumption becomes proportional to the square of the speed. The reason for this relationship is that the distance sailed is linearly proportional to speed, so when speed increases, the time to cover the distance decreases, but the power demand rises sharply. As a result, even a small increase in speed has a disproportionately large effect on fuel consumption.

This relationship is a simplification of real-world conditions but is considered sufficiently accurate for the purposes of this analysis. In scenarios where vessels increase speed to recover lost time, the additional fuel consumption is applied only to the voyage leg where the speed increase occurs. All other legs of the route are assumed to be sailed at the baseline fuel consumption.

Methodology and assumptions for calculation of freight revenue effect (spending longer on route)

The calculation of the freight revenue effect is based on the principle that any increase in voyage duration reduces the number of round trips a vessel can complete within a given period, thereby lowering potential earnings. The model translates freight revenue into a time-based metric and applies this to the additional days introduced by operational changes, such as a bunkering stop. The lost freight revenue effect is only valid if the ship does not change its speed to recover lost time from the additional bunkering stop.

The logic begins by determining the total revenue for one round trip, calculated as the product of the freight rate per 40-foot container (FEU), the number of containers transported, and the assumed load factors for head haul and back haul. For the head haul, a typical load factor of 75% is applied, while the backhaul uses 40%. Since one FEU equals two TEU, the number of FEUs carried is derived by dividing the TEU capacity by two and multiplying by the respective load factor. For example, with a freight rate of USD 1,500 per FEU and a vessel capacity of 18,000 TEU, the head haul revenue equals USD 13.5 million ($18,000 \div 2 \times 0.75 \times 2,000$), and the backhaul revenue equals USD 1.8 million ($18,000 \div 2 \times 0.40 \times 500$), giving a total round-trip revenue of USD 15.3 million. This figure is then divided by the baseline round-trip duration of 99 days to derive a daily revenue rate, which in this case is approximately USD 154,000 per day. The opportunity cost of extra time is calculated by multiplying this daily rate by the number of additional days caused by the bunkering stop.

The model assumes a fixed freight rate of USD 2,000 per FEU for the head haul Shanghai–Rotterdam route and 500 USD on the backhaul Rotterdam–Shanghai. Container freight rates are based on market data from Drewry, where the rates have been historically volatile in the past 6 years due to events such as the pandemic and the Red Sea conflict. We have chosen to use rates classified as “recovery rates” for both cases, meaning freight rates that are recovering from non-normal events such as the pandemic and the Red Sea crisis, indicating normal demand. We have used load factors of 75% on the head haul and 40% on the backhaul, reflecting typical container flow.

The freight revenue opportunity cost associated with increased voyage duration is calculated using the assumptions and methodology summarised in Table A 15.

Table A 15 : Assumptions and calculation of freight revenue opportunity cost from increased voyage duration

Route	Freight Rate Head / Back Haul (\$/FEU)	Load Factor Head / Back Haul (%)	Round-trip revenue (million USD)	Round-trip duration (days)	Daily earnings (USD/day)
Shanghai – Rotterdam – Shanghai (18k TEU)	2,000 / 500	75 / 40	15.3	99	154,871
Shanghai – UAE – Shanghai (3k TEU)	1,500 / 900	85 / 40	2.5	40	60,869

Assumptions for calculation of fuel/bunkering cost

In the calculation of the deviation costs for the case studies, we have used the term “bunkering cost”, which covers the cost of the fuel and any additional port costs connected to the bunkering. The bunkering cost levels are based on the future fuel pricing assessment.

A.5 RECOMMENDATIONS

A.5.1 Approach to identifying barriers and developing recommendations

This study followed a structured process to ensure that the recommendations presented in Chapter 10 are traceable to the assessment findings.

The process consisted of the steps as presented in Figure A 55 below.

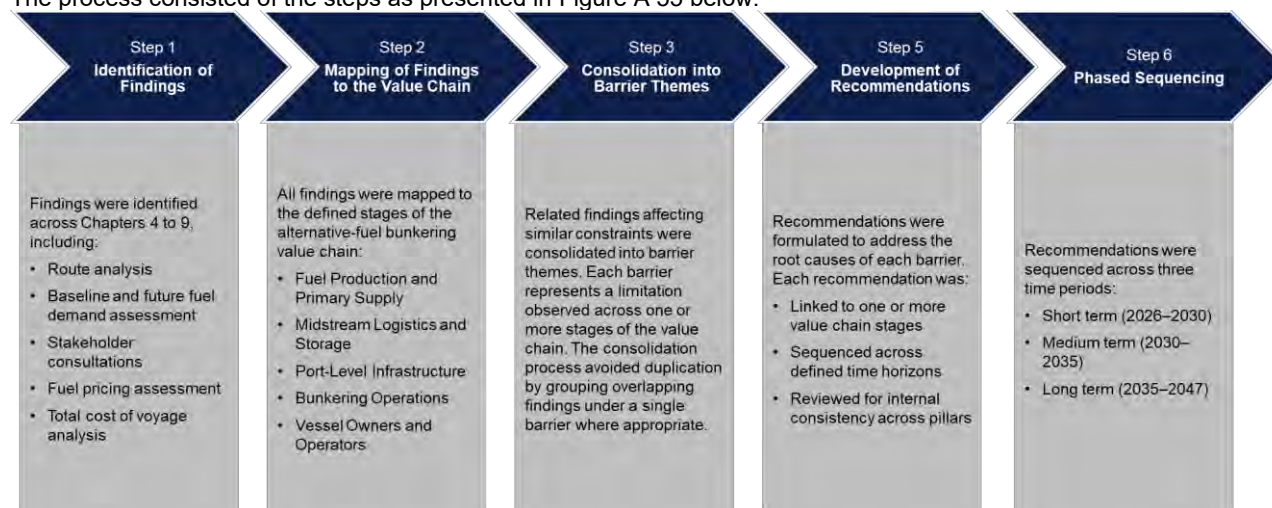


Figure A 55: Approach for developing recommendations

A.5.2 Consolidated Barrier Matrix

This section presents the consolidated barrier matrix derived from the analytical findings across Chapters 4–9.

Each barrier:

- Is supported by specific findings from chapters 4-9
- Is mapped to one or more value chain stages

The matrix below provides a structured summary of this mapping.

Barriers	Barrier value chain	Based on Findings
Barrier 1: Absence of Credible Long-Term Demand Commitments	Fuel Production & Primary Supply 1.1 Fuel producers are unlikely to proceed with final investment decisions (FID) for alternative fuel production facilities without firm long-term offtake agreements. 1.2 Without demand visibility, producers prioritise other markets or customers. Midstream logistics & Bulk storage 1.3 Uncertain demand delays investment in tanks, barges and logistics chains Port level bunkering infrastructure 1.4 Ports and terminal operators hesitate to invest in dedicated bunkering infrastructure without visibility on expected future bunkering volumes Vessel Owners & Operators 1.5 Bunkering demand is largely spot-based and not based on long term agreements	1. Availability of alternative marine fuels for bunkering remains uncertain, as fuel producers cannot commit to new production projects without long-term offtake agreements and sufficient price certainty. 2. Demand is driven mainly by vessels already calling Indian ports, not by passing traffic. 3. International container liners are the strongest short-term scale segment, and methanol seems to be an early fuel pathway. 4. Domestic/regional fleets are smaller but can support pilots for baseline utilisation. 5. Uncertain demand and fuel availability make it hard to finance storage, barges, terminals without utilization visibility. Stakeholders highlight high capital costs and lack of risk-sharing, leading to isolated pilots rather than scalable services.
Barrier 2: Limited availability of ancillary services alongside bunkering	Port level infrastructure 2.1 Bunkering is not consistently positioned alongside transshipment, repairs, and crew services Bunkering Operations 2.2 Bunkering services are not fully coordinated with other port services such as cargo handling, crew change, repairs, and supplies Vessel Owners & Operators 2.3 Shipowners prefers getting multiple services at the same place, not fuel availability alone	6. Ancillary service offerings can make (or break) demand conversion. This includes predictable pilotage/towage availability, berth windows, turnaround efficiency, documentation workflows, crew change etc. 7. Port-level tariffs and incentives are inconsistent and not transparently disclosed

Barriers	Barrier value chain	Based on Findings
Barrier 3: Limited policy and institutional coordination for alternative fuel bunkering development in India	Fuel Production & Primary Supply 3.1 Producers receiving incentives may prioritise export or other end uses over supply to ports in India Midstream Logistics & Storage 3.2 Storage and transport for bunkering are not planned as part of an end-to-end supply chain Port-Level Infrastructure 3.3 Land allocation and zoning for alternative fuel remains ad hoc and not planned	8. India has evidence that competitive auction support is feasible; this design must translate into port bunkering supply 9. Availability of alternative fuels for maritime use remains uncertain, as producers will not invest without long-term offtake agreements.
Barrier 4: Fragmented Approvals and unclear regulatory responsibilities	Production and Logistics 4.1 Permits for storage, transport, and fuel movement involve multiple agencies. Port-Level Infrastructure 4.2 Responsibilities for approvals are split across central, state and port authorities (no single standard approval sequence) Bunkering Operations 4.3 Operational permissions and safety clearances vary across ports	10. Responsibilities are fragmented across central, state, and port-level authorities; limited coordination and dispersed information across ports, with independent decision-making. 11. Port-level tariffs and incentives are inconsistent and not transparently disclosed, increasing cost uncertainty and discouraging repeat bunkering. 12. Ports need clear methanol / ammonia / H2 handling codes. 13. Port safety readiness and SIMOPS enablement are practical constraints that can limit real operations.

Barriers	Barrier value chain	Based on Findings
Barrier 5: High infrastructure cost for alternative fuel production and distribution	Fuel Production 5.1 Alternative-fuel production facilities require high upfront capital investment. Midstream Logistics & Storage 5.2 Storage tanks, pipelines, transport systems, and barges are capital-intensive Port-Level Infrastructure & Bunkering Assets 5.3 Bunker barges, safety systems, and port modifications require dedicated investment. 5.4 Dedicated alternative-fuel bunker vessels are not yet widely deployed, limiting regular service availability.	14. Upstream logistics for alternative fuels is investment-heavy and sensitive to utilisation risk 15. Uncertain demand and fuel availability make it hard to finance storage, barges, terminals without utilization visibility. Stakeholders highlight high capital costs and lack of risk-sharing, leading to isolated pilots rather than scalable services. 16. Initial infrastructure needs mobile assets (e.g., bunker barges), but this requires clustering and planning discipline.
Barrier 6: High production costs of alternative fuels, especially e-methanol and e-ammonia.	Fuel Production 6.1 Production of e-methanol and e-ammonia is costly 6.2 Costs remain high mainly due to electricity costs and the capital cost of production facilities. While electricity prices are largely determined by energy markets, technology and plant costs may decline as production scales up. Midstream Logistics & Bulk Storage 6.3 Storage tanks, transport, and handling systems have high fixed costs 6.4 They handle low volumes, so their fixed costs are spread over fewer tonnes. Vessel Owners 6.5 Shipowners see higher delivered prices compared to established hubs and prefer to bunker elsewhere.	17. Production cost is the dominant driver of delivered alternative-fuel price, and is especially high for e-methanol and e-ammonia. 18. Low current bunkering volumes in India (2–3 Mt/yr vs ~55 Mt/yr in Singapore) reduce economies of scale and lead to higher delivered prices because fixed charges and taxes are borne by significantly lower volumes. 19. India bunker prices are 50–70% higher than Singapore/Fujairah (pre-port charges).

Barriers	Barrier value chain	Based on Findings
Barrier 7: Port-Level Charges and Tax	Port level bunkering infrastructure 7.1 Port dues, pilotage, berth hire, and other port-controlled charges are higher than in major bunkering hubs. 7.2 Tariff structures vary across ports and are not always clearly disclosed, creating cost uncertainty. 7.3 Existing incentives, such as ESI-linked rebates, are not designed specifically to encourage bunkering calls. Bunkering Operations 7.4 GST is applied on bunker fuel supplied to international shipping, increasing the final delivered price. 7.5 Variable port charges make it difficult for bunker suppliers to offer predictable and competitive pricing. Vessel Owners & Operators 7.6 Shipowners consider total delivered cost at the vessel, and higher all-in charges reduce the incentive to bunker in Indian ports.	20. Port fees (port dues, pilotage, berth hire etc.) are estimated to be 2–10x higher than major hubs, even if bunkering/operational charges are comparable. 21. GST applied on bunker fuel supplied to international shipping reduces delivered-cost competitiveness. 22. Port-level tariffs and incentives are inconsistent and not transparently disclosed, increasing cost uncertainty and discouraging repeat bunkering 23 ESI-linked incentives exist at some ports, but are not designed to trigger bunkering calls.
Barrier 8: Unavailability of operational standards and safety protocols for alternative fuel bunkering	Port-Level Infrastructure 8.1 No nationally adopted fuel specific bunkering procedures Bunkering Operations 8.2 SIMOPS rules, emergency response procedures, and transfer protocols are not consistently defined. 8.3 Operational practices vary across ports, increasing execution risk. Vessel Owners & Operators 8.4 Bunkering services are not predictable or repeatable across ports (concerns on schedule disruption)	23. Even with infrastructure, operational repeatability and service reliability are decisive for early market uptake. Stakeholders emphasise repeatability/reliability, and clear service offerings matter in the initial phase. 24. Port safety readiness and SIMOPS enablement are practical constraints that can limit real operations. 25. Containers > RoRo > LNG carriers in passing traffic; liners prioritize SIMOPS reliability/turnaround.



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