GOVERNMENT OF KERALA

Kochi Green Hydrogen Valley Roadmap

Study by:

mec+

Supported by:

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igef Indo-German Energy Forum

H2Uppp
International Hydrogen Ramp-up Program

As a federally owned enterprise, GIZ supports the German Government in achieving its objectives in the field of international cooperation for sustainable development.

Published by:
Deutsche Gesellschaft für
Internationale Zusammenarbeit (GIZ) GmbH

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Acknowledgements:
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peppermint werbung berlin gmbh, Berlin

The International Hydrogen Ramp-up Programme (H2Uppp) of the German Federal Ministry for Economic Affairs and Climate Action (BMWK) promotes projects and market development for green hydrogen in selected developing and emerging countries as part of the National Hydrogen Strategy.

New Delhi, September 2024

Foreword by MNRE

Shri Ajay Yadav, IAS
Joint Secretary, MNRE

The Government of India is committed to achieve energy independence by the year 2047 and to attain net-zero emissions by 2070. In this context, Green Hydrogen is envisaged to play a pivotal role.

On January 4, 2023, the Government launched the National Green Hydrogen Mission with the overarching objective of positioning India as a Global Hub for the production, usage, and export of Green Hydrogen and its derivatives. The ambitious target set for 2030 is the annual production of at least 5 Million Metric Tons (MMT) of Green Hydrogen, with the potential to reach 10 MMT as export markets expand.

Recognizing the technical and logistical challenges inherent in transporting Hydrogen over long distances, the Mission envisages a cluster-based production and utilisation model to enhance the viability of Green Hydrogen projects. This approach would enable economies of scale and convergence of key infrastructure requirements in geographically proximate areas.

The National Green Hydrogen Mission is committed to identifying and developing regions capable of supporting large scale production and utilisation of Hydrogen in Green Hydrogen Hubs. Projects in these hubs will be planned in an integrated manner to allow pooling of resources and achievement of scale.

(Cont.)

Foreword by MNRE

The Mission also envisages the establishment of the required infrastructure for storage and delivery of Green Hydrogen and its derivatives. The development of port infrastructure to enable exports of Green Hydrogen derivatives, and pipelines to facilitate bulk transport of Green Hydrogen is of utmost importance to the Mission.

The roadmap for a Green Hydrogen valley in Kochi is a significant step towards achieving a shared infrastructure of the entire Hydrogen value chain including production, storage, transportation, and offtake. The roadmap provides guidance for the establishment of an interconnected Hydrogen ecosystem and suggests the development of a hub or valley in a phase wise manner.

The stakeholders under the Indo-German Green Hydrogen Task Force, including Government of Kerala, industry stakeholders and involved partners, have produced a comprehensive document which shall guide interested parties in creating a navigable path for the development of Green Hydrogen Hubs.

This roadmap shall serve as an inspiration for the analysis of further potential Green Hydrogen hubs and valleys across the country enabling an accelerated scale up of an international Green Hydrogen economy.

Ajay Yadav (IAS)
Joint Secretary
Green Hydrogen, International Relations & Climate Change
Ministry of New and Renewable Energy (MNRE)

Foreword by Govt. of Kerala

As the global focus intensifies on reducing carbon emissions, Kerala is positioning itself as a leader in the green hydrogen sector, with ambitious investment plans and strategic initiatives. The state aims to become a hub for green hydrogen production, initially exploring the feasibility of exporting to Western markets, including Europe, Norway, and the United States.

Kerala's strategy encompasses establishing a sustainable green hydrogen ecosystem, amply supported by government undertakings like Bharat Petroleum Corporation Ltd, Cochin Shipyard, Kochi Metro Rail, and Cochin International Airport Ltd. The state's favourable conditions, such as low-impurity water bodies and advantageous terrain, make it an ideal location for cost-effective green hydrogen production.

Despite the current high costs of deploying green hydrogen fuel within the state, technological advancements over the next five to ten years are expected to make it more affordable. This transition is supported by proposed green hydrogen valleys in Thiruvananthapuram and Kochi, and preparations for the Vizhinjam project, marking significant steps towards several pilot projects. Additionally, the Kerala Government has received investment proposals from ReNew Power, Leap Green Energy, HLC Green Energy, and Enfinity Global, all expressing interest in exporting green ammonia from Kerala ports.

(Cont.)

Shri K.R. Jyothilal, IAS
Add. Chief Secretary,
Government of Kerala

Foreword by Govt. of Kerala

Kerala is also discussing projects in green hydrogen production, compression, storage, and refuelling facilities for hydrogen vehicles. Collaborations with academic and R&D institutes aim to explore innovations like production green hydrogen from agricultural biomass and other wastes. These initiatives are essential as Kerala strives to use green hydrogen for long-distance vehicles and water transport.

Kerala's Power Department is instrumental in promoting these green hydrogen pilots, with plans to develop green hydrogen hubs. The Power Department is committed to exploring project proposals, prioritising the execution of pilot production within a short span of time.

This insightful report by MEC Intelligence, supported by IGEF, offers vital insights for investor community, and serves as a strategic roadmap for businesses considering investments in the green hydrogen sector. In a field where data is often scarce, this report is expected to be a ready reference, explaining ground-level data and insights on green hydrogen users and their requirements. Significant efforts have been put into this research to demonstrate the various interconnections between renewable energy, green hydrogen, and decarbonisation. It evaluates the dynamic relationships between renewable energy systems and green hydrogen production, considering the economic and technical dimensions of transitioning to a sustainable energy future.

K. R. Jyothilal (IAS)
Additional Chief Secretary, GAD and Power
Government of Kerala

Foreword by ANERT

The international climate agenda prioritises the reduction of carbon emissions, which are a key factor in global warming. India aligns with this global commitment through initiatives such as the Strategic Interventions for Green Hydrogen Transition (SIGHT) incentive program and the Hydrogen Valley Innovation Cluster, placing Green Hydrogen at the forefront of its sustainable energy strategies.

Kerala is taking serious efforts to reduce its reliance on imported fuels and the need to procure electricity from other regions within India. The state's strategic shift to green hydrogen, complemented by a robust renewable energy policy, signifies a transition to achieving energy autonomy and strengthening security. Kerala actively seeks to maximise its renewable energy potential, majorly in floating solar power, wind, and biomass. Kerala aims to use green hydrogen to balance the fluctuations in solar and wind energy, supported by its installed capacity of over 1 GW in non-hydro renewable energy. The Kerala Green Hydrogen Policy, which is under development, reflects the state’s proactive direction.

In its concerted effort to transition to cleaner energy, Kerala has set ambitious benchmarks such as achieving 100% renewable energy by 2040 and net-zero emissions by 2050, targets that exceed the nation’s goals. Green hydrogen is crucial to realising these targets, potentially transforming the state's energy landscape.

(Cont.)

Shri Narendra Nath Veluri, IFS
CEO, ANERT

Foreword by ANERT

Currently, Kerala’s industrial players depend on grey hydrogen, which contributes to carbon emissions during production. Transitioning to green hydrogen represents a significant opportunity for these industries and other sectors, such as transportation, to reduce their environmental impact. The anticipated demand mandates for fertiliser and refinery units are expected to activate the domestic demand.

Integral to Kerala's green trajectory, this comprehensive report by MEC Intelligence, supported by GIZ, is intended to be an important element for governmental planning and an informative guide for potential investors.

With its excellent wind resources, strategic access to port, and proximity to busy shipping routes for bunkering opportunities, Kerala is poised to emerge as a nexus for green hydrogen derivative exports.

As global trends move decisively toward innovative energy systems, Kerala is pre-emptively aligning its renewable energy policies and laying the groundwork for a specialised green hydrogen ecosystem. The state is poised to take a leadership role in optimising the full spectrum of its renewable assets, positioning itself as a key player in the export of green hydrogen derivatives and an attractive hub for investment in the energy sector of the future.

Narendra Nath Veluri (IFS)
CEO, ANERT

Reading Guide

Report Overview

Objective and Methodology

- The objective of this report is to create a roadmap for the development of the 'Green Hydrogen Valley in Kochi' encompassing different green hydrogen value chain components
- The report has been prepared using a 'two-way approach' wherein research was carried out to understand the global hydrogen landscape and the emergence of valleys, understanding the commonalities and learnings from global valleys
- This global valley experiences was then overlaid on an in-depth understanding of Kochi's industrial & economic landscape and the opportunities identified through interactions with more than 20 stakeholders in Kerala including industries, mobility companies, ports, infrastructure companies, technology providers, associations and government stakeholders to develop the roadmap for a green hydrogen valley in Kochi

Structure of the Report

The report is divided into 5 sections:

1. Global H_2 Landscape and valley Focus
2. Kochi Hydrogen Valley – Summary
3. Kochi Hydrogen Valley – Design Choices
4. Kochi Hydrogen Valley – Background Information
5. Kochi Hydrogen Valley – Global Valley Profiles

- Section 1 summarizes the global hydrogen landscapes and learnings from global green hydrogen valleys
- Section 2 summarizes the development of the Kochi Green Hydrogen Valley
- Section 3 talks about the design choices that were made while choosing the valley specifics presented in Section 2
- Section 4 gives the background information that is used in determining the design choices and provides deep dives into sectors, resource availability and supply side economics
- Section 5 deep dives into the 5 selected valleys from which the learnings are summarized and presented in section 1
- The valley is envisioned in a phase wise manner with specific objectives for the 3 phases. Two scenarios (base and aggressive) are also considered of which base case is selected for the valley development (as explained in Section 2)

Source: MEC+ analysis

Reading Guide

Sectional Overview

Section	Objective	
Global H2 Landscape and valley Focus	Section 1 talks about the global hydrogen landscape and how green hydrogen valleys are emerging in different geographies of the world. It also gives a summary of the lessons learned from the 5 global valleys that were studied for the purpose of this report	
Kochi Hydrogen Valley – Summary	Section 2 gives an overall summary of the Kerala Valley; the vision for the valley, the offtake potential, supply requirements to meet demand, investment requirement, governance model and socioeconomic impact of the valley	
Kochi Hydrogen Valley – Design Choices	Section 3 delves into valley design choices; anchor sectors selection, summary of assessments in various sectors (economic cases, regulatory support, technology readiness, and offtake willingness). Possible valley configurations, selection rationale, existing premiums, viability gaps, and factors influencing landed costs	
Kochi Hydrogen Valley – Background Information	Section 4 extensively examines each of the 6 anchor sectors, exploring landscape, technology readiness, economic cases, landed costs/TCOs, regulations, offtake willingness, and possibilities for green hydrogen adoption, Kerala's resource potential and the supply-side economics of green hydrogen/ammonia.	
Kochi Hydrogen Valley – Global Valley Profiles	Section 5 deep-dives into the 5 global green hydrogen valleys that were studied in-depth to understand the functioning of green hydrogen valleys in terms of the archetype, investments, governance models, demand & supply scenarios and stakeholder engagement	
Appendix	This section provides the methodologies for socio-economic impact, infrastructure costs considered, land requirements, industries mapping and summaries of stakeholder interactions	

Source: MEC+ analysis

Definitions

I/IV

Term	Definition
Aggressive Case	Aggressive case refers to a scenario where expectations for adoptions are more optimistic and rapid compared to the base case. It represents a more ambitious outlook, projecting faster and larger-scale adoption of a technology but needs proactive involvement of all stakeholders to achieve the goal
Base case	Base case refers to a conservative scenario anticipating slower adoption compared to the global trend. It represents a cautious outlook, outlining small yet achievable cases amid expectations of lagging adoptions. The term serves as a realistic baseline for forecasting, considering potential challenges in the adoption process
Blue Hydrogen	Hydrogen produced via natural gas or coal gasification combined with carbon capture storage (CCS) or carbon capture use (CCU) technologies to reduce carbon emissions
Carbon Abatement	Carbon Abatement refers to the amount of carbon that is not emitted/reduced as a result of use of clean energy sources like green hydrogen
Carbon Tax	A carbon tax is a type of penalty that businesses must pay for excessive greenhouse gas emissions
Coastal Waterways	Coastal waterways (here) are the navigable routes through the sea that goes close to the coast of the country. Coastal shipping is the transport of cargo as a business and shipping within 20 nautical miles of the coastline
Depleted Gas Fields	A depleted gas field refers to a natural gas reservoir that has undergone significant extraction or production, resulting in a substantial reduction in the amount of recoverable natural gas. It is an option for hydrogen storage
Electrolysis	Electrolysis is the process of using electricity to split water into hydrogen and oxygen
Energy Banking	Energy banking is an arrangement where the surplus energy generated is banked with the grid. This surplus energy known as banked energy is then supplied back during periods of low RE generation
FCEV	A Hydrogen Fuel Cell Electric Vehicle (FCEV) is a type of electric vehicle that uses a hydrogen fuel cell to generate electricity on board for powering an electric motor. Unlike traditional internal combustion engine vehicles, FCEVs do not burn hydrogen; instead, they chemically react hydrogen with oxygen from the air in a fuel cell to produce electricity, water, and heat

Source: Websites; Research Articles; MEC+ analysis

Definitions

II/IV

Term	Definition
Green Hydrogen	Green Hydrogen is hydrogen produced using renewable energy, including, but not limited to, production through electrolysis or conversion of biomass. Renewable energy also includes such electricity generated from renewable sources which is stored in an energy storage system or banked with the grid in accordance with applicable regulations
Green Hydrogen Derivatives	Green Hydrogen derivatives are products like green ammonia, methanol etc that are produced using green hydrogen
Green Hydrogen Valley	A defined geographic area where various hydrogen applications are integrated into a unified ecosystem covering the entire hydrogen value chain, from production to end-use, with the aim of making projects more economically viable. These valleys create networks of producers, consumers, and local infrastructure, accelerating the use of hydrogen.
Grey Hydrogen	Hydrogen produced via natural gas through the process of steam methane reformation
GVA	GVA (here) is the value added as a result of the economic activities happening in the valley due to the production and consumption of green hydrogen
HICE	A Hydrogen Internal Combustion Engine (HICE) is a type of internal combustion engine specifically designed to run on hydrogen as a fuel. It follows the same principles as a traditional internal combustion engine but is configured to handle the unique characteristics of hydrogen as a fuel
Inland Waterways	Inland waterways are the rivers, lakes and canals or narrow channels. These waterways are used for transportation of goods and passengers is called inland water transport
Innovation Cluster	Innovation Cluster (here) refers to the sectors that have limited contribution to the green hydrogen demand currently but may have the potential to scale in the future. These are fringe sectors contributing less than 10% of the total valley demand
ISTS Grid	ISTS Grid is a system for the conveyance of electricity by means of a main transmission line from the territory of one state to another
Jobs	Jobs (here) refer to the number of jobs created by the valley for a specific period of time. This could vary from 6 months to 2 years for one-time jobs like construction to lifecycle of the asset developed for the operational and maintenance jobs

Source: Websites; Research Articles; MEC+ analysis

Definitions

III/IV

Term	Definition
Landed Cost	Landed cost refers to the total delivered cost including production, transportation, storage and dispensing costs
LOHC	Liquid organic hydrogen carriers are organic compounds that can absorb and release hydrogen through chemical reactions
NH_3 conversion Infrastructure	NH_3 conversion infrastructure refers to the systems required to convert green hydrogen into ammonia
Phase I	Phase I is the preparatory phase. This phase would focus on capacity building, stakeholder engagement and development of standards. Comprehensive studies will be carried out in this stage to ascertain the feasibility of green hydrogen in the selected sectors.
Phase II	Phase II would be the pilot phase. Based on the studies in Phase I, pilots will be set up in phase II to evaluate the production and consumption operations. This phase will help address the operational challenges
Phase III	Phase III will the scale-up phase. Based on the success of pilots in phase II and the learnings, the valley will be scaled up to the envisioned size. The select industries based on the success of the pilots will move for scaled adoption of green hydrogen
Price Premium	The additional price that the consumer has to pay for substituting the current fuel/feedstock with green hydrogen
Restricted Banking	Banking of energy with the distribution company considering 1000 hours of grid banking
Rock Cavern	Rock caverns are mined underground cavities in solid rock deep underground. It is an option for hydrogen storage
RTC RE	Round the Clock RE combines Variable Energy with stable complementary power from conventional sources such as thermal, hydro etc. and/or from Energy Storage Systems to provide 24/7 power supply
Salt Cavern	Salt caverns are artificial cavities in underground salt formations which are created by the controlled dissolution of the rock salt by the injection of water during the solution mining process. It is an option for hydrogen storage
Section 8 Company	A Section 8 Company is a type of non-profit organization in India that is established for the promotion of charitable or social causes such as education, art, science, religion, or any other charitable objective. This type of company is governed by the Companies Act, 2013 and is registered under Section 8 of the Act

Source: Websites; Research Articles; MEC+ analysis

Definitions

IV/IV

Term	Definition
Sector Coupling	Sector coupling refers to the process of aggregating the needs of two or more sectors to provide a common solution, this could be a common infrastructure or an aggregation of demand (for RE/H_2) of sectors and provision of the same from a common source
Socioeconomic Benefits	Socioeconomic benefits (here) refer to the benefits offered to the region in the form of social and economic benefits like creation of jobs, value addition to the economy and the reduction of emissions leading to better health and well being
Solid Metal Hydride	Solid metal hydrides are compounds formed by the combination of metals with hydrogen, resulting in a solid substance. These materials are known for their ability to absorb and release hydrogen gas, making them valuable for hydrogen storage applications
Stranded Assets	Stranded assets are those that lose value or turn into liabilities before the end of their expected economic life due to factors within or outside the control of the organization
Total Cost of Ownership	Total cost of ownership (TCO) includes the purchase price of a particular asset, plus operating costs, over the asset's life spa
TRL	Technology Readiness Levels (TRL) are a type of measurement system used to assess the maturity level of a particular technology. With TRL 1 being the basic research level to TRL 9 meaning it is a proven technology and the system is ready for full commercial deployment
Trunk Infrastructure	Trunk infrastructure (here) refers to the basic infrastructural requirement for the functioning of the hydrogen valley including the pipelines, storage, refuelling infrastructure and assets like buses and boats
Unrestricted Banking	Banking of energy with the distribution company considering 4000+ hours of grid banking

Source: Websites; Research Articles; MEC+ analysis

Abbreviations

(I/III)

ANERT: Agency for New and Renewable Energy Research and Technology
APAC: Asia-Pacific
ASU: Air Separation Unit
AWE: Alkaline Water Electrolyser
BAU: Business as Usual
BNEF: Bloomberg New Energy Finance Limited
BOO: Build Own and Operate
BPCL: Bharat Petroleum Corporation Limited
CAGR: Compounded Annual Growth Rate
CAPEX: Capital expenditure
CDAC: Centre for Development of Advanced Computing
CEA: Central Electricity Authority
CGD: City gas distribution
CO_2: Carbon di-oxide
COB: Chairman of the Board
Cr: Crore
CSIR: Council of Scientific & Industrial Research
CSL: Cochin Shipyard Limited
CSS: Cross-Subsidy Surcharges
CUF: Capacity Utilisation Factor
DAP: Di-Ammonium Phosphate
DEVEX: Development Expenditure
DOE: Department of Energy, USA
DPR: Detailed Project Reports
DST, India: Department of Science and Technology, India
DST, South Africa: Department of Science and Technology, SA
EBITDA: Earnings Before Interest, Taxes, Depreciation and Amortization
EPC: Engineering, Procurement and Construction
ESG: Environmental, Social and Governance
EU: European Union
EV: Electric Vehicles
EVE: Energy Agency of Basque
EXIM: Export-Import
FACT: Fertilizers and Chemicals Travancore Limited
FCEV: Fuel Cell Electric Vehicle
FCH-JU: Fuel Cell Hydrogen Joint Undertaking
FCRA: Foreign Contribution Regulation Act
FERA: Foreign Exchange Regulation Act
FID: Final Investment Decision
GH_2: Green Hydrogen
GHG: Green House Gases
GHIC: Green Hydrogen Industrial Cluster
GJ: Gujarat
GNH_3: Gaseous Ammonia
GoI: Government of India
GW: Giga-Watt
H_2: Hydrogen
HAC: Hazardous Area Classification

Source: MEC+ analysis

Abbreviations

(II/III)

HAZID: Hazard Identification Study
HAZOP: Hazard and operability study
HDV: Heavy-duty Vehicles
HFCP: Hydrogen Fuel Cell Partnership
HICE: Hydrogen Internal combustion engine
HOCL: Hindustan Organic Chemicals Limited
HP: Himachal Pradesh
HSE: Health, Safety and Environment
HV Transformer: High Voltage Transformer
IEA: International Energy Agency
INR: Indian Rupee
IOCL: Indian Oil Corporation Limited
IPCEI: Important Project of Common European Interests
IRENA: International Renewable Energy Agency
ISO: International Organization for Standardization
ISTS: Interstate Transmission System
IWAI: Inland Waterways Authority of India
JV: Joint Ventures
KINFRA: Kerala Industrial Infrastructure development Corporation
KL: Kerala
KMB: Kerala Maritime Board
KMML: Kerala Metals and Minerals Ltd
KMRL: Kochi Metro Rail Limited
KPACT: Kottayam Port and Container Terminal
KSINC: Kerala Shipping and Inland Navigation Corporation Ltd
KSTRC: Kerala State Road Transport Corporation

KSWTD: Kerala State Water Transport Department
kTPA: Kilo tons per Annum
KWA: Kerala Water Authority
kWh: Kilowatt hour
KWML: Kerala Water Metro Limited
kWp: Kilowatt peak
LH$_2$: Liquid Hydrogen
LNH$_3$: Liquid Ammonia
LOI: Letter of Intent
LPG: Liquified Petroleum Gas
LTO Battery: Lithium-titanate Battery
MH: Maharashtra
MLD: Million Liters per day
MLI: Member Lending Institutions
MMBtu: Metric Million British Thermal Unit
MMT: Metric Million tons
MNRE: Ministry of New and Renewable Energy
MoU: Memorandum of Understanding
MP: Madhya Pradesh
MT: Million tons
MW: Megawatt
N$_2$: Nitrogen Gas
NEC: New Energy Coalition
NGHM: National Green Hydrogen Mission
NGO: Non-Governmental Organization
NH$_3$: Ammonia

Source: MEC+ analysis

Abbreviations

(III/III)

NIWE: National Institute of Wind Energy
NPK: Nitrogen, Phosphorus and Potassium
NZE: Net Zero Emission
O&M: Operation and Maintenance
O_2: Oxygen Gas
OD: Odisha
OPEX: Operational Expenditure
OSW: Offshore Wind
PAT: Perform Achieve and Trade Scheme
PAWE: Pressurized Alkaline Water Electrolyser
PB: Punjab
PDPP: Propylene Derivatives Petrochemicals Project
PEM: Proton Exchange Membrane
PGCIL: Power Grid Corporation of India
PLI: Production Linked Incentives
PMU: Project management Unit
PV: Photovoltaic
QRA: Quantitative risk assessment
R&D: Research and Development
RE: Renewable Energy
REC: Rural Electrification Corporation Limited
RE-RTC: Round the Clock -Renewable Energy
RJ: Rajasthan
ROW: Right of Way
RRF: Recovery and Resilience Facility part of EU economic recovery fund
SEC: Specific Energy Consumption

SECI: Solar Energy Corporation of India
SHP: Small Hydrogen Power
SIGHT Scheme: Strategic Interventions for Green Hydrogen Transition
SMR: Steam Methane Reforming
SNN: Northern Netherlands Alliance
Sox/Nox: Sulphur Oxide/Nitrous Oxide
SPV: Special Purpose Vehicle
TCO: Total Cost of Ownership
TPA: tons per annum
TRL: Technology readiness levels
UKTL: Udupi Kasargod Transmission Limited
UNIDO: United Nations Industrial Development Organization
USD: United State Dollar
VGF: Viability Gap Funding
WACC: Weighted Average Cost of Capital
WCC: West Coast Canal

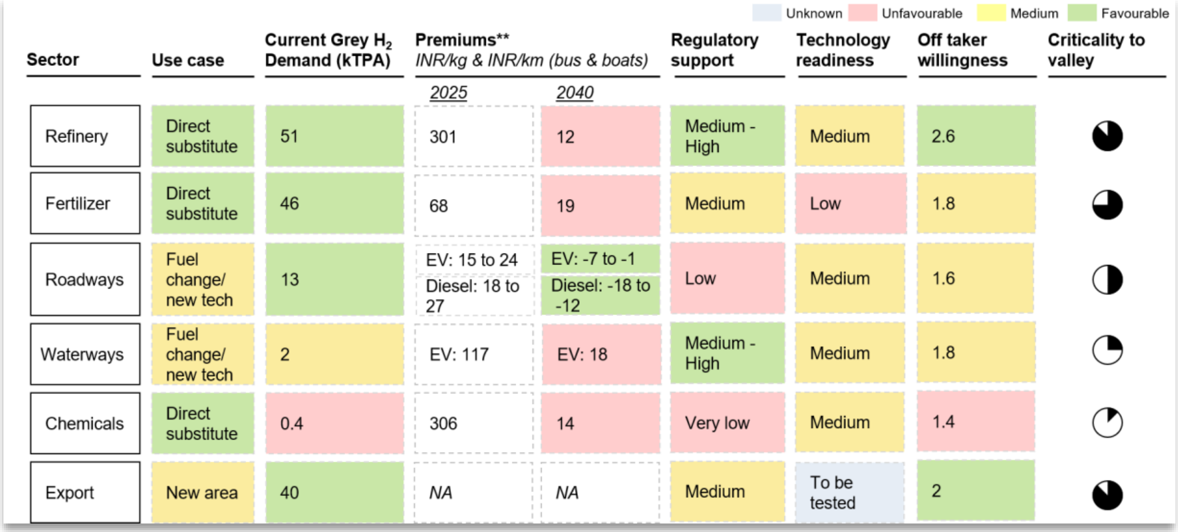
Source: MEC+ analysis

Kochi industries can potentially consume 120 kTPA of Green Hydrogen but require a coordination agency to realise the potential

- Kochi is a major port city on the Malabar Coast of India and its industrial base includes a refinery, fertiliser, ship-yard, port, container terminal, LNG terminal and airport along with other industries
- The presence of port and heavy industries can create aggregated demand up to nearly 120 kilo tons per annum of Green Hydrogen. This translates to a demand of nearly 1 GW of electrolysers and associated infrastructure in renewable energy (5GW), grid infra (ISTS s/s), storage, pipeline (27 km), and end use (including buses, boats, refuelling infrastructure)

- 90% of the current existing demand is concentrated within refinery and fertiliser
- However, each sector is represented by only 1 player with limited coordination amongst them due to different business models and use cases
- There are no set plans and timelines for GH_2 adoption amongst these players due to high costs, already sunk-in infra costs, and no clear plans for decarbonisation
- Establish an export-oriented unit to cater to additional markets due to presence of water and development of port infrastructure in the green hydrogen valley

Exhibit 1: Relative attractiveness among players for adopting Green Hydrogen



🟦 Unknown 🟥 Unfavourable 🟨 Medium 🟩 Favourable

Sector	Use case	Current Grey H_2 Demand (kTPA)	Premiums** *INR/kg & INR/km (bus & boats)*		Regulatory support	Technology readiness	Off taker willingness	Criticality to valley
			2025	*2040*				
Refinery	Direct substitute	51	301	12	Medium - High	Medium	2.6	◕
Fertilizer	Direct substitute	46	68	19	Medium	Low	1.8	◕
Roadways	Fuel change/ new tech	13	EV: 15 to 24 Diesel: 18 to 27	EV: -7 to -1 Diesel: -18 to -12	Low	Medium	1.6	◑
Waterways	Fuel change/ new tech	2	EV: 117	EV: 18	Medium - High	Medium	1.8	◔
Chemicals	Direct substitute	0.4	306	14	Very low	Medium	1.4	◔
Export	New area	40	*NA*	*NA*	Medium	To be tested	2	◕

Note: TCO case for roadways is a one-off niche case for 400 km and fleet of 10 buses

Source: MEC+ analysis

Demand is around refinery and fertiliser, all sectors require coordination, infra development, technology reliability and manpower training

Parameters	Opportunities	Challenges
Refinery	• Direct use case of 51 kTPA going to 70 kTPA by 2040 • Economic case by 2030 vs Blue H2 • Technology availability	• Already existing contract with AirProducts • No govt targets at refinery level / no feedstock emission reduction targets • Bina refinery is currently being considered as hub
Fertiliser	• Ammonia use case of 281 kTPA today – 46 kTPA of GH_2 going to 70 kTPA by 2030 • Uses imported LNG (as do all fertiliser companies)	• Process integration with NPK and DAP is untested • Minimum size of ammonia plant is 200 kTPA and hence requires significant decision and infrastructure • Economic case for GH_2 most likely by 2035
Road Transport	• 1000 buses on long routes can anchor 13 kTPA GH_2 • Cost comparable to Diesel for 400 km round trip by 2030 but Electric Vehicles are cheaper • Owned by State Govt and hence quick to act	• CAPEX, and OPEX on maintenance for refuelling infra and offtake to be supported by the government • High costs of H_2 initially – should not be locked in
Marine Transport	• Local ship-yard & multiple shipping routes – local, inland, and international provide unparallel base for adoption • State Govt plans to increase marine traffic and go net zero • TCO against EV boats for high distance routes can exist	• Very little traffic on local and inland routes due to local opposition by road transport operators – however, pilots can lead to higher growth • Re-skilling, CAPEX infra & initial H_2 costs are a barrier
Export Potential	• Port is on the east coast and competes with Colombo, Singapore, Dubai and Malaysian ports for transshipment traffic • Existing proposals from leading IPP to set up H2 base	• High level of subsidies requested by the IPPs • Current financial conditions of the government agencies is poor

Source: MEC+ analysis

Offtake is limited till 2025, pilots will be required to realise and build the capacity in 2030

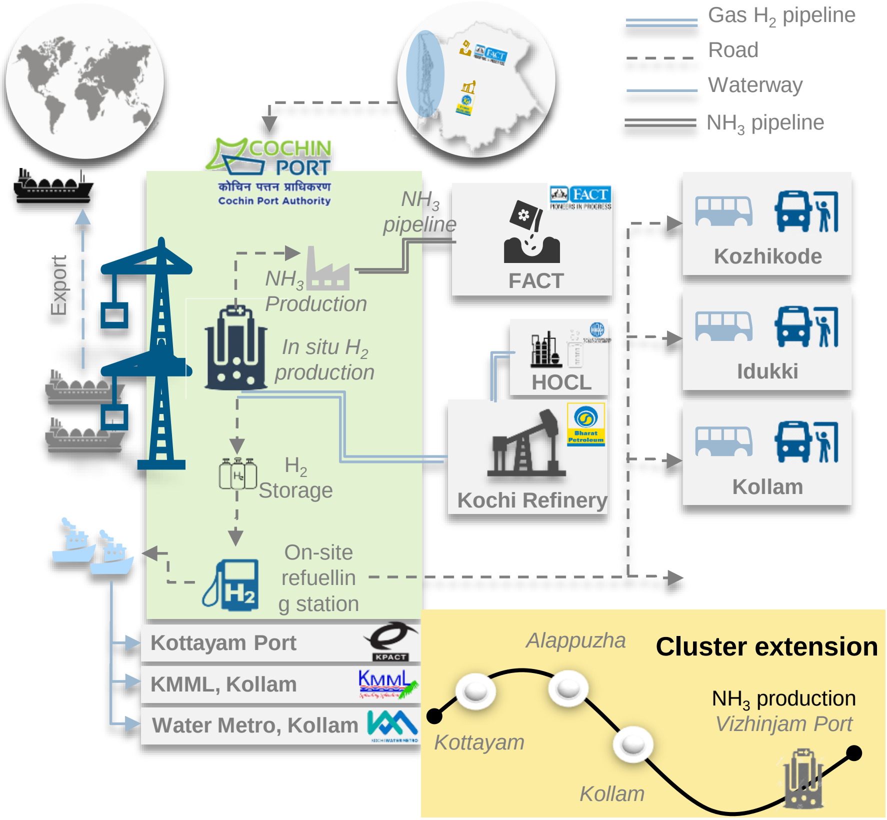
- There are no signs of offtake until 2025, with pilot programs scheduled between 2025 and 2027. A feasible timeline for domestic offtake is anticipated around 2030
- Local players need time to develop decarbonisation plans, evaluate feasibility, and assess the impact on existing contracts
- There is an absence in sector coupling due to planning done in silos and individually
- There is limited capacity to approve, and process permits for hydrogen, develop port infrastructure, and enhance renewable energy infrastructure in the state bodies
- Financial and budgeting activities are primarily concentrated on securing budgetary approvals from the Kerala government, with some funds available from MNRE, but lacking international grants
- In the current setup, skill and certification development face notable challenges
- No processes for standards and certifications exist

- A phase wise approach to realise the potential of the green hydrogen valley has been suggested
- The first phase is focussed towards creating a supportive environment through policies, stakeholder engagement, demand aggregation, etc.
    - During 2024-25, focus will be to ensure feasibility assessments, stakeholder engagement, and sector coupling through RE, and coordination with international agencies and valleys
- The second phase is focussed towards conducting pilots studied in techno-commercial feasibilities to test the infrastructural and offtake development
    - During 2026-30. focus will be on set up of pilot projects, development of shared infrastructure, development of funding pipeline for CAPEX from state/ central/ other funds
- The third phase is focussed towards creating a green hydrogen hub by upscaling the pilots to scaled up offtake and creating a centralised demand supply structure
    - During 2030-40, create infrastructure for scaling up of GH2

Source: MEC+ analysis

A centralised Green Hydrogen facility at the port supported with pipelines serving nearby industries is suggested

- The industries in Kochi are in proximity and can be served from a single central location producing green hydrogen, also served by transport and storage infrastructure
- A centralised electrolyser to be placed at the port infrastructure in order to supply fuel
- Further, the configurations require a refuelling infrastructure setup for the boats and buses as well as pipelines running from Port to BPCL refinery and FACT fertiliser unit
- The cluster can be expanded to Vizhinjam port connecting industries in Kottayam, Alappuzha, Kollam to an NH_3 production unit at Vizhinjam
- Total cumulative funding needed from government will be INR ~731 Crores to be spent on supporting techno-commercial assessments (INR 45 Crores) transmission infrastructure (INR 351 Crores), pipeline and refuelling infrastructure (INR 264 Crores), offtake infrastructure (INR 70 Crores)
- Total Green H2 subsidy needed to bridge the viability gap ranges as INR 1,055 and INR 2,908 crores in phase 2 and 3 respectively
- Total capex investments in the valley amount to INR 18,542 Crore. Out of which INR 4,166 Crore will be spent on electrolyser and ammonia plants and INR 12,687 Crore on Renewable Energy set up
- Around 3,600 jobs can be created in the green hydrogen valley cumulatively with an abatement of 0.49 Mt $CO2_e$



Source: MEC+ analysis

Pilots to be realised to test the feasibility for infrastructure and cost

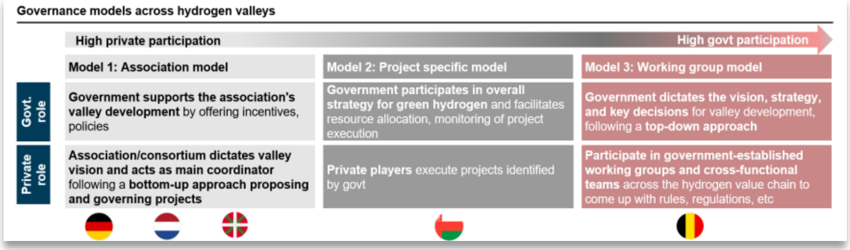
	Sector	Offtaker	Projects
Proposed pilots	Refinery	Bharat Petroleum	• Set-up 5.1 kTPA green hydrogen pilot in Kochi refinery for testing infrastructure requirements
	Roadways		• Setup 9 buses with mix of HICE & FCEV technology • Build centralised refuelling infra at port/ KMRL high court station • Test 1 decentralised refuelling station with transport infra
	Waterways	WATER METRO KSINC	• Run 1 cargo barge as per feasibility report with KSINC/ KMML or Kottayam port or run 1 fast passenger ferry to Kollam with water metro • Test run in coastal canal for operational challenges & use bus refuelling station in Cochin port
Offtake in scale up phase	fertiliser	FACT	• **No pilot for fertiliser sector**, in base case with green ammonia export opening in phase III and catering to fertiliser sector.
	Chemicals	एच ओ सी HINDUSTAN ORGANIC CHEMICALS LIMITED	• No pilot for chemical sector in base case due to minimum demand and low feasibility
	Export	COCHIN PORT कोचिन पत्तन प्राधिकरण Cochin Port Authority Any developer	• Test and setup for infrastructure: storage infra, development of port infra for exports and trunk infra and setup for pilots from the export proposals

Source: MEC+ analysis

Governance of valley will require adopting best practices from globally successful models and immediate capacity building within Kochi, Kerala

- Across 80+ valleys, 3 major models for governance structures exist – working group model, project specific model and association model wherein international experience should be captured by Kochi
- For the Kochi valley, working group model for governance structure has been developed due to presence of public sector companies
- The working group model follows a top-down vision of green hydrogen valley wherein the government plays the key role of coordinator
- The Department of Science and Technology (DST) has approved Kochi Hydrogen Valley Innovation Cluster's (HVIC) proposal for financial support.
- DST has designated RE nodal agencies as the nodal agency for HVIC. ANERT is proposed to play the role of the coordination agency as it is already the nodal agency for RE in the state.
- ANERT is proposed to undertake two set of activities –
    - Working with national, local and international stakeholders to develop projects, bring funds, R&D and to meet compliance requirements
    - Development of infra required to support the Green H2 adoption
- The development of infrastructure is proposed to be undertaken in a separate company as a subsidiary. Successful models exist in international valleys that have been able to monetise such development
- The coordination and partnership should be done via a department within ANERT – herein referred to as a council
- The council to collaborate with international valleys and programs in Germany and other European countries

Exhibit 1: Global valleys

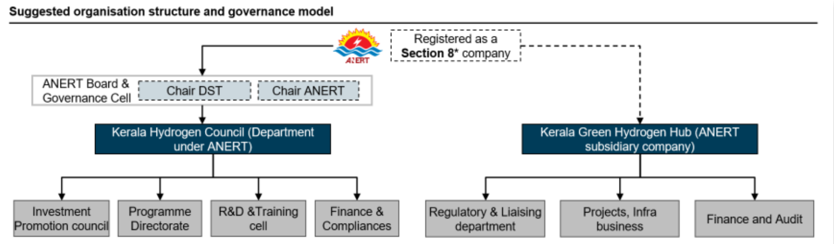


Governance models across hydrogen valleys

High private participation → High govt participation

	Model 1: Association model	Model 2: Project specific model	Model 3: Working group model
Govt. role	**Government supports the association's valley development** by offering incentives, policies	**Government participates in overall strategy for green hydrogen** and facilitates resource allocation, monitoring of project execution	**Government dictates the vision, strategy, and key decisions** for valley development, following a **top-down approach**
Private role	**Association/consortium dictates valley vision and acts as main coordinator** following a **bottom-up approach proposing and governing projects**	**Private players** execute projects identified by govt	**Participate in government-established working groups and cross-functional teams** across the hydrogen value chain to come up with rules, regulations, etc

Exhibit 2: Green Hydrogen governance structure



Suggested organisation structure and governance model

ANERT

Registered as a **Section 8*** company

ANERT Board & Governance Cell

Chair DST

Chair ANERT

Kerala Hydrogen Council (Department under ANERT)

Investment Promotion council

Programme Directorate

R&D &Training cell

Finance & Compliances

Kerala Green Hydrogen Hub (ANERT subsidiary company)

Regulatory & Liaising department

Projects, Infra business

Finance and Audit

Source: MEC+ analysis

Recommendations (1/7)

🟩 High priority 🟨 Medium priority 🟥 Low priority

Theme	Recommendations
Policy	**1** 🟩 • Align Kerala Green H_2 policy to national Green H_2 policy for provision of subsidies, funding required and sector adoption target and SPV requirements
	2 🟩 • Conduct policy advocacy with Government of India to create plant specific targets in refinery, fertiliser, and chemical sector with minimum adoption of GH_2, GNH_3 targets to be set in place
	3 🟩 • Create policies for supporting large scale deployment of export oriented GH_2 setup as well as supporting pilots in the transportation, and maritime sectors
Governance	**4** 🟩 • Setup ANERT as a nodal agency for implementation of green hydrogen policy
	5 🟩 • Additionally, register ANERT as a Section 8 company (Kerala Green Hydrogen Council) due to requirement of DST and to get FCRA funds from multilateral & bilateral programmes
	6 🟩 • Setup a regulatory and stakeholder facilitation body within ANERT to support developers and offtakers for clearances and approvals under the council

Source: MEC+ analysis

Recommendations (2/7)

🟩 High priority 🟨 Medium priority 🟥 Low priority

Theme		Recommendations
Governance	7 🟩	• Create a subsidiary company within ANERT (Kerala Green Hydrogen Hub) for developing and owning shared infrastructure in the valley
	8 🟩	• Allow ANERT to raise finance through this subsidiary (Kerala Green Hydrogen Hub) for development of infrastructure
Coordination	9 🟩	• Setup GH2 cluster partnerships via ANERT with existing GH2 valleys in Germany and other European countries along with important national stakeholders to increase efficiency, reliability, quantity and quality of green hydrogen solutions, facilitate trade and foster growth in sectors within the valley
	10 🟩	• The council can reap significant benefits through collaboration of an Indo-German cluster partnership, thereby harnessing the technical expertise derived from the successful implementation of hydrogen clusters in Europe
	11 🟩	• Improve capacity at ANERT to develop technical standards and coordinate the R&D ecosystem in India
	12 🟩	• Setup a facilitation office within ANERT for aggregating demand, designing of pilots, and for decentralised hydrogen project funding • Setup a PMO within ANERT to monitor the progress of the GH2 policy
	13 🟩	• Create working groups and task forces with public and private players in H2 valley to allocate funds for valley development

Source: MEC+ analysis

Recommendations (3/7)

🟩 High priority 🟨 Medium priority 🟥 Low priority

Theme			Recommendations
Coordination	**14**	🟩	• ANERT to Promote export-based setup for valley as compared to domestic setup as the domestic offtake is limited until 2030
	15	🟩	• ANERT to Setup an innovation fund to leverage the maritime infrastructure and existing skills within the valley
	16	🟨	• ANERT to run education programs for communities nearby port to educate about safety and advantage of GH2
	17	🟨	• ANERT to create a reskilling program for technical manpower development
Infrastructure	**18**	🟩	• Create transmission infrastructure, hydrogen/NH3 pipelines, and refuelling stations via ANERT infra development subsidiary (KGHH)
	19	🟩	• Create distribution and transmission infrastructure for RE RTC requirement of industries in Kochi to enable sector coupling around shared RE RTC infrastructure • ANERT to set up & own 400 kV transmission S/s for ISTS RE supply to industries for sector coupling

Source: MEC+ analysis

Recommendations (4/7)

🟩 High priority 🟨 Medium priority 🟥 Low priority

Theme			Recommendations
Infrastructure	**20**	🟩	ANERT to Acquire land at ports for setting transmission infra, electrolyser and NH3 setup and storage of H2 and NH3
	21	🟩	ANERT to acquire land for pipeline between port and refinery and port and fertiliser industry
Valley development	**22**	🟩	Valley to be developed in phase wise manner with defined goals in each phase – Preparation phase, Pilot phase and Scale Up phase
	23	🟩	Preparation phase for 2024-25 recommended for feasibility studies and innovation-based funding of projects aligned with valley objectives as well as mapping infra requirement
	24	🟩	4 year of Pilot phase from 2026-2030 recommended to support specific pilots through infra creation to test technology and economic feasibilities
	25	🟩	10-year Scale up phase from 2030-2040 where valley goes into self-sustain phase and investments scales as per pilot results with an upside post 2040

Source: MEC+ analysis

Recommendations (5/7)

🟩 High priority 🟨 Medium priority 🟥 Low priority

Theme	Recommendations		
Feasibility studies	26	🟩	• ANERT to conduct water feasibility study for adequacy and round the year availability from Periyar river and its conflict with local use and impact of ecology
	27	🟩	• Create specific funds for feasibility studies for the taskforces and budgeting for the setup of the capacity in the valley
	28	🟩	• ANERT to setup taskforce to work with BPCL for conducting feasibility studies for becoming the central fuel supplier of GH_2 for Kochi as well as setting up port to BPCL infra pipeline
	29	🟩	• ANERT to setup a taskforce with FACT to ascertain a minimum technical feasible size for NH_3 that can integrate with current DAP process as well as setup a pipeline infra to connect port and FACT
	30	🟩	• ANERT to setup a taskforce with KSRTC and mobility stakeholders to assess safety considerations and skill building in the road sector for H2 busses and refuelling station and conduct feasibility for introducing a mix of HICE and FCEV buses within the valley
	31	🟩	• ANERT to setup a taskforce with KSINC to improve coastal shipping by working with KMML to use 1 boat between Kochi to Kollam • Expand the taskforce with Kochi water metro for assessing feasibility of 1 fast ferry

Source: MEC+ analysis

Recommendations (6/7)

🟩 High priority 🟨 Medium priority 🟥 Low priority

Theme		Recommendations
Feasibility studies	32 🟩	• Setup a taskforce to ascertain amount of funding that can be giving to the export-oriented units within KL and their timelines and their ability to supply RE without compromise of industry and local stakeholders
	33 🟩	• ANERT to subsidise INR 4.5-6 crore for feasibility studies suggested for the anchor sectors
Pilots	34 🟩	• Set-up 5.1 kTPA green hydrogen pilot in Kochi refinery for testing infrastructure requirements
	35 🟩	• No pilot for fertiliser sector, in base case with green ammonia export opening in phase III and catering to fertiliser sector
	36 🟩	• Setup 9 buses with mix of HICE & FCEV technology • Build centralised refuelling infra at port/ KMRL high court station • Test 1 decentralised refuelling station with transport infra
	37 🟩	• Run 1 cargo barge as per feasibility report with KSINC/ KMML or Kottayam port or run 1 fast passenger ferry to Kollam with water metro • Test run in coastal canal for operational challenges & use bus refuelling station in Cochin port

Source: MEC+ analysis

Recommendations (7/7)

🟩 High priority 🟨 Medium priority 🟥 Low priority

Theme	Recommendations		
Pilots	**38**	🟥	No pilot for chemical sector in base case due to minimum demand and low feasibility
	39	🟩	Test and setup for infrastructure: storage infra, development of port infra for exports and trunk infra and setup for pilots from the export proposals
	40	🟩	Government to provide INR 69 crores for initial pilots and offtake of green hydrogen as CAPEX subsidies for road and marine sectors to deploy HICE and HFCEV buses as well as HFCEV boats

Source: MEC+ analysis

Table of Content

Sectional Summary

Global Hydrogen Landscape and Valley Focus

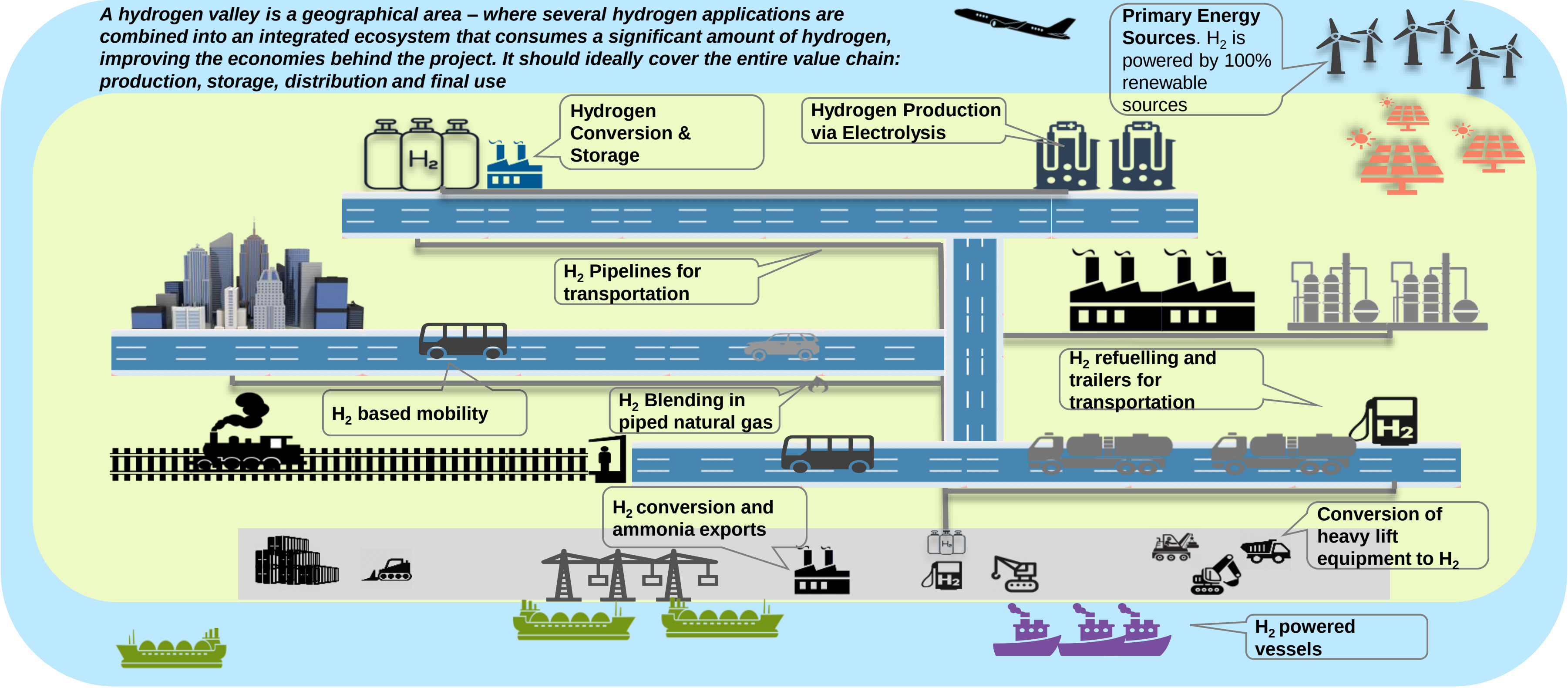
Global H_2 Landscape and valley Focus

- A valley is a defined geographic area where various hydrogen applications are integrated into a unified ecosystem covering the entire hydrogen value chain
- A green hydrogen value chain typically consists of 4 stages - production, storage, transportation and offtake
- Hydrogen valleys provide an environment for demonstration projects to be carried out across the entire value chain, thus enabling a hydrogen ecosystem
- Green Hydrogen has been gaining global momentum with nearly 41 countries actively working on their green hydrogen strategy
- Globally 80+ valleys have been recognized with majority concentration in EU
- Two distinct archetypes are seen globally, valleys that leverage their abundant RE resources and valleys that leverage their existing infrastructure
- In governance, valleys are emerging with association model (high private participation), project specific model (government facilitates and private players execute) and working group model (high govt. participation)
- Across the valleys, govt. have actively supported in demand aggregation, supply side incentives and in providing public and private funding

Source: MEC+ analysis

A Hydrogen Valley

combines multiple end-use sectors in a geographical location through shared use of hydrogen and/or hydrogen derivatives



A hydrogen valley is a geographical area – where several hydrogen applications are combined into an integrated ecosystem that consumes a significant amount of hydrogen, improving the economies behind the project. It should ideally cover the entire value chain: production, storage, distribution and final use

Primary Energy Sources. H_2 is powered by 100% renewable sources

Hydrogen Conversion & Storage

Hydrogen Production via Electrolysis

H_2 Pipelines for transportation

H_2 refuelling and trailers for transportation

H_2 based mobility

H_2 Blending in piped natural gas

H_2 conversion and ammonia exports

Conversion of heavy lift equipment to H_2

H_2 powered vessels

Note: Illustration inspiration to Ava Horton/Revolve
Source: Revolve; MEC+ analysis

The term hydrogen valley/cluster/hub are used interchangeably

to define a hydrogen ecosystem across multilateral institutes and country/agencies

Emerging definition of valleys, clusters and hubs across multilateral bodies and countries

Hydrogen Valley		A specific area, like a city, region, island, or industrial cluster**, integrates diverse hydrogen applications into a system consuming significant hydrogen**. **This enhances the project's economics**, ideally **covering the complete hydrogen value chain**: production, storage, distribution, and final use
		A Hydrogen Valley **aggregates multiple demand segments** along key hydrogen production, routes **within a specific geographic region**
		A **specified region** where hydrogen is **utilised across multiple sectors** like mobility, industry, and energy. This **encompasses the entire hydrogen value chain**, including production (often from dedicated renewable electricity), storage, and transportation to various end-users.
Hydrogen Cluster	iea International Energy Agency	A hydrogen cluster, also called hub or valley, is defined as **a network of hydrogen producers** (sometimes including renewable electricity production), **potential users and infrastructure** connecting the two
	UNIDO	Green hydrogen industrial clusters (GHIC) that **share green hydrogen and renewable energy for various purposes**, including material production, heating and cooling, power balancing, local mobility, and industrial feedstock
Hydrogen Hub		Clean hydrogen hubs will **create networks** of hydrogen producers, consumers, and local connective infrastructure to **accelerate the use of hydrogen** as a clean energy carrier that can deliver or store tremendous amounts of energy

Across these definitions, we define a green hydrogen valley as:
A **defined geographic area** where **various hydrogen applications** are integrated into a **unified ecosystem covering the entire hydrogen value chain**, from production to end-use, with the aim of making projects more **economically viable**. These valleys create networks of producers, consumers, and local infrastructure, **accelerating the use of hydrogen.**

Source: Clean Hydrogen Partnership, EU; DST, South Africa; DST, India; IEA; UNIDO; DOE, USA; MEC+ analysis

The objective of a Green Hydrogen Valley

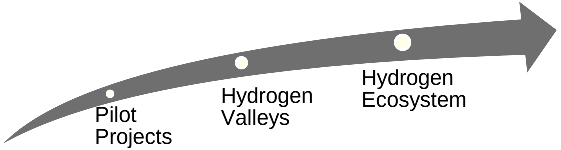
is to scale up production through demand aggregation and to leverage optimized cost of fuel for all participants in the ecosystem

Purpose of Green Hydrogen Valley

Decarbonisation Goals

- Several countries have undertaken pledges to achieve net zero by mid-century or sooner
- One of the key pillars of decarbonisation is electrification, the use of low-emission electricity in place of fossil fuels
- However, **electrification alone cannot lead to achieving net zero** goals
- **Hence, green hydrogen plays an essential role in the global effort to achieve net-zero emissions by 2050**
- Green hydrogen is the only **long-term, scalable, and affordable** option for **decarbonisation in hard-to-abate industries** like ammonia, petrochemicals, mobility, maritime, etc.
- Green hydrogen also complements other decarbonisation technologies like renewable energy, biofuels, or developments in energy efficiency.

Hydrogen valleys provide an environment for demonstration projects to be carried out across the entire value chain, thus enabling a hydrogen ecosystem.



Parameter	Description
① **Market Creation**	• Government promotes the development of local hydrogen markets for supply and off-takers through mandates, and policy initiatives
② **Demand Aggregation**	• Pool hydrogen demand of several end-users within the valley creating a bigger significant market
③ **Economies of Scale**	• Large scale hydrogen production and local supply chain development leads to cost competitiveness
④ **Sharing of Critical Infrastructure**	• Foster deeper coordination & collaboration among actors across value chain segments, resulting in reduced transaction costs (H_2 storage and transportation expenses)
⑤ **Socio-Economic**	• Hydrogen Valleys attract investment, spur regional infrastructure development, boost the economy, foster technology innovation & skill development through pilot projects

Source: Hydrogen Council; Net Zero by 2050- IEA; MEC+ analysis

Global Momentum: Green Hydrogen gaining worldwide traction

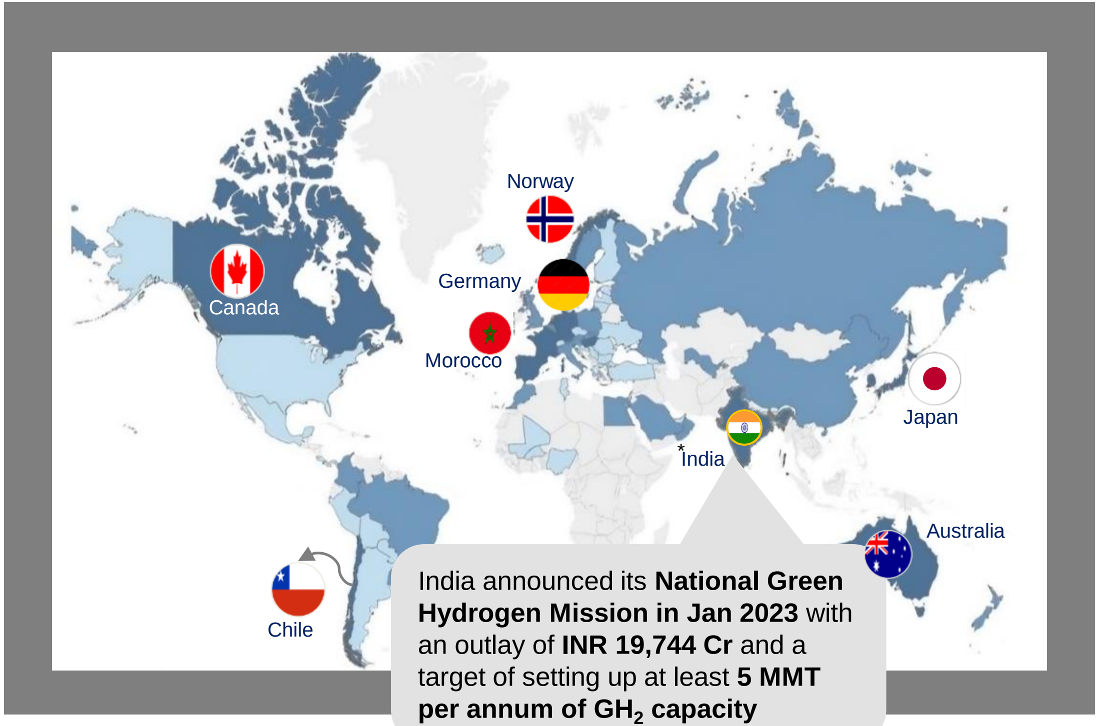
with nearly 41 countries actively working on a national hydrogen strategy

Global landscape of announced hydrogen strategies by 2021

■ Published national strategy

■ National strategy in preparation

■ Initial policy discussions/demo projects



India announced its **National Green Hydrogen Mission in Jan 2023** with an outlay of **INR 19,744 Cr** and a target of setting up at least **5 MMT per annum of GH_2 capacity**

A total of 41 governments, accounting for nearly 80% of global energy-related CO_2 emissions, have now adopted hydrogen strategies

Despite this momentum, low-emission hydrogen still accounts for less than 1% of global hydrogen production and use, and will need to grow more than 100-fold by 2030 to get in line with the NZE Scenario

Note: NZE- Net zero emission; *For India the status of strategy has been updated for 2023

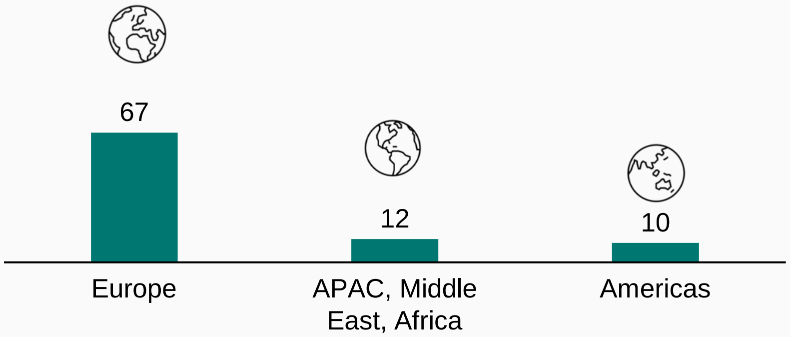
Source: World Energy Council; MNRE; Global Hydrogen Review 2023, IEA; MEC+ analysis

Globally 80+ valleys have been recognised

EU leading the concentration; however, majority of valleys are at early stage of development, highest at pre-FID stage

Global hydrogen valley landscape

Geographic split of hydrogen valleys across regions
Number of valleys



Total Investment:

11,06,940.3 INR Cr

Electrolyser Capacity:

40.34 GW

EU Funding for Valley:

1,770 INR Cr

70% of the global valleys

Concept developed	*10.77%*	**Initial idea** for establishing a GH$_2$ valley formulated, outlining the basic framework and objectives
Feasibility study	*15.38%*	**Assessment in progress to determine the practicality, viability**, and potential success of implementing the GH$_2$ valley
Pre-FID phase	*46.15%*	Pre-Final Investment Decision stage where **detailed plans, costs, risks,** and necessary arrangements are prepared
Post -FID phase	*7.69%*	**Execution of plans, securing financing**, and moving towards the implementation of the valley
Under construction	*12.31%*	**Physical work and installations** for the infrastructure of the GH$_2$ valley are in progress
Operational	*7.69%*	GH$_2$ valley is **functioning, producing, and distributing hydrogen** with planned systems and operations in place

Note: 1 EUR = INR 88.5
Source: Mission Innovation Platform; European Commission; MEC+ analysis

Lessons – Archetype | Globally, distinct archetypes have emerged

each leverages its position in the hydrogen value chain to foster the development of a robust valley

Valley archetypes across hydrogen valleys

	Archetype 1: RE focussed	Archetype 2: Supply infra driven
	Renewable Power Production Storage, Conversion Transport, Distribution Offtake	Renewable Power Production Storage, Conversion Transport, Distribution Offtake
Objective	**Leveraged abundant RE** to reduce the cost of GH_2 by **leveraging scale via abundant renewable energy sources** that are present in the region and therefore reducing CAPEX considerably	**Leveraged the existing infrastructure available** in the region to secure supply of Green H_2 from various sources
Purpose	Focused on doing multiple projects to **assess their feasibility,** paving the way for transition to **using hydrogen across multiple applications**	**These valleys focused on aggregating demand** and **initiating pilot programs** to test conversion of infrastructure to GH_2
Location	Focused on countries where **RE can be easily setup at low costs**	Focused on countries where RE availability is low or expensive but have **good infrastructure set-up such as pipelines, ports, land for storage facilities etc**
	The Netherlands utilizes North Sea OSW energy for the HEAVENN project, showcasing multiple end-use applications Abundant solar energy in Oman fuels a valley project, emphasizing green ammonia production Basque harnesses its wind and solar potential to establish a hydrogen corridor, capitalizing on abundant natural resources	Germany leveraged its transmission grid, port facilities for docking and existing gas network suitable for hydrogen transport Belgium leveraged its ports and existing natural gas pipelines to set up a green hydrogen valley leveraging its position in storage, transport & distribution

Note: Infra - Infrastructure
Source: Global Valley Profiles; MEC+ analysis

Lessons – Governance | Three models emerge across global valleys

each exhibiting a different degree of participation between the public and private sectors, shaping the structure of the valley

Governance models across hydrogen valleys

High private participation → **High govt participation**

	Model 1: Association model	Model 2: Project specific model	Model 3: Working group model
Govt. role	**Government supports the association's valley development** by offering incentives, policies	**Government participates in overall strategy for green hydrogen** and facilitates resource allocation, monitoring of project execution	**Government dictates the vision, strategy, and key decisions** for valley development, following a **top-down approach**
Private role	**Association/consortium dictates valley vision and acts as main coordinator** following a **bottom-up approach proposing and governing projects**	**Private players** execute projects identified by govt	**Participate in government-established working groups and cross-functional teams** across the hydrogen value chain to come up with rules, regulations, etc
Lessons learnt	In Germany, Netherlands, Basque, an association model prevails, bringing together a consortium of public, private, and knowledge-based bodies. This **unified approach towards the common goal** of the success of the valley facilitates **easy access to funding, political backing and public acceptance**	In Oman, a **tailored auction system, spearheaded by the government** for green hydrogen projects, outlines **defined roles and responsibilities for the developer**. This approach ensures **efficient resource allocation, robust project development, and designated offtake mechanisms**	Belgium's **clear government-driven hydrogen strategy** prompted the establishment of a dedicated program office overseeing specialized working groups. These groups, possess **distinct roles and responsibilities** spanning the hydrogen value chain, thus ensuring a **resilient and structured framework**

Source: Global Valley Profiles; MEC+ analysis

Lessons – Government support | Govts. have actively supported

supply-side incentives, demand aggregation as well as significant fund allocation for first-mile infra in the hydrogen valleys

Key enablers of a successful hydrogen valleys globally

▨ Govt. □ Private/Priv-Govt.

	Supply creation **(providing incentives, subsidies, etc)**	**Demand creation** **(ensuring substantial offtake)**	**Funding** **(need for both public and private funding)**
Germany	• Gasnetz Hamburg, wholly owned company of the city of Hamburg is working on expanding the existing pipeline which will be suitable for hydrogen	• State owned company to offtake demand for district heating purposes	• State owned company along with private company to fund one third of the total investment amount
Netherlands	• Govt allocated approximately INR 17 Cr towards the development of the Delfzijl Chemical Park, aimed at fostering the growth of a hydrogen hub	• The Municipality of Groningen agreed to purchase, own, and operate hydrogen powered garbage trucks and light duty vans ensuring offtake	• Secured public and private funding. Public contribution comprised support from the region and the state. The valley suggests simplification of regulations for funding
Basque	• Three electrolyser plants to be setup by Petronor, a privately held company	• Boosted by local petrochemical demand and natural gas substitution. Expected mobility demand by Araba, Gipuzkoa, and Bizkaia Provincial Councils	• Public private funding of ~INR 3796 Cr received
Oman	• Govt conducted auctions and awarded land and resources basis auction criteria easing hydrogen supply	• The developers signed an MoU with Yara for complete offtake of the green ammonia produced	• Received loan from REC of approximately ~INR 4000 Cr
Belgium	• Flemish govt invested in electrolyser for GH_2 production (INR 38 Cr) H_2 pipeline (INR 2212 Cr) for transportation	• Demand offtake largely concentrated around ports in various use cases such as refinery, mobility, chemicals	• Significantly funded by the government

Note: Pvt - Private
Source: Global Valley Profiles; MEC+ analysis

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Sectional Summary

Kochi Hydrogen Valley - Summary

Demand in the valley and scenarios for valley development	• Green Hydrogen demand is seen in 10-12 sectors of which all are present in Kerala. This brings the total potential of GH_2 to around 120 kTPA and an additional demand of 40-100 kTPA through exports
	• Within this potential demand, more than 100 kTPA demand is concentrated within Kochi consisting of refineries, fertilizers, chemicals, transport hubs etc.
	• For the Kochi Valley, India's best RE resources, centralised hydrogen production and refuelling infrastructure and green hydrogen/ammonia transportation through pipelines are envisioned with offtakers including BPCL, FACT, HOCL, KSRTC, KWML, KSINC and exports
	• To realize this supply and demand, 2 scenarios exist:
	  • Base Case with a potential demand of 92 kTPA requiring 0.9 GW electrolyser and 4.8 GW RE by 2040
	  • Aggressive Case with a potential demand of 195 kTPA requiring 2 GW electrolyser and 10.3 GW RE by 2040

Adoption of base case and phases of valley development	• The valley will adopt base case as this requires lesser changes in regulations, and more time for technology shift • The adoption will be in three phases - Phase I - preparation phase, Phase II - pilot phase and Phase III - scale up phase and activities to be carried out across 5 sectors (Refineries, Fertilizers, Road Transport, Water Transport and Exports) and adoption in Chemicals • Phase I to be focused on stakeholder engagement, developing workplans, conducting feasibility studies and mobilization of funds across the 5 sectors • Phase II to be focused on the commissioning of the pilots based on results of the feasibility studies, testing the performance of pilots and the technology, understanding and addressing practical challenges and initiation of commercial scale adoption • Phase III to be focused on the scale-up of adoption across the sectors, linkages between the sectors and synchronizing the operations of the valley

Source: MEC+ analysis

Sectional Summary

Kochi Hydrogen Valley - Summary

Governance model in the valley

- ANERT being the nodal agency for RE in Kerala is well-positioned to be the nodal agency for hydrogen valley ANERT will have defined roles in all 3 phases from stakeholder engagement to being the implementation agency for the valley
- ANERT to establish Kerala Hydrogen Council (department under ANERT) and Kerala Green Hydrogen Hub (subsidiary company)
- Kerala Hydrogen Council to have 4 functional departments and will be responsible for fund co-ordination, techno-commercial feasibilities, R&D, standards & certification and reporting
- Government funds for R&D, training and salaries to council employees to be disbursed through the council
- Kerala Green Hydrogen Hub to function as an asset holding company, holding the shared infrastructure investments and projects on its balance sheet
- All investments on shared infrastructure and purchase of assets to be made through the subsidiary

Investments in the valley and socio-economic impact

- This valley development will require significant CAPEX investments. Investments required in hydrogen production, infrastructure development for H_2, NH_3 and transmission grid totaling to INR 56 crore, INR 669 crore and INR 5130 crores in the three phases additionally
- Additionally, development of RE would require INR 903 crores in phase I and INR 836 crores in Phase II if Kerala RE is used and INR 10,948 crores for phase 3 additions
- The development of this valley will create significant socio-economic benefits by enabling 8 out of 17 SDGs with focus on jobs, carbon abatement and net value addition
- The valley would generate ~3,600 jobs with more than 80% during the construction phase (one-off jobs)
- The valley would abate nearly 0.49 million tons of CO_2e from Kerala emissions reducing the total emissions by ~2%

Source: MEC+ analysis

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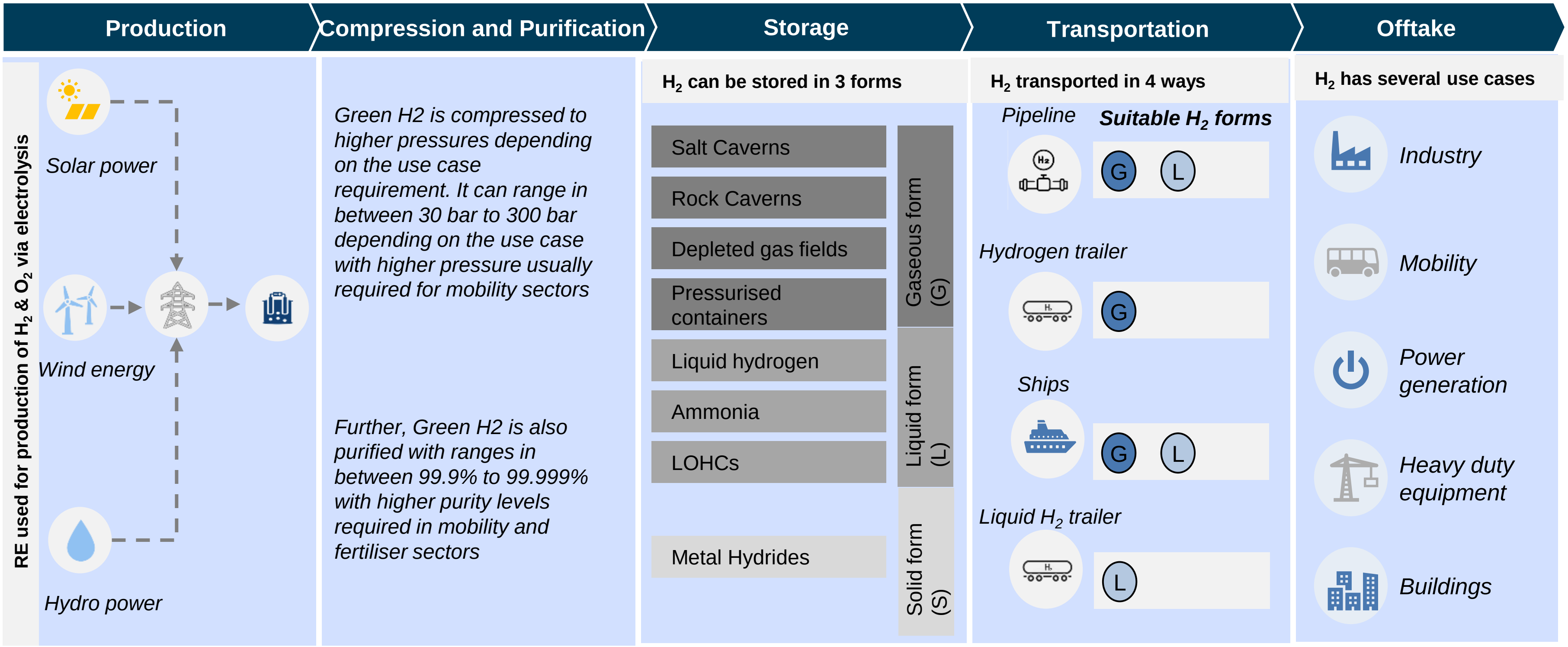
Various costs get added to LCOH

depending on the configurations and design choices throughout From the production to point of consumption

Hydrogen value chain and the opportunities across each stage



Production

RE used for production of H_2 & O_2 via electrolysis

Solar power

Wind energy

Hydro power

Compression and Purification

Green H2 is compressed to higher pressures depending on the use case requirement. It can range in between 30 bar to 300 bar depending on the use case with higher pressure usually required for mobility sectors

Further, Green H2 is also purified with ranges in between 99.9% to 99.999% with higher purity levels required in mobility and fertiliser sectors

Storage

H_2 can be stored in 3 forms

Gaseous form (G):
- Salt Caverns
- Rock Caverns
- Depleted gas fields
- Pressurised containers

Liquid form (L):
- Liquid hydrogen
- Ammonia
- LOHCs

Solid form (S):
- Metal Hydrides

Transportation

H_2 transported in 4 ways

	Suitable H_2 forms
Pipeline	G L
Hydrogen trailer	G
Ships	G L
Liquid H_2 trailer	L

Offtake

H_2 has several use cases

- *Industry*
- *Mobility*
- *Power generation*
- *Heavy duty equipment*
- *Buildings*

>50% of Kerela's GHG emissions are from hard to abate sectors

Kerala has annual GHG emissions of 32 $MtCO_2$. Hence the state must consider Hydrogen as a part of its decarbonisation plan

Kerala's climate targets

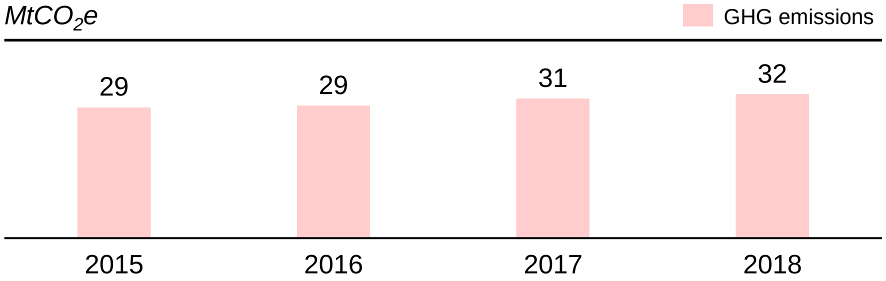
Achieve 100% renewable energy by 2040

Become a net carbon neutral state by 2050

Kerala's carbon emissions over the years

GHG emissions between 2015-2018

$MtCO_2e$

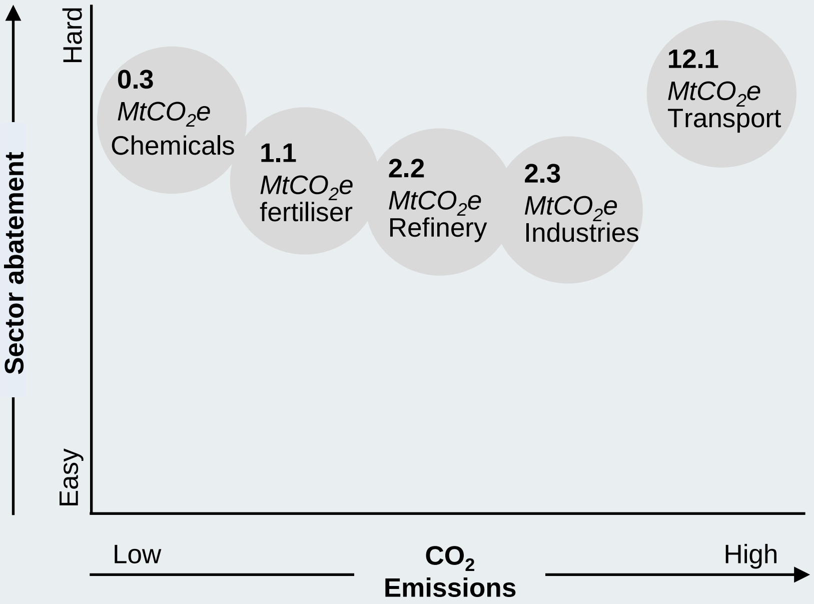


Note: Total GHG emissions include the following sectors Energy, Industrial process & product use, waste sector, Agriculture, Forestry and Other Land Use (Only emissions, removals not considered)

Sector wise carbon emissions vs Ease of abatement

Sector wise GHG emissions*

$MtCO_2e$



Note: *Non-exhaustive list of sectors; Ammonia Production considered for fertilizers; Industries (others) and chemicals (others); CO2e – GWP-AR6

Source: Trend analysis of GHG emissions in Kerala; GHG Platform; BPCL; MEC+ analysis

Green Hydrogen demand in Kerala is driven by 6 sectors

10-12 use cases for green hydrogen currently exist , all of which are present in Kerala, however, only 6 drive the potential demand

Green hydrogen use case in various sectors and presence in Kochi

🟩 TRL 7-9 🟨 TRL 6-7 🟥 TRL < 6

	Description	Use case	TRL	Total H_2 Demand	Relevance for valley
Direct use case	Grey H_2 used for processes like hydrocracking, hydrotreating etc can be **directly substituted with GH_2** produced from RE sources in existing equipment and processes. This substitution aims to reduce GHG emissions without requiring major infrastructure or technological change	Refinery	7-8	51 kTPA	↑
		fertiliser	6-7	46 kTPA	↑
		Chemicals	7-8	0.4 kTPA	↑
		Industry (Steel, Cement etc)	5	Low	↘
		Gas Blending	7	Upcoming	→
Indirect use case	Indirect replacement refers to the use of GH_2 to generate electricity or produce clean fuels that **replace fossil fuels by converting chemical energy to electric energy in fuel.** This replacement requires purchase of new assets and deployment of new infrastructure	Buildings	6	Low	↓
		Power generation	6	6 kTPA	→
		Buses	7-8	13 kTPA	↑
		Heavy duty equipment	8-9	0.7 kTPA	→
		Aircraft	3-4	Upcoming	↓
		H_2 Vessels	6	2 kTPA	↗
		NH_3 Vessels	5	Upcoming	↓
New sector		Export	6-7	40 kTPA	↑

- Sectors with high demand and medium to high technology readiness will be the anchor off takers for pilots and scale up in the valley
- Sectors with low/upcoming demand with low to medium readiness will be a part of the R&D Innovation cluster

Note: Demand for power generation based on houseboats demand; Heavy duty equipment like cranes are being electrified in ports; Within chemicals demonstration projects are being conducted globally; For fertilizers demonstrations are being conducted at smaller scales

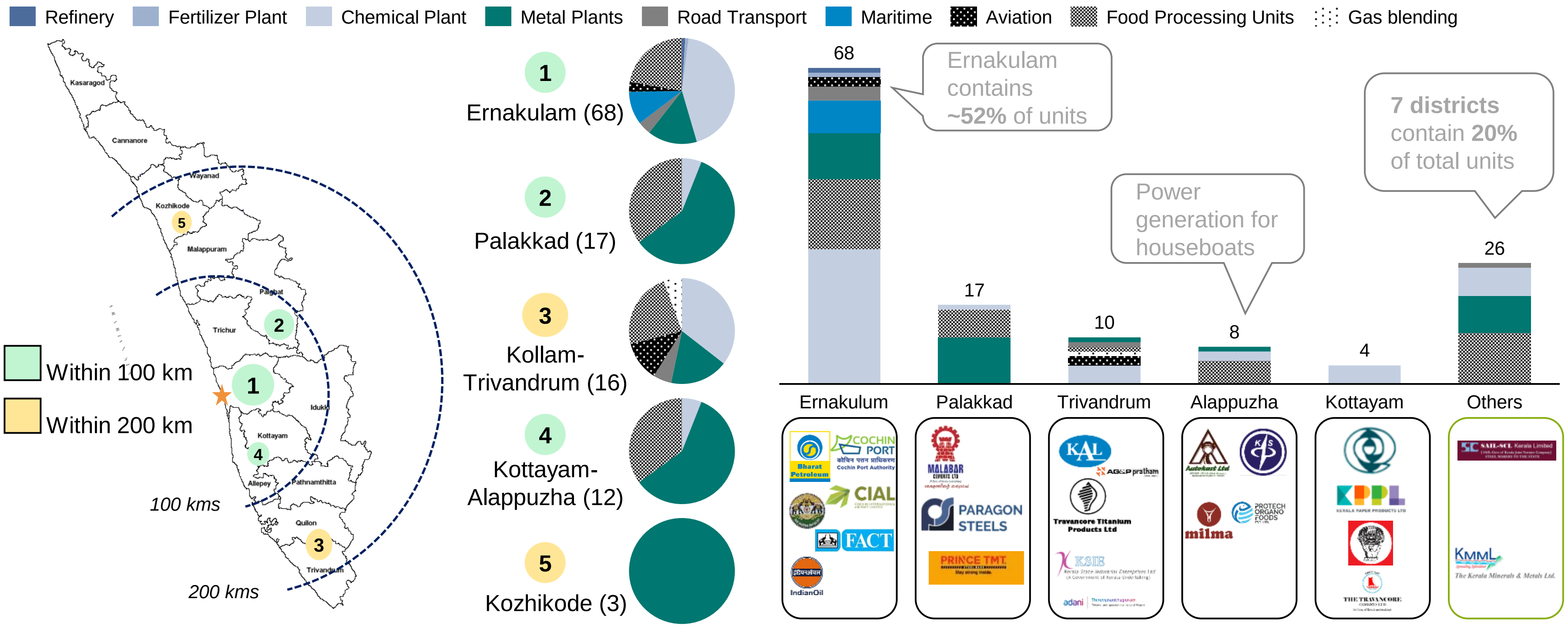
Source: Oxford-DTU; ITIF-IEA; KTH; Green Hydrogen Industrial Cluster Guidelines; MEC+ analysis

Ernakulam/Kochi is the biggest cluster

Of the 5 industrial clusters in the states where relevant end users can be seen

Demand clusters arising in Kerala and their concentrations

Number of units



Ernakulam contains ~**52%** of units

Power generation for houseboats

7 districts contain **20%** of total units

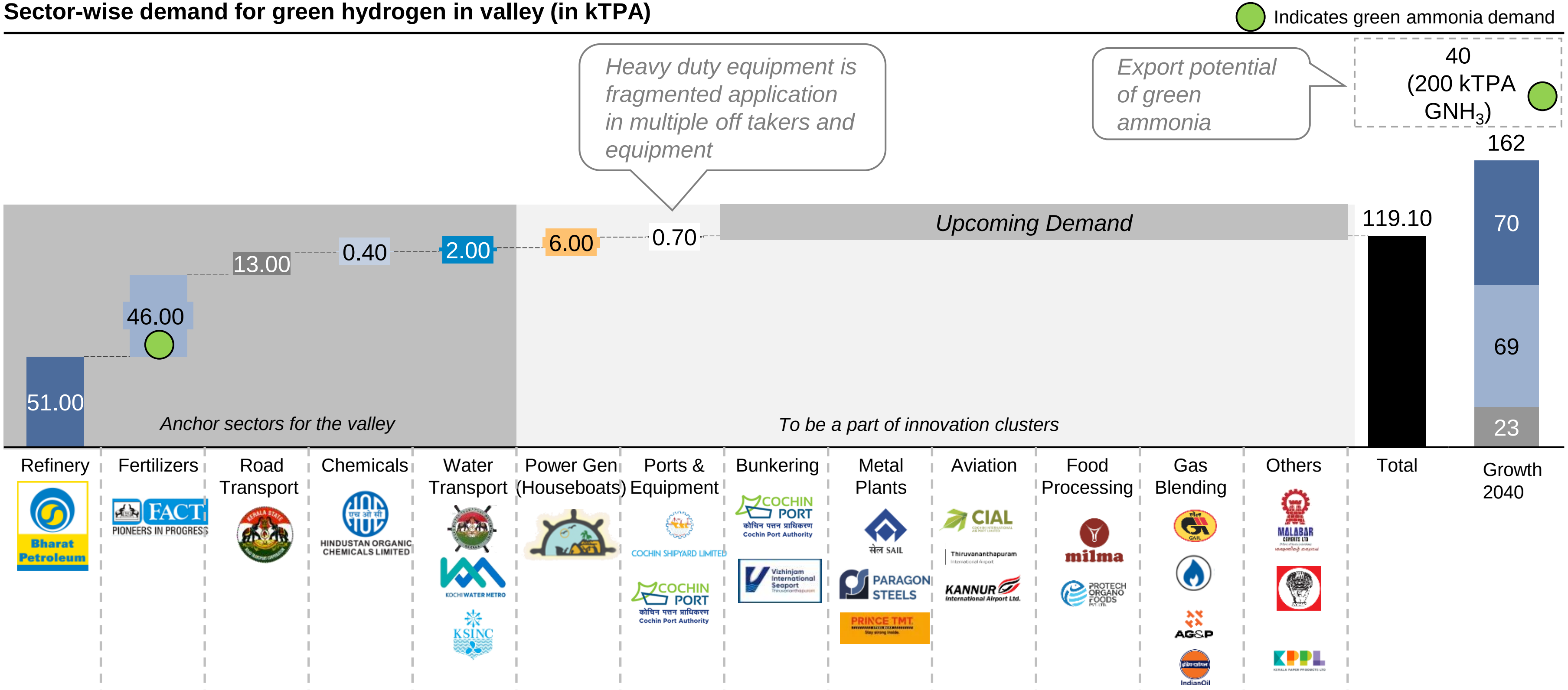
Note: Food processing and chemical units are smaller in size but higher in numbers

Source: Company Websites; MEC+ analysis

Overall, Kerala has an intrinsic GH$_2$ offtake potential of ~120 kTPA

which is expected to reach 162 kTPA by 2040; additionally, valley could require 40 kTPA GH$_2$ for green ammonia export facility

Sector-wise demand for green hydrogen in valley (in kTPA)



Heavy duty equipment is fragmented application in multiple off takers and equipment

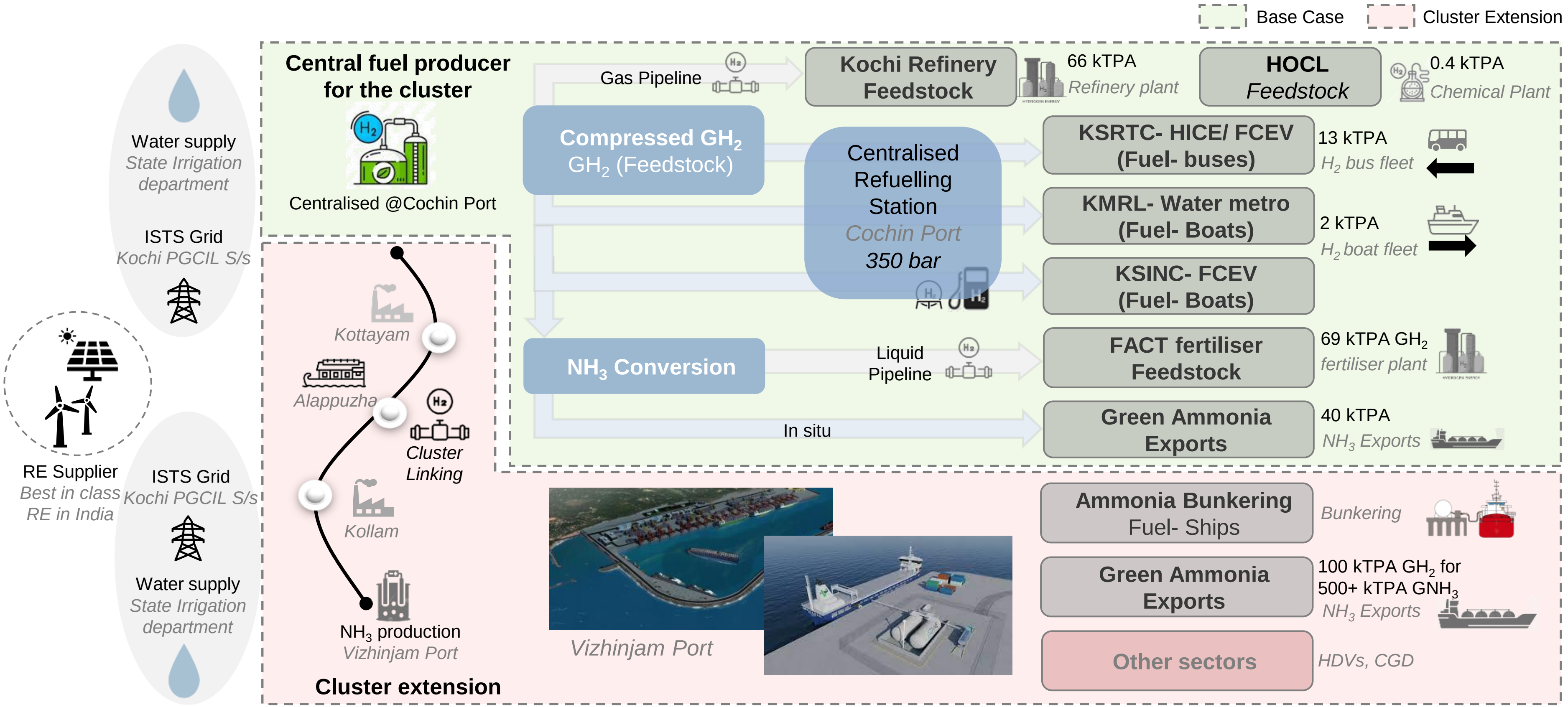
Export potential of green ammonia

Note: Growth plans of fertilisers accounted via primary; refinery growth estimated via global rates; 1-2% growth rates accounted for rest of the sectors; all numbers for green hydrogen and not hydrogen derivatives, conversion in subsequent slides

Source: Primary interview; Annual Reports; MEC+ analysis

KERALA GREEN HYDROGEN VALLEY- VISION 2040

🟩 Base Case 🟥 Cluster Extension



Water supply
State Irrigation department

ISTS Grid
Kochi PGCIL S/s

RE Supplier
Best in class RE in India

ISTS Grid
Kochi PGCIL S/s

Water supply
State Irrigation department

Central fuel producer for the cluster

Centralised @Cochin Port

Gas Pipeline

Compressed GH_2
GH_2 (Feedstock)

Centralised Refuelling Station
Cochin Port
350 bar

NH_3 Conversion

Liquid Pipeline

In situ

Kochi Refinery Feedstock — 66 kTPA *Refinery plant*

HOCL *Feedstock* — 0.4 kTPA *Chemical Plant*

KSRTC- HICE/ FCEV (Fuel- buses) — 13 kTPA *H_2 bus fleet*

KMRL- Water metro (Fuel- Boats) — 2 kTPA *H_2 boat fleet*

KSINC- FCEV (Fuel- Boats)

FACT fertiliser Feedstock — 69 kTPA GH_2 *fertiliser plant*

Green Ammonia Exports — 40 kTPA *NH_3 Exports*

Kottayam

Alappuzha

Cluster Linking

Kollam

NH_3 production
Vizhinjam Port

Cluster extension

Vizhinjam Port

Ammonia Bunkering Fuel- Ships — *Bunkering*

Green Ammonia Exports — 100 kTPA GH_2 for 500+ kTPA GNH_3 *NH_3 Exports*

Other sectors — *HDVs, CGD*

Kochi Green H_2 valley is based on the end-use of Green Ammonia

with demand of 40 kTPA GH_2/260 kTPA GNH_3 in base and 71 kTPA GH_2/625 kTPA GNH_3 in aggressive case 2040

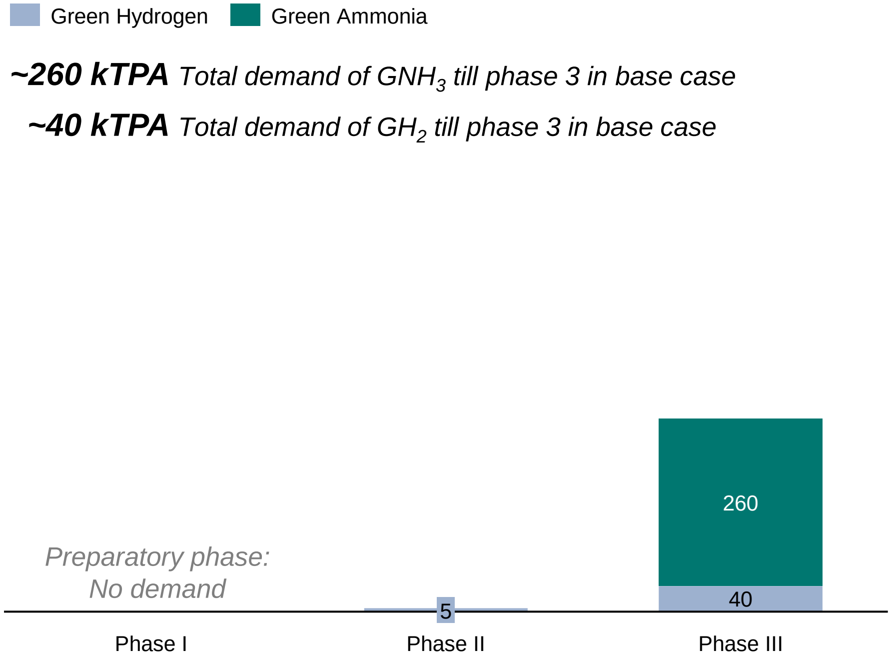
PRODUCT MIX FOR THE VALLEY | Demand for green hydrogen and green ammonia in the valley

In kTPA, Base and Aggressive Cases

Base Case

~260 kTPA *Total demand of GNH_3 till phase 3 in base case*

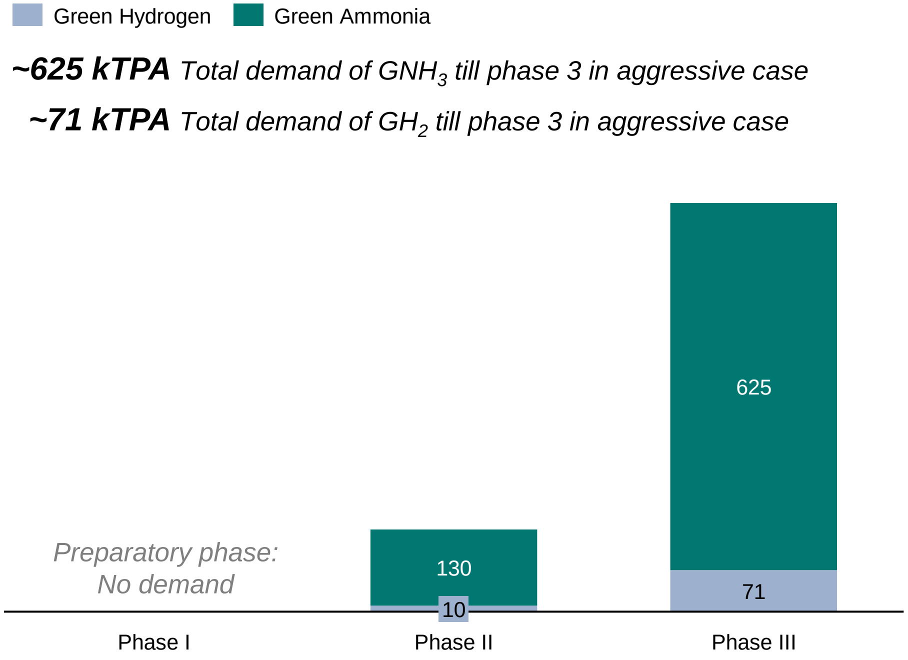
~40 kTPA *Total demand of GH_2 till phase 3 in base case*



Aggressive Case

~625 kTPA *Total demand of GNH_3 till phase 3 in aggressive case*

~71 kTPA *Total demand of GH_2 till phase 3 in aggressive case*



Source: Primary interviews; Annual reports; MEC+ analysis

…this translates to green hydrogen demand of 92 kTPA in base case

and 195 kTPA in aggressive case including exports

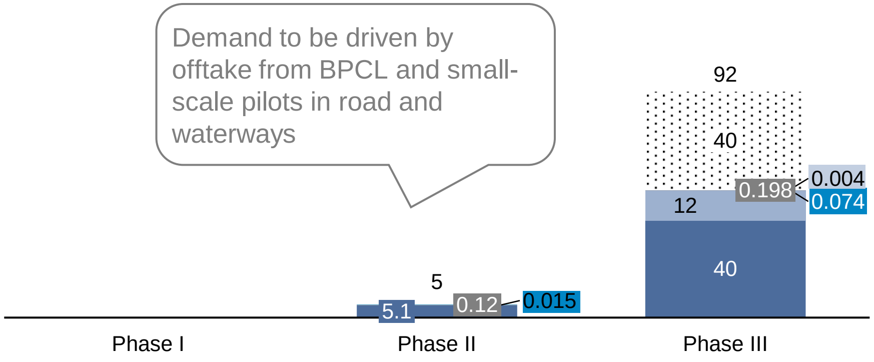
Sector-wise demand for green hydrogen valley

In kTPA, Base and Aggressive Cases

⁙ Export ▨ Chemicals ▨ Waterways ▨ Roadways (Buses) ▨ Fertilizers ▨ Refineries

Base Case

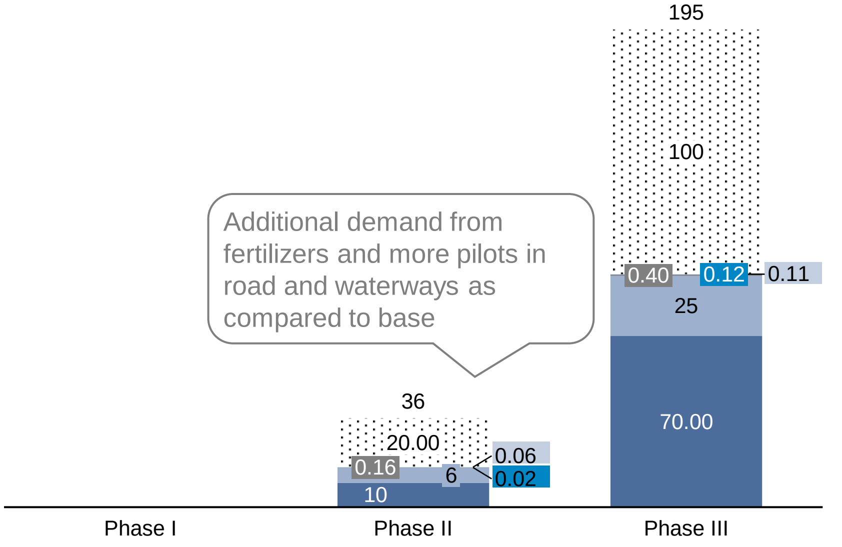
~92 kTPA *Total demand with exports till phase 3 in base case*



Demand to be driven by offtake from BPCL and small-scale pilots in road and waterways

Aggressive Case

~195 kTPA *Total demand with exports till phase 3 in aggressive case*



Additional demand from fertilizers and more pilots in road and waterways as compared to base

Source: Primary interviews; Annual reports; MEC+ analysis

Requiring to install 1 GW electrolyser in base case in 2040

and doubling to 2 GW electrolyser in aggressive case

Supply requirements for green hydrogen valley

Base and Aggressive Case cumulative numbers

		Base Case			Aggressive Case		
		Phase I	Phase II	Phase III	Phase I	Phase II	Phase III
Inputs	Renewable Energy	0.3 GW	0.5 GW	4.8 GW	0.3 GW	2.3 GW	10.3 GW
	Water		1.04 lakh KL	18.4 lakh KL		7.3 lakh KL	39.0 lakh KL
Hydrogen	Electrolyser		0.05 GW	0.9 GW		0.4 GW	2 GW
	Pipelines			14.1 km(NH_3) 12.4 km (H_2)		14.1 km(NH_3) 12.4 km (H_2)	14.1 km(NH_3) 12.4 km (H_2)
	Land Requirement		3.3 Acres	175.3 Acres		88.3 Acres	409.1 Acres
Other Infrastructure	Refuelling		400kg/day station	400kg/day x2 station		600kg/day station	1600kg/day station
	H_2 Refuelling Storage (kg)		400	800		600	1600
	Conversion Infra (NH_3)			296 kTPA NH_3 Plant		148 kTPA NH_3 Plant	706 kTPA NH_3 Plant
	H_2 Storage		16 tons	279 tons		110 tons	592 tons
	Vessels		1 Vessel	3 Vessel		1 Vessel	3 Vessel
	Buses		9 Buses	15 Buses		12 Buses	30 Buses

Note: Water considered at 20 litres/kg H_2; Land req. for H_2 & NH_3 production, refuelling station, pipeline and H_2 buffer storage considered. Area for pipeline and storage based on surface area and 10% buffer excludes land for substations (high level estimates); Vessel in Phase II (aggressive) to operate for more days in the year

Source: (Vattiata, 2023); ISPT; Iberdrola; Research Articles; MEC+ analysis

Valley to adopt the base case

As multiple challenges exist to adopt aggressive case in lines of policy interventions and steep decline in economics

Selection of base case | Criteria

Regulations

Adopting the aggressive case would need multiple regulatory interventions on:

- **Plant level mandates** on different sectors
- **Specific incentives** and support from government for offtake
- **Standards and certifications** to measure validity & safety of green hydrogen/derivatives

Currently in India, direct mandates for offtake of GH_2/derivatives do not exist at plant level and there are limited set of standards and certifications, hence, the offtake is expected to be slow favouring the base case

Economic Case

Shift towards a new technology renders challenges in terms of high costs when compared to:

- Incumbent carbon intensive fuel
- Alternate mature low carbon intensive technologies

Currently in India, small scale production of green hydrogen/derivatives is undertaken leading to comparatively higher costs which are expected to decline in future due to economies of scale and maturity in technology, hence, the initial offtake is expected to be slow favouring the base case

Technology readiness

Adopting the aggressive case would require high technology readiness via:

- Infrastructure development
- Process integration at small and large scale

Currently in India, these provision do not exist at scale and hence slow-paced offtake will be expected favouring the base case

The present scenario of regulatory, economic and technology landscape lowers the possibility of aggressive case leading to the **selection of base case for the development of the green hydrogen roadmap**

Source: MEC+ analysis

TOC

A phased approach is suggested for valley development

in base case, wherein initial phases are focussed on preparatory activities, phase II on pilots and phase III on scale-up

	2024-25 **Phase 1 | Preparation Phase**	2026-2030 **Phase 2 | Pilots phase**	2030-2040 **Phase 3 | Hub phase**
Policy design & stakeholder engagement	- Alignment of KL GH_2 policy to national policy and policies in refinery, fertilizers sectors - Capacity building & stakeholder engagement program - Creating standard & certification for H_2 production, transport, storage & refuelling infra; in line with international standards - International cooperation for joint learning on valleys	- Policy review & realignment	
Supply side & infrastructure	- Creating policy environment for supporting supply-side infrastructure (10-year period) including single window permitting and open access charges waiver - ANERT is the nodal agency for sector coupling via RE; creating shared HV Transformer, for ISTS import	- Expansion of role of ANERT to create hydrogen parks and all associated shared infrastructure for H_2 delivery - Individual and smaller electrolyser as per pilot demand - 1 centralised refuelling station in port	- Central production units at Port for economies of scale - Expansion of hub to Vizhinjam (Thiruvananthapuram)
Demand Side & investments	- Sector by Sector techno-commercial feasibility evaluations and funded innovation projects (e.g. CSL for innovation in vessel conversion) - Sector coupling for demand aggregation - Provision of 200 – 300 MW RE and development of transmission infrastructure	- 10% green hydrogen consumption obligation on refineries - Initiation of pilots – 9 buses to test both HICE and FCEV technologies, 1 barge on the Kochi to Kottayam route - Renewable energy and associated infrastructure	- Feedstock switch-over by refineries and fertiliser -10% to 100% adoption - Scaling up of road and waterways to 15 buses and 3 vessels & adoption in chemicals - Export of green NH_3/H_2 derivatives

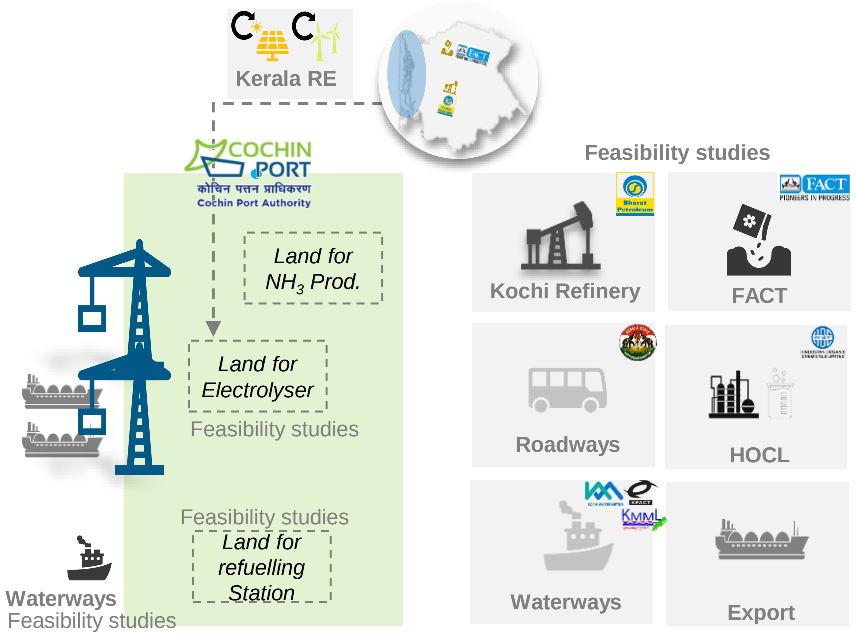
Source: MEC+ analysis

Phase I is the preparation phase for the valley

wherein sector-wise feasibilities are analysed, policies and standards are aligned, and offtake sectors are coupled through RE-RTC supply

Kochi Green Hydrogen Valley | Phase I

Visualisation



Kerala RE

Cochin Port Authority

Land for NH_3 Prod.

Land for Electrolyser

Feasibility studies

Feasibility studies

Land for refuelling Station

Waterways

Feasibility studies

Feasibility studies

Kochi Refinery

FACT

Roadways

HOCL

Waterways

Export

RE	200-300 MW	*Development of RE for sector coupling*
Electrolyser	📖	*Studies on resource availability and DPRs to be carried out for hydrogen production at Port*
Pipeline	📖	*Studies on material and feasibility of pipelines to be carried out*
Refuel	📖	*refuelling infrastructure requirement and possibilities of scaling up can be studied*
Refinery	📖	*Studies on the potential of BPCL as a centralised fuel supplier in the valley. DPR for setting up 5.1 kTPA GH_2 plant at Kochi Refinery*
Fertiliser	📖	*Studies on the minimum feasible size for GNH_3 unit that can integrate with the process. Studies on pipelines and technical feasibility*
Bus	📖	*Studies on the risks and challenges of green hydrogen, safety standards development and infrastructure requirement*
Boat	📖	*Studies and DPRs for barges in WCC, potential of coastal sea-going passenger vessels and infrastructural challenges*
Chemical	📖	*Studies on the viability of green hydrogen adoption in chemicals*
Export	📖	*Port infrastructure development, financing*

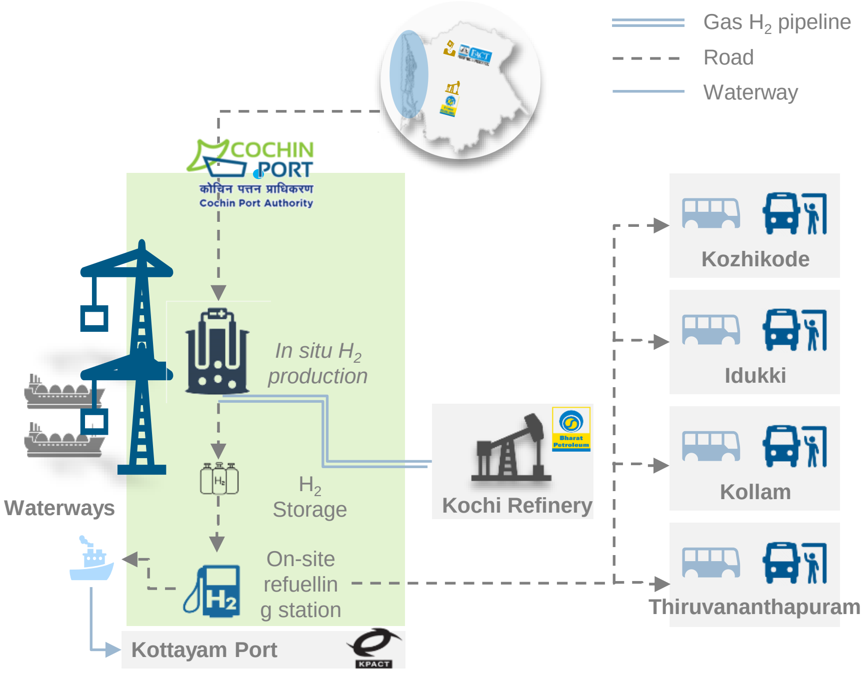
Source: MEC+ analysis

Phase II is the pilot phase for the valley

where common infra built for RE-RTC is extended for GH_2 pilot projects and demonstrations are taken up for 3 use-cases- transport in road & water, refinery

Kochi Green Hydrogen Valley | Phase II

Visualisation



RE		510 MW	*Cumulative RE required in Phase II. This demand can be met by using RE resources in Kerala*
Electrolyser		51 MW	*Pilot installation of small-scale electrolyser at the port*
Pipeline		12.4 KM	*Pipeline running from Cochin Port to BPCL*
Refuel		400 Kg/day	*refuelling station and storage (1 day) set-up at Port. To fulfill the requirements of buses and boats*
Refinery		5.1 kTPA	*Green hydrogen transported from the Port to refinery to meet min. 10% of the refinery demand in phase II*
Fertiliser		0 kTPA	*No demand from fertiliser sector*
Bus		0.12 kTPA	*FCEV and HICE buses to operate on long and medium distance routes. Phase II to have 9 buses operating on the defined routes*
Boat		0.015 kTPA	*1 Hydrogen powered barge to operate from Kochi to Kottayam Port to test the feasibility, scale up based on the traffic and result of pilot*
Chemical		0 kTPA	*No demand from chemical sector*
Export		0 kTPA	*If export picks up, Green Ammonia to be manufactured (NH_3 production infra to be set up) at port and exported to Europe and Asia*

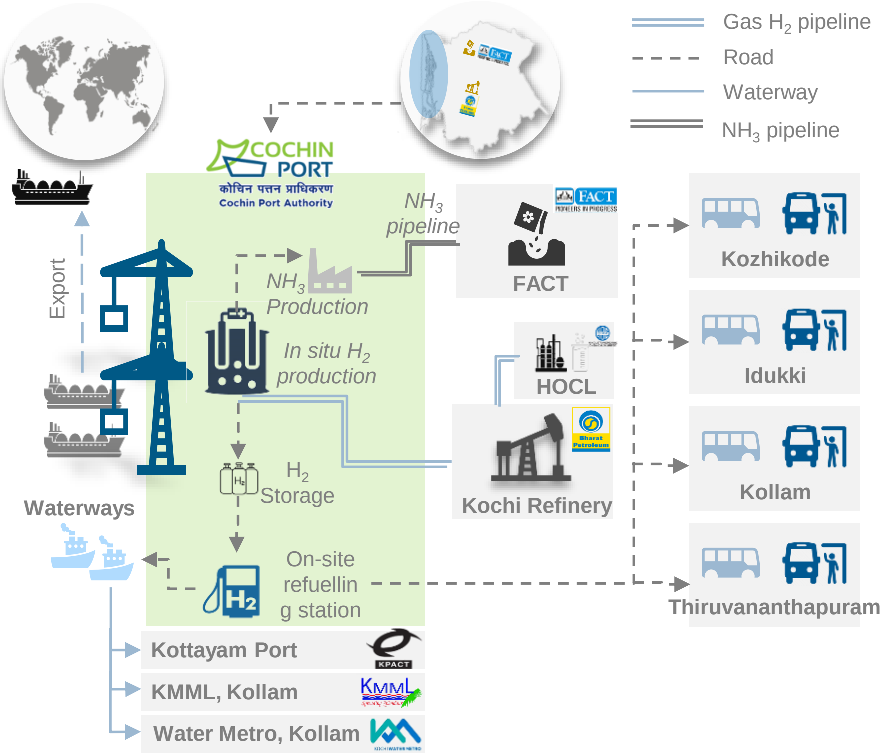
Source: MEC+ analysis

Phase III is the scale-up for the valley

with centralised electrolyser at port trunk infra coupling multiple end use sectors including refinery, fertiliser, road & water transport and chemicals

Kochi Green Hydrogen Valley | Phase III

Visualisation



RE	4.8 GW	*Cumulative RE required in the valley. Phase III additions to be sourced from outside Kerala*
Electrolyser	0.9 GW	*Cumulative electrolyser deployment in the valley. centralised hydrogen production in Port area*
Pipeline	27 KM	*Pipeline laid between Cochin Port and BPCL for the transportation of H_2 (~12.4km) and Cochin Port to FACT for LNH_3 (~14.1 km)*
Refuel	800 Kg/day	*refuelling station and storage (1 day) set-up at Port. To fulfill the requirements of buses and boats*
Refinery	39.6 kTPA	*Green hydrogen transported from the Port to refinery to meet min. 60% of the refinery demand in phase III*
Fertiliser	12.3 kTPA	*Green hydrogen transported from the Port to refinery to meet min. 30% of the demand at FACT in Phase III*
Bus	0.2 kTPA	*FCEV and HICE buses to operate on long and medium distance routes. Valley to have 15 buses operating in phase III*
Boat	0.07 kTPA	*Hydrogen powered barges to operate from Kochi to Kottayam & KMML (WCC) and sea-going fast vessels on coastal route (Kochi-Kollam)*
Chemical	0.004 kTPA	*Chemicals (HOCL) to use min. 1% green hydrogen in phase III*
Export	40 kTPA*	*If export picks up, Green Ammonia to be manufactured (NH_3 production infra to be set up) at port and exported to Europe and Asia*

Note: *Green Hydrogen Requirement for Ammonia production; LNH_3: Liquid Ammonia

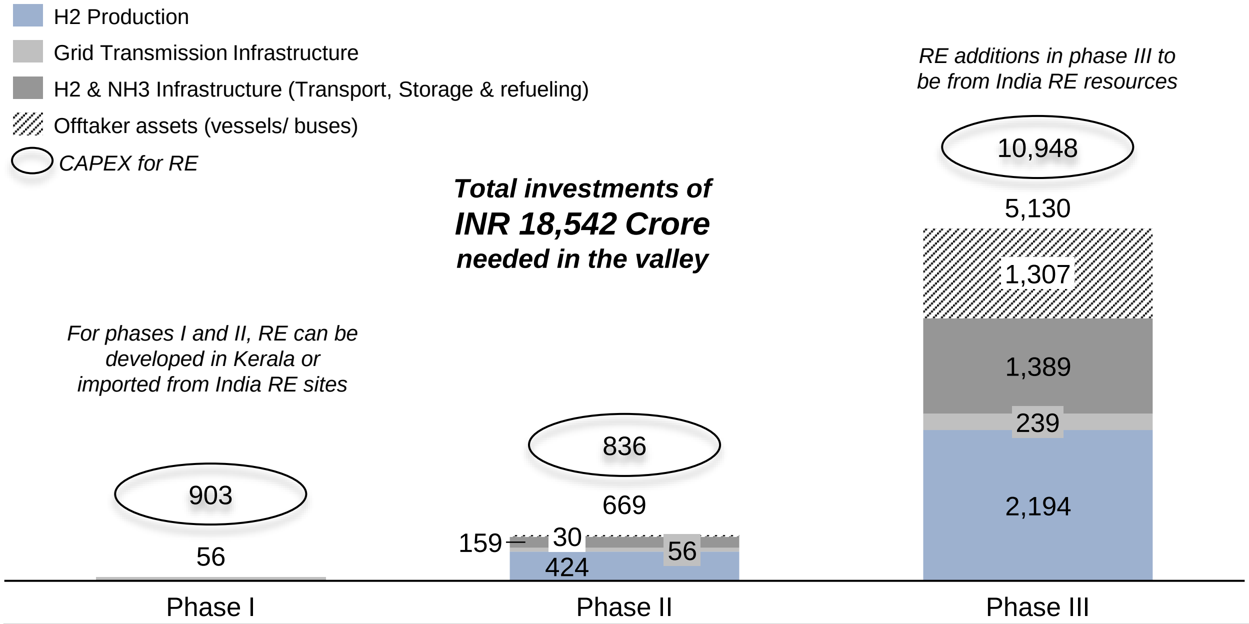
Source: MEC+ analysis

Development of valley will require significant CAPEX investment

669 Crores for pilots and additionally 5130 Crore in scale-up phase, excluding investments in RE

Capital Investment additions required by phases

In INR Crores



Total investments of INR 18,542 Crore needed in the valley

For phases I and II, RE can be developed in Kerala or imported from India RE sites

RE additions in phase III to be from India RE resources

- The valley would require an investment of INR 56, INR 669 and INR 5130 crores across the three phases leading to a cumulative investment of INR 5855 crores (Excl. Kerala RE)
- Phase I is majorly development of RE for industry electrification
- Phase II investments are focussed on RE development (KL RE) and deployment of electrolysers
- In Phase III, electrolyser scaling, ammonia plant and H_2 & NH_3 infrastructure are the major investments

RE includes cost of setting up Renewable Energy Plant | H_2 production includes cost of setting up electrolyser for hydrogen production | Transmission infrastructure includes the cost of substations and land required for substations | H_2 & NH_3 Infrastructure includes H_2 refuelling and storage, H_2 pipeline, H_2 buffer storage, NH_3 pipeline and NH_3 storage and land costs for H2, NH_3, H_2 storage, H2 pipeline and NH_3 pipeline | Offtake includes CAPEX for buses, boats and ammonia production facility (Haber Bosch and Nitrogen-ASU)

Note: Cost of RE in phase 2 is less than phase 1 due to decrease in RE CAPEX and minimal increase in RE volume

Source: Primary Interviews; Research Articles; MEC+ analysis

The 3 phases have different agendas

Phase 1 is based on conducting feasibility assessments, engagements; phase II for initiating pilots and Phase III for scaling up the valley with development of trunk infrastructure

Phase 1 (2024-25)

Preparation of green hydrogen clusters

- Assess: Conduct deep **sectoral feasibility studies** to test the viability of the project from different angles
- **Engage:** Create funds, mandates and technology confidence amongst stakeholders for participation in the valley
- **Incentivize:** Create taxation environment to incentivize/penalize emissions, create mobility in MLI funding for pilots
- **Regulation:** Create a nodal agency and single window clearances for governance and approvals
- **Setup:** Setup RE RTC through ANERT, create innovation fund for new sectors

Phase 2 (2026-2030)

Deployment of technologies for green hydrogen

- Commissioning of pilots as per the results of the feasibility studies to test various setups such as centralised vs distributed fuel supply
- Process adaptation & use of green hydrogen in industrial processes for refinery, fertiliser, chemicals
- Testing the pilots to understand the performance of technology and practical challenges in mobility and industrial sectors
- Initiation of commercial operations using green hydrogen

Phase 3 (2030-2040)

Upscaling of the use of green hydrogen in industry

- Programme for scaling hubs: Scaled replacement of feedstock to green hydrogen and creation of green highways and waterways
- Creation of integrated network for demand and supply for GH_2/GNH_3
- Upscale of the export facility and inclusion of innovation cluster demand sectors in the valley

Source: UNIDO; MEC+ analysis

Refinery sector – Phase I: 4 Feasibility Studies are Suggested

to assess various configuration of in-situ vs. offsite electrolyser, phase II has a pilot adoption, phase III envisions BPCL as the key off taker and participant in valley in 2040

Phase 1: Preparatory phase

Assess (DPR/ feasibility):

- Conduct feasibility of developing BPCL as GH_2 fuel supplier for the valley, supplying to FACT, refuelling hub. Check technical limitation, infra and financial limitations
- Create DPR for 5.1 kTPA and assess risk of stranded assets and cost impact
- Feasibility of BPCL- Port pipeline for hydrogen transport
- Infrastructure requirement for BPCL/ FACT/ export potential hub at Kochi with pipeline & storage

Engage:

- BPCL for centralised fuel supply set up
- Central govt. for refinery level mandates and funds
- Multilateral and trade bodies for funds
- NGOs

Incentivize/ Penalties

- Considerations on introduction of carbon pricing to be promoted
- Introduction of emission standards
- Financial mobilization for pilot funding with MLIs, global valleys

Regulation

- Designate ANERT as nodal agency
- Develop permitting process clarity and single-window clearance with ANERT
- Draft safety & standards
- Draft certification process for GH_2 verification
- Verification/ certification process of GH_2

Setup

- RE-RTC through ANERT

Phase 2: Pilot Phase

Pilots:

- Set-up 5.1 kTPA green hydrogen pilot in Kochi refinery for testing infrastructure requirements

Pilot objectives:

- In pilot, verify DPR assumptions on:
  - Energy & water requirements
  - Technology & process responsiveness
  - Infrastructure requirement
  - Costs- CAPEX, OPEX, DEVEX & Cost development trajectories
  - Power production profile actual vs. expectation
  - Need for buffer storage
  - Manpower requirement, need for re-skilling & training
  - Permitting requirement & agencies involved
  - Finalize ability to make BPCL as central production unit for valley

Organisation requirement:

- Set-up department for co-ordination with ANERT | Technical team to be set-up
- Set-up PMU for pilot monitoring & evaluation

Phase 3: Valley Phase

Possible development directions:

- Scale for 50-100% feedstock change-over
- Creating integrated network for supply for GH_2 in the valley through BPCL

Vision:

- Two pathways for BPCL to develop fully for self-supply ramp-up or to further scale-up and develop as the central fuel supplier for the multiple use-cases in the valley | BPCL might consider being part of the JV that might come up in the valley

Note: DPR: Detailed Project Report; CAPEX: Capital Expenditure; OPEX: Operational Expenditure; DEVEX: Development Expenditure; PMU: Project Management Unit

Source: MEC+ analysis

Fertiliser sector – Phase I: Integration Studies are required

to understand the technicalities of the process, however, there is no pilot in phase II with direct adoption in scale-up phase, given the dynamics of minimum viable GNH_3 plant

Phase 1: Preparatory phase

Assess (DPR/ feasibility):
- Conduct feasibility study for minimum feasible size of GNH_3 unit that can integrate with the process
- Assessment of impact of green hydrogen substitution of natural gas import on energy efficiency targets
- Assess of feasibility to link FACT via H_2 pipeline
- Impact assessment for economics, technology, CAPEX and social benefits

Engage:
- FACT for centralised NH_3 supply set up
- Central govt. for mandates (NPK) and funds, inclusion of GH_2 in the PAT scheme
- Multilateral and trade bodies for funds
- EXIM companies
- NGOs

Incentivize/ Penalties
- Considerations on carbon pricing
- Introduction of emission standards
- Financial mobilization for pilot funding with MLIs

Regulation
- Designate ANERT as nodal agency
- Develop permitting process clarity and single-window clearance with ANERT
- Draft safety & standards
- Draft certification process for GNH_3 verification

Setup
- Infrastructure for RE-RTC through ANERT for FACT green power supply (20 MW)

Phase 2: Pilot Phase

No pilot for fertiliser sector, in base case with green ammonia export opening in phase III and catering to fertiliser sector.

If mandates are to be enacted in aggressive case, FACT may pilot small scale GNH_3 plant, based on feasibility study results. To test:
- Energy & water requirements
- Technology & process responsiveness
- Infrastructure requirement | impact on life of equipment
- Costs- CAPEX, OPEX, DEVEX & Cost development trajectories
- HSE requirements and incidents (leakages, waste handling etc.)
- Power production profile actual vs. expectation
- Transport of ammonia using barges
- Need for buffer storage
- Manpower requirement, need for re-skilling & training
- Permitting requirement & agencies involved

Phase 3: Valley Phase

Possible development directions:
- Scale for 18-36% feedstock change-over
- Explore network to upscale production (other fertiliser units)
- Explore export for green ammonia
- Explore green ammonia bunkering at Kochi/ Vizhinjam

Vision:
- FACT is an anchor consumer sourcing H_2 fuel at competitive rates by providing scale to the plant being set-up in Kochi and participate in new JV that might come-up

Source: MEC+ analysis

Road Transport – Phase I: 4 Feasibility Studies are Suggested

along with development of safety standards for passenger transport use case; 9 buses to run pilots

Phase 1: Preparatory phase

Assess (DPR/ feasibility):
- Risk and safety considerations in buses, disaster management principles and skill building
- Technical and commercial feasibility of complete electrification of KSRTC fleet | challenges & infra requirement | RE-RTC required for electrification
- Infra requirement for scaling H_2 supply from central node to decentral H_2 supply
- Standards for buses and refuelling infra

Engage:
- KSRTC- build confidence with commitment for CAPEX for pilots & securing funds
- Cochin Port for refuelling infra
- State government for creating time-bound decarbonisation targets & mandate for road sector
- Multilateral and trade bodies for funds
- Manufacturers of HICE, FCEV, refuelling infra
- NGOs

Incentivize/ Penalties
- Introduction of emission standards
- Financial mobilization for pilot funding with MLIs

Regulation
- Designate ANERT as nodal agency
- Draft safety & standards

Setup
- RE-RTC through ANERT for EV chargers
- Innovation Fund: Assess proposals for award of fund for demonstrations in innovative use case*

Phase 2: Pilot Phase

Pilots:
- Setup 9 buses with mix of HICE & FCEV technology
- Build centralised refuelling infra at port/ KMRL high court station
- Test 1 decentralised refuelling station with transport infra

Pilot objectives:
- In pilot, verify DPR assumptions on:
    - Unit economics of HICE vs. FCEV
    - Ranges in single fuelling
    - CAPEX and OPEX considerations
    - Need for manpower & skill building | cost of maintaining three technologies in the valley (EV, HICE, FCEV)
    - Environmental impact of CO2 abatement as well as SOX/NOX comparison in HICE
    - HSE requirement for HICE; fuel handling; disaster management
    - Pathways to build decentral refuelling infra and optimization of size, also storage vs. exchange of cylinders

Organisation requirement:
- Set-up department for co-ordination with ANERT
- Training & skilling- operators and maintenance workforce
- Set-up PMU for pilot monitoring & evaluation

Phase 3: Valley Phase

Possible development directions:
- Scale for 15-30 buses running long-routes
- Develop optimal set-up for refuelling strategy and set-up

Vision:
- Achieve green coastal and road highway by 2040 through mix of EV on short-routes, HICE on medium routes and FCEV on longest routes
- Develop infra in Kochi-Trivandrum hub and along the route

Note: * Innovative use case for the valley such as HICE retrofits in existing assets, FCEV bus/ component manufacturing, new tech in H_2 mobility

Source: MEC+ analysis

Waterways – Phase I: Infrastructure Requirement Studies

to understand challenges; followed by pilots in phase II and scale up based on the success of pilots in phase III

Phase 1: Preparatory phase

Assess (DPR/ feasibility):
- DPR for 1 boat (cargo) using bus refuelling infrastructure | Comparison of Kochi to Kollam vs. Kochi to Kottayam route)
- Build 2nd DPR with Water metro for 1 fast ferry (sea-going) from Kochi to Kollam
- Assess potential of coastal shipping in Kerala (passenger vs. cargo) and readiness status
- Assess RE RTC requirements of EV ferries
- Socio-economic impacts of transport through water-ways, impact on fishing communities

Engage:
- Possible Operators: Kochi Water Metro, KSINC and users KMML, Kottayam port & Kochi Port
- KMB & State Government for vision and target of coastal shipping
- Multilateral funding; central govt for designated FCEV pilots NGOs (especially coastal community linked)
- Cochin Shipyard & KPIT for vessels

Incentivize/ Penalties
- Lower taxation in waterways for initial phase
- Financial mobilization for supporting pilot

Regulation
- Designate ANERT as nodal agency
- Draft safety & standards
- Target for switch of traffic from road to water ways; State owned enterprise to have target for %age cargo through waterway

Phase 2: Pilot Phase

Pilots:
- Run 1 cargo barge as per feasibility report with KSINC/ KMML or Kottayam port or run 1 fast passenger ferry to Kollam with water metro
- Test run in coastal canal for operational challenges
- Use bus refuelling station in Cochin port

Pilot objectives:
- In pilot, verify DPR assumptions on:
  - Unit economics of FCEV
  - Design considerations
  - Finalize optimum routes

Organisation requirement:
- Set-up department for co-ordination with ANERT
- Set-up PMU for pilot monitoring & evaluation

Phase 3: Valley Phase

Possible development directions:
- Scale in line with coastal shipping vision of the government
- Extend from Kollam to Trivandrum covering Kochi to Trivandrum route (200 kms)
- Scale refuelling station at port to meet requirement
- Develop second refuelling in Trivandrum (Vizhinjam)

Vision:
- Run Coastal route and national waterway (WCC) with FCEV
- Develop refuelling integrated infra within Kochi/ Trivandrum route

Note: WCC: West Coast Canal; RE-RTC for water metro & feeder bus fleet; Build 1 FCEV barge & 1 FCEV fast ferry with cochin shipyard & KPIT Innovation fund; Assess proposal projects innovative use-case & demonstrations, including houseboat retrofit, mfg. of vessels, tech innovation in H_2 mobility; award fund through bid

Source: MEC+ analysis

Green NH_3 Export

Phase I & II to focus on infrastructure, standards and asset development leading to exports in phase III

Phase 1: Preparatory phase

Assess (DPR/ feasibility):
- Infra requirement for setting up port infrastructure at the port of Kochi and Vizhinjam
- Ability to supply Green H_2 from grid connection and the infra for electrical assessment, Identify land that can be given near S/s & competing use

Engage:
- Department fundings available for port infrastructure development
- Funding available for augmenting the electricity infrastructure and create a separate GH_2 corridor around port of Kochi and Vizhinjam
- NGO and local port communities on the space requirements and HSE, ESG requirements
- Incentivize/ Penalties
- Specify the waivers on land, water, electricity
- Specify the extent of banking and the amount by providing clarity on the financial outlay for providing banking & no. of years

Regulation
- Designate ANERT as nodal agency
- Develop permitting process clarity and single-window clearance with ANERT
- Draft safety & standards
- Draft certification process for green NH_3
- Draft plan to monitor the implementation of the project when the project incentives scale down

Setup
- Infra for RE-RTC power, water for Vizhinjam

Phase 2: Pilot Phase

Infrastructure
- Storage Infrastructure
- Port Infrastructure
- Trunk Infrastructure

Assess
- Identify extent of ROW to port and the upgrade needed
- Assess incentives
- Assess the export proposals received by the Kerala Government

Phase 3: Valley Phase

Possible development directions:
- Create a central hub for export and supply

Vision:
- Vizhinjam and Kochi port become major fuel supplier on the south west coast of India

Note: We have not deep dived in phase development of chemicals sector given it is a very fringe sector

Source: MEC+ analysis

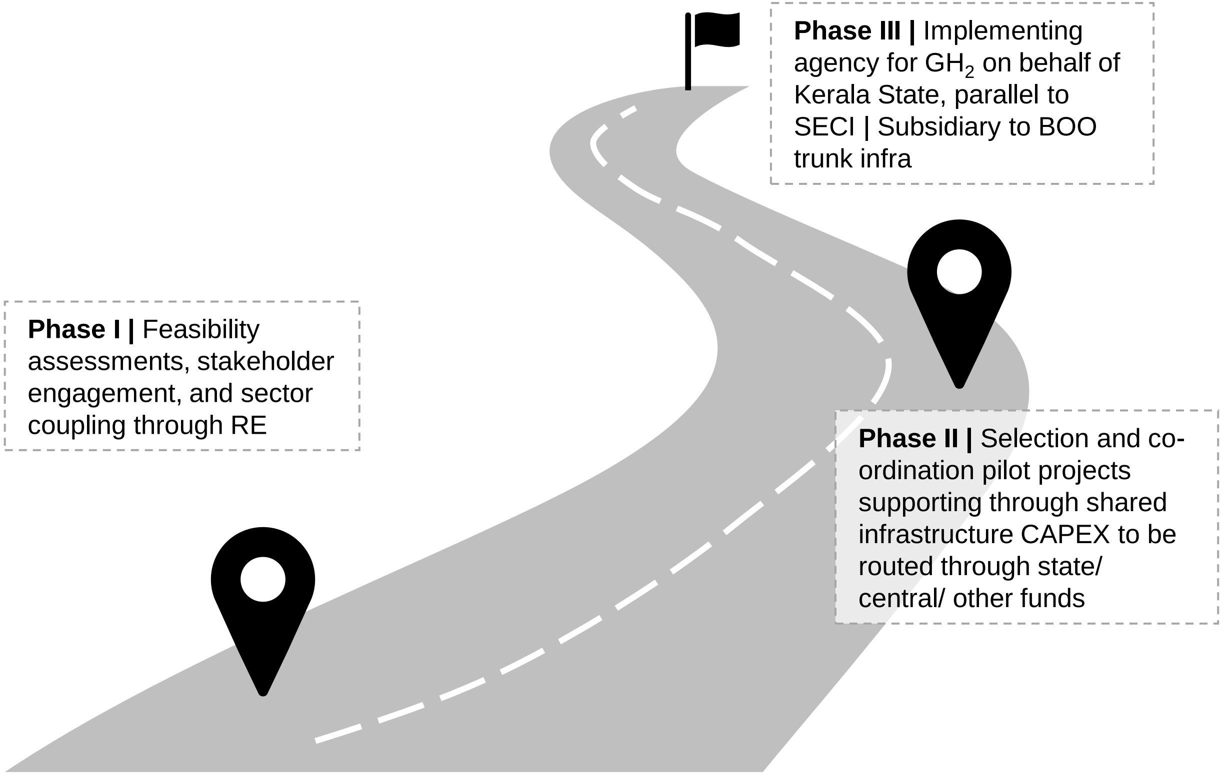
TOC

Nodal agency is required – ANERT most suitable

To perform preparatory activities in phase I, support pilot infra in phase II and as implementing agency in phase III | ANERT most suitable to play the roles

Nodal Agency

- The valley requires a nodal agency to be able to co-ordinate the activities across sectors and across the value-chain needed to develop a successful hydrogen valley
- State nodal agencies have a role of ensuring implementation of central and state programmes related to clean energy, hence ANERT is well-positioned to take on the role for green hydrogen valley activities
- The Department of Science and Technology has designated RE nodal agencies as the nodal agency for Hydrogen Valley Innovation Clusters, hence ANERT's role will align with the objective



Phase I | Feasibility assessments, stakeholder engagement, and sector coupling through RE

Phase II | Selection and co-ordination pilot projects supporting through shared infrastructure CAPEX to be routed through state/ central/ other funds

Phase III | Implementing agency for GH_2 on behalf of Kerala State, parallel to SECI | Subsidiary to BOO trunk infra

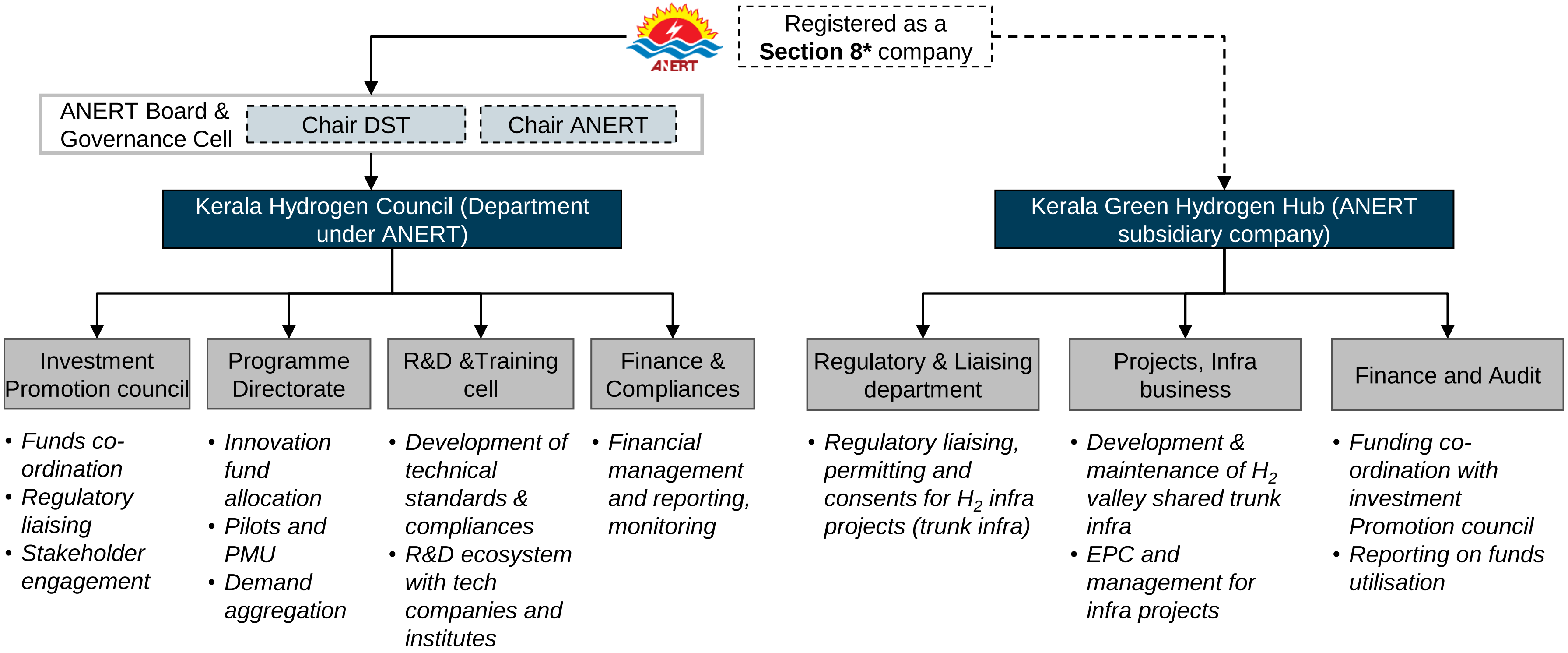
Note: PMU- Project Management Unit; trunk Infrastructure related to common infra such as pipeline, grid, refuelling etc.

Source: Interviews with ANERT; MEC+ analysis

ANERT to Register as Section 8 & Establish Hydrogen Department

separately asset hold-co to be created as an ANERT subsidiary company for shared infra creation

Suggested organisation structure and governance model



Registered as a **Section 8*** company

ANERT Board & Governance Cell

Chair DST

Chair ANERT

Kerala Hydrogen Council (Department under ANERT)

Kerala Green Hydrogen Hub (ANERT subsidiary company)

Investment Promotion council
- *Funds co-ordination*
- *Regulatory liaising*
- *Stakeholder engagement*

Programme Directorate
- *Innovation fund allocation*
- *Pilots and PMU*
- *Demand aggregation*

R&D &Training cell
- *Development of technical standards & compliances*
- *R&D ecosystem with tech companies and institutes*

Finance & Compliances
- *Financial management and reporting, monitoring*

Regulatory & Liaising department
- *Regulatory liaising, permitting and consents for H_2 infra projects (trunk infra)*

Projects, Infra business
- *Development & maintenance of H_2 valley shared trunk infra*
- *EPC and management for infra projects*

Finance and Audit
- *Funding co-ordination with investment Promotion council*
- *Reporting on funds utilisation*

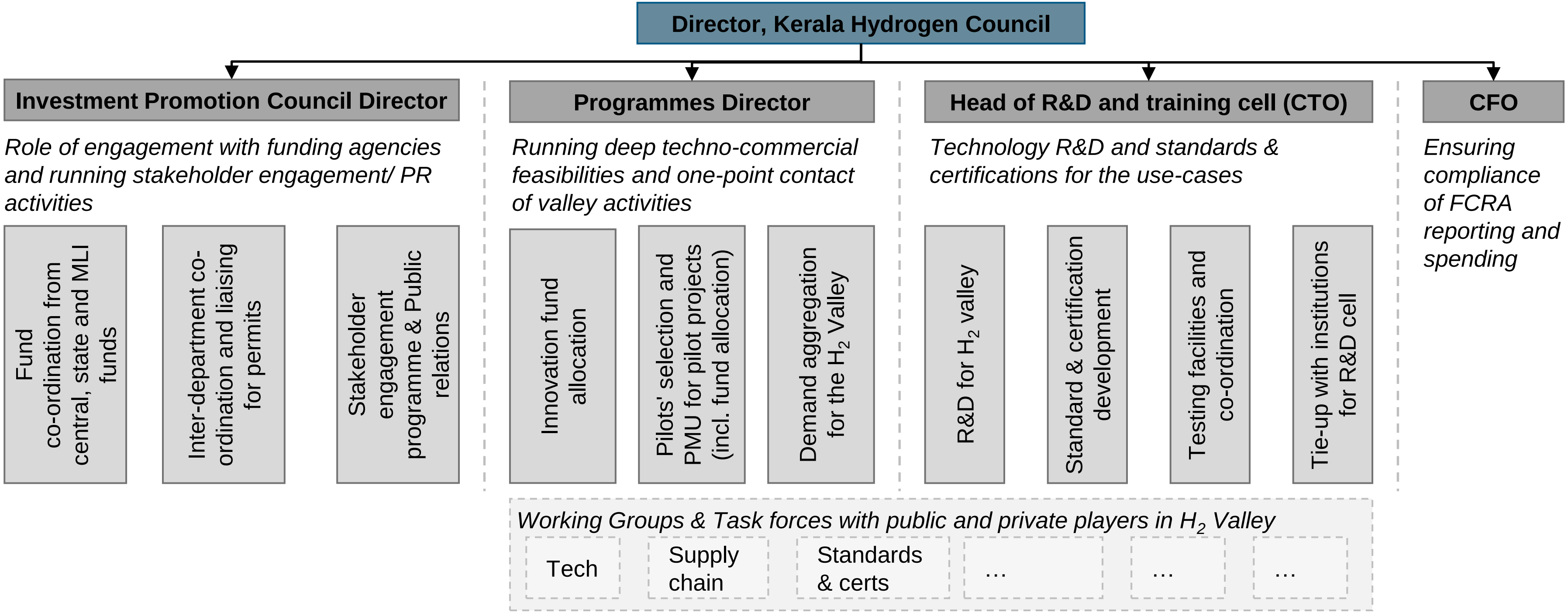
Note: *ANERT to be registered as Section 8 company- non-profit; trust deed needed with one of the stated objectives linked to dev. of hydrogen economy in Kerala

Source: Interviews with ANERT; Transmission companies in India – organisation structure; MEC+ analysis

Kerala Hydrogen Council to be structured in 4 functions;

investment promotion council, programmes directorate, R&D and training cell, and compliances department

The Kerala Hydrogen Council will be responsible for achievement of Kerala Hydrogen-related objectives, fund co-ordination, demand aggregation, supporting R&D and training programs as well as reporting and monitoring



Director, Kerala Hydrogen Council

Investment Promotion Council Director

Role of engagement with funding agencies and running stakeholder engagement/ PR activities

- Fund co-ordination from central, state and MLI funds
- Inter-department co-ordination and liaising for permits
- Stakeholder engagement programme & Public relations

Programmes Director

Running deep techno-commercial feasibilities and one-point contact of valley activities

- Innovation fund allocation
- Pilots' selection and PMU for pilot projects (incl. fund allocation)
- Demand aggregation for the H_2 Valley

Head of R&D and training cell (CTO)

Technology R&D and standards & certifications for the use-cases

- R&D for H_2 valley
- Standard & certification development
- Testing facilities and co-ordination
- Tie-up with institutions for R&D cell

CFO

Ensuring compliance of FCRA reporting and spending

Working Groups & Task forces with public and private players in H_2 Valley

- Tech
- Supply chain
- Standards & certs
- …
- …
- …

Source: Primary discussions; MEC+ analysis

Kerala Hydrogen Council to play a pivotal role across phases

moving from role of fund aggregation and valley activities co-ordination body in phase I to Kerala's coordination authority for GH_2 *projects in phase III*

Department	**Phase I | Preparation Phase 2024-2025**	**Phase II | Pilot Phase 2026-2030**	**Phase III | Valley Phase 2030+**
Investment Promotion Council	• Aggregation of funds from various sources including central & state govt., trade bodies, multi-lateral institutes for funding valley activities • Co-ordinating stakeholder engagement activities	• Continuing fund aggregation and stakeholder engagement • … additionally acting as one-stop shop for all regulatory liaising requirements on pilots as well as shared infrastructure in the valley through inter-department footwork	• Transition into the implementation agency (SECI) for Green hydrogen projects in Kerala State, including role of: • Fund co-ordination • Demand aggregation • Auctions for project selection towards aggregated demand • Project monitoring and resolution of challenges
Programme Directorate	• Running the innovation fund for award of funds to low maturity tech demonstrations • Selection and award of feasibility studies required for preparation of valley, one-point contact for knowledge partners	• Selection of pilots in line with valley roadmap and objectives • Project monitoring Unit (PMU) set-up to monitor progress of pilots, address challenges and collate results | co-ordination with relevant pilot outside Kerala	
R&D and technology cell	• Supporting creation of technical documentation related to safety, standards, certification and testing in the valley • Co-ordination between state, national and international labs/ institutions related to research and innovation, knowledge management and new technology development • GH_2 cluster partnerships via ANERT with GH_2 valleys in Germany & EU countries • Development of training program & skilling for manpower needed in the valley		• Evolution of standards & certifications in line with technology trends • Equipment testing facilities for ensuring safety and compliance in the valley
Compliances	• Executing all functions related to financial audit, reporting and monitoring in line with FCRA requirements		

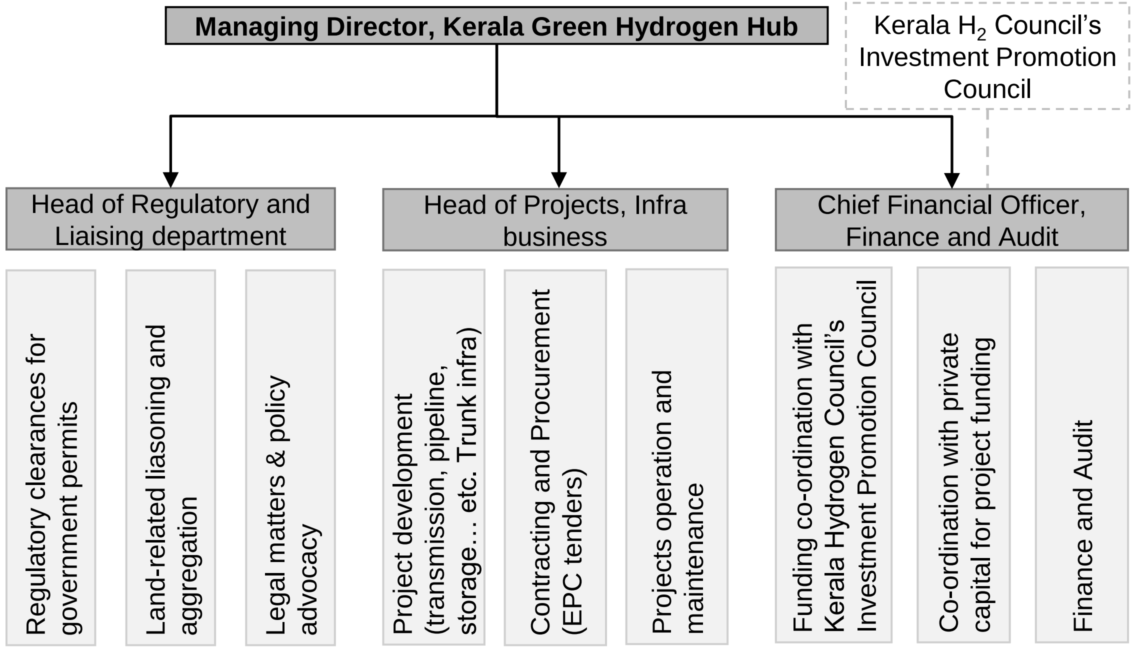
Source: Primary discussions; MEC+ analysis

KGHH to develop as a subsidiary company

with core function of developing trunk infrastructure projects to create shared assets for the valley

The Kerala Green Hydrogen Hub (KGHH) will be a subsidiary company of ANERT functioning as an asset hold-co, holding all shared infrastructure CAPEX and projects on its balance sheet. The subsidiary to function as a large infrastructure development company

Organisation Structure



Managing Director, Kerala Green Hydrogen Hub

Kerala H_2 Council's Investment Promotion Council

- Head of Regulatory and Liaising department
  - Regulatory clearances for government permits
  - Land-related liasoning and aggregation
  - Legal matters & policy advocacy
- Head of Projects, Infra business
  - Project development (transmission, pipeline, storage… etc. Trunk infra)
  - Contracting and Procurement (EPC tenders)
  - Projects operation and maintenance
- Chief Financial Officer, Finance and Audit
  - Funding co-ordination with Kerala Hydrogen Council's Investment Promotion Council
  - Co-ordination with private capital for project funding
  - Finance and Audit

Projects to be taken up by KGHH

Phase I	Owning and operating 400kV/220kV substation for 200-300 MW RE aggregation
Phase II	Owning and operating trunk infra structure for pilots including buses, boats, pipeline and central refuelling station
Phase III	Owning and operating trunk infrastructure for all shared infra needed in the valley including pipeline, refuelling station, mobility assets etc.

Source: Primary discussions; MEC+ analysis

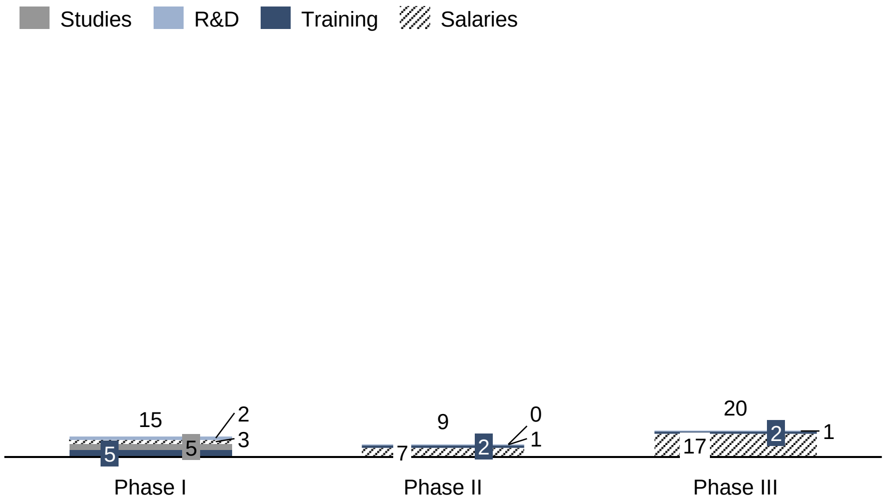
Investments in the valley are carried out by Council and Subsidiary

Council allocates funds for feasibility studies, R&D, training and manpower; Subsidiary allocates funds for infrastructure and offtake

Bifurcation of Government Spending

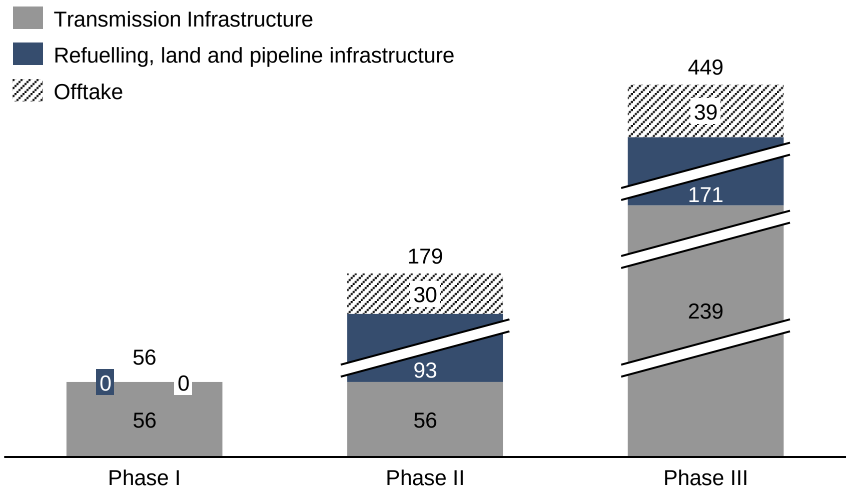
In INR Crore

COUNCIL



Investments by the council are towards feasibility studies in the different sectors, Research and development expenditure (for CDAC, CSIR and IIT Palakkad), training material, trainer training and salaries for the employees

SUBSIDIARY



Subsidiary to spent on transmission infrastructure, land, H_2 and NH_3 pipeline infrastructure, refuelling stations and capex in offtake sectors like buses and boats

Note: Spent on R&D to include allocations to Cochin Shipyard; Salaries considered for 6,8 and 10 employees

Source: Govt. of Kerala; MEC+ analysis

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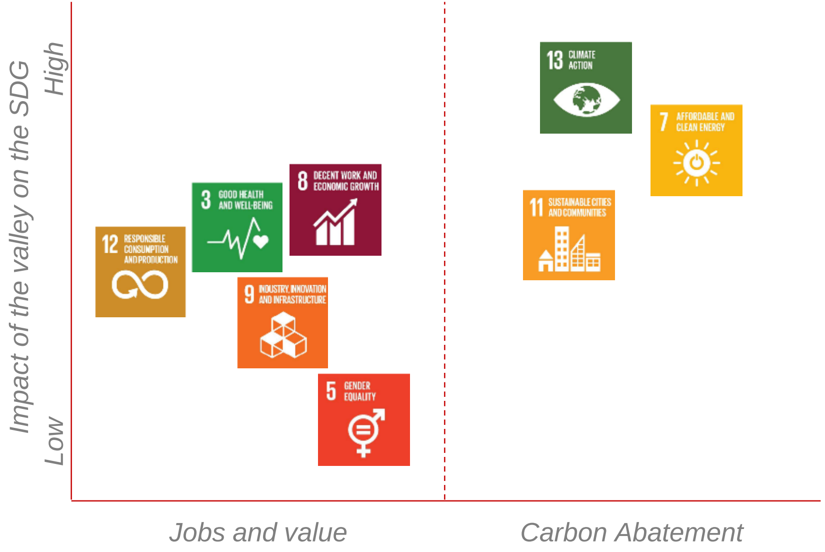
Sustainable Development Goals

Valley to impact 8 SDGs enabling socioeconomic development through employment, value addition and CO_2 abatement



- Sustainable Development Goals were adopted in 2015 as a universal call to action to end poverty, protect the planet and ensure by 2030 that all people enjoy peace and prosperity
- The valley to impact 8 out of the 17 sustainable development goals

The valley with the use of green hydrogen will lead to positive climate action, development of clean energy, sustainable mobility options, opportunities for jobs, economic growth and development of infrastructure in the region

Note: Image credit: Azote Images for Stockholm Resilience Centre; UNDP

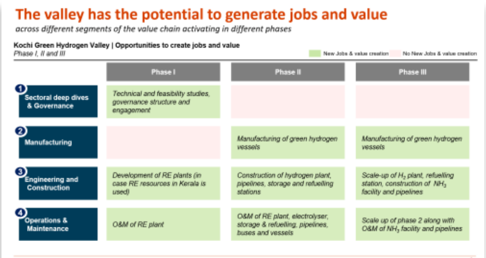
Source: UN SDG; UNDP; MEC+ analysis

Socioeconomic Impact of the Kochi Green Hydrogen Valley

could be seen through 3 indicators; employment generation, value added to economy and carbon abatement

Parameters to assess the socioeconomic impact of the green hydrogen valley

Employment Generation



The valley has the potential to generate jobs and value

across different segments of the value chain activating in different phases

Kochi Green Hydrogen Valley | Opportunities to create jobs and value

Phase I, II and III

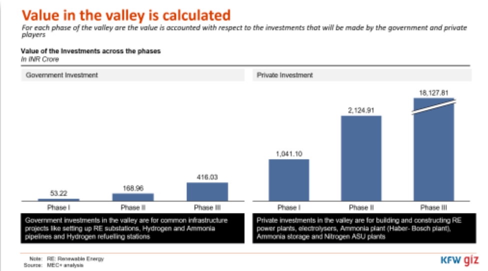
🟩 New Jobs & value creation 🟥 No New Jobs & value creation

	Phase I	Phase II	Phase III
① Sectoral deep dives & Governance	*Technical and feasibility studies, governance structure and engagement*	🟥	🟥
② Manufacturing	🟥	*Manufacturing of green hydrogen vessels*	*Manufacturing of green hydrogen vessels*
③ Engineering and Construction	*Development of RE plants (in case RE resources in Kerala is used)*	*Construction of hydrogen plant, pipelines, storage and refuelling stations*	*Scale-up of H_2 plant, refuelling station, construction of NH_3 facility and pipelines*
④ Operations & Maintenance	*O&M of RE plant*	*O&M of RE plant, electrolyser, storage & refuelling, pipelines, buses and vessels*	*Scale up of phase 2 along with O&M of NH_3 facility and pipelines*

Note: Within sectoral deep-dives and Governance additional jobs created in phases II and III are minimal hence not considered
Source: MEC+ analysis

- The employment generation of Kochi Valley is assessed based on the job creation potential of different value chain activities of green hydrogen and their different lifecycle stages
- The valley would generate **~3600 jobs cumulatively with more than 80% of the jobs being generated during the construction phase**

Value Added



Value in the valley is calculated

For each phase of the valley are the value is accounted with respect to the investments that will be made by the government and private players

Value of the Investments across the phases

In INR Crore

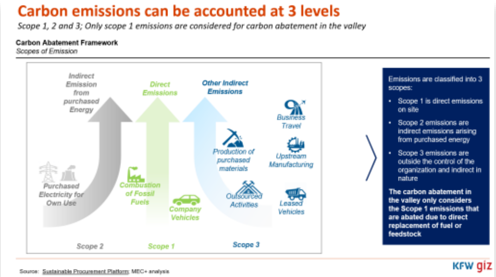
Government investments in the valley are for common infrastructure projects like setting up RE substations, Hydrogen and Ammonia pipelines and Hydrogen refuelling stations

Private investments in the valley are for building and constructing RE power plants, electrolysers, Ammonia plant (Haber- Bosch plant), Ammonia storage and Nitrogen ASU plants

Note: RE: Renewable Energy
Source: MEC+ analysis

- The value in the Kochi Valley is assessed based on the total investments that would be done by both the Government and Private players over the different phases of the valley
- The valley would have a net **present value of 20832 INR Crore in the across the different phases of the valley**

Carbon Abatement



Carbon emissions can be accounted at 3 levels

Scope 1, 2 and 3; Only scope 1 emissions are considered for carbon abatement in the valley

Carbon Abatement Framework

Scopes of Emission

Emissions are classified into 3 scopes:

- Scope 1 is direct emissions on site
- Scope 2 emissions are indirect emissions arising from purchased energy
- Scope 3 emissions are outside the control of the organization and indirect in nature

The carbon abatement in the valley only considers the Scope 1 emissions that are abated due to direct replacement of fuel or feedstock

Source: Sustainable Procurement Platform; MEC+ analysis

- The carbon abatement potential of the Kochi Valley is measured based on the potential demand of green hydrogen in different sectors and the amount of CO_2 emissions it can prevent
- The Kochi Valley has the potential to **abate up to 0.49 $MtCO_2e$ by 2040, this can bring down the total emissions by 2% from 2018 levels**

Note: SDG: Sustainable Development Goal
Source: MEC+ analysis

Jobs and value additions are assessed

From RE production to offtake of green hydrogen at different lifecycle stages

Framework | Assessment of Jobs and value addition in the green hydrogen value chain
Value chain and lifecycle stages

			Value-chain of the proposed hydrogen valley			
Lifecycle of Different value chain components		**Renewable Energy**	**Hydrogen Production**	**Transportation & Storage**	**Refuelling Stations**	**Sectoral Offtake of green hydrogen**
Sectoral deep-dives & Governance	*Technology experts, Consultants, policy experts, finance, engineers*	Feasibility studies, technical studies, safety and standards, project financing, DPRs for pilots, stakeholder awareness				
		Governance Structure, selection of committee, engagement plans				
Engineering Manufacturing Construction	*Engineers, site managers, logistics, plant managers workers, contract labourers*	Substations Manufacturing	Electrolyser Manufacturing	Pipeline Manufacturing & Installation	Compression systems & Storage	H_2 Vessel Manufacturing
		RE Equipment Manufacturing	H_2 Production Plant Installation	Pressurized Storage Tanks		Conversion to Ammonia
		RE Transmission infra development				H_2 Bus Deployment
		Installation/Deployment of RE, electrolyser, pipelines, refuelling stations etc				
Operations & Maintenance	*Facility managers, equipment operators, bus and vessel operators, Administrative and management staff*	Operations and Maintenance of Equipment (Solar Panels, Wind Turbines, Electrolysers, Pipelines, refuelling stations etc)				Buses and Vessels O&M
						O&M for conversion facility (NH_3)

Source: South Africa Hydrogen Valley; MEC+ analysis

The valley has the potential to generate jobs and value

across different segments of the value chain activating in different phases

Kochi Green Hydrogen Valley | Opportunities to create jobs and value

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Note: Within sectoral deep-dives and Governance additional jobs created in phases II and III are minimal hence not considered

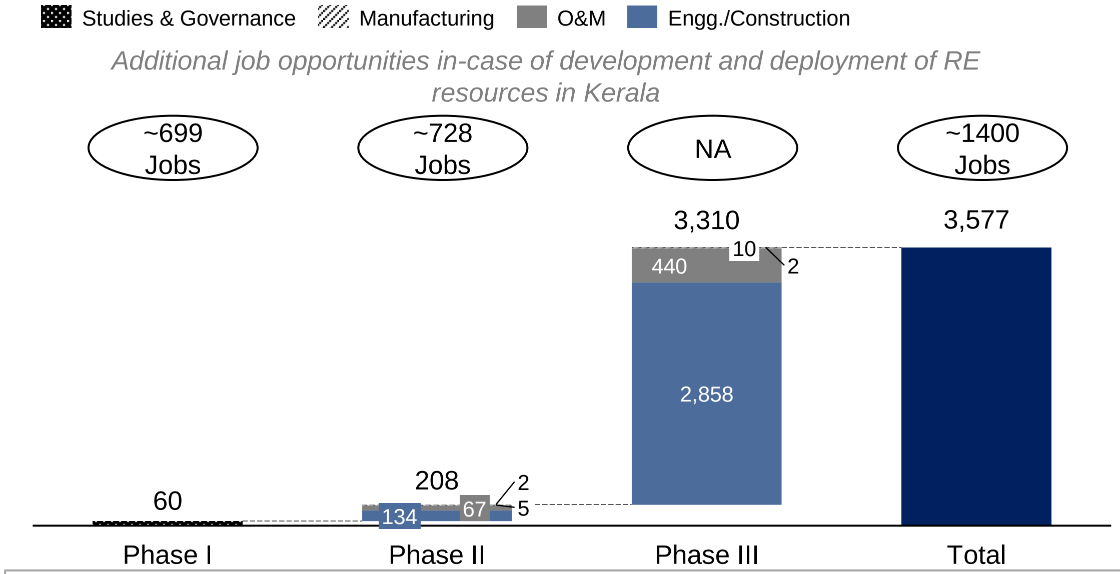
Source: MEC+ analysis

The valley has the potential to create ~3600 jobs in total

with majority of the jobs created in the construction phase

Kochi Green Hydrogen Valley | Jobs Created (cumulative)

Jobs by Activity



The valley has the potential to cumulatively create ~3600 jobs with **more than 80% of the jobs created in the construction activities in the valley**

Additionally, development and use of **Kerala RE** resources in phase I and II can cumulatively create **~1400 more jobs**

Notes and Assumptions: Jobs refer to number of people required for a specified time-period and not total job years/FTEs. Time periods can vary for construction jobs between 6 months to 2 years (2 years for electrolyser plant installation, 1.5 years for ammonia plant, 1 year for storage and vessel manufacturing, 6 months for refuelling stations) | Feasibility studies to span between 3 to 6 month | All O&M activities considered across the lifetime of the asset | RE evacuation infrastructure (site level) considered as included in RE plant construction jobs and other STU/CTU level infrastructure considered to be built as per existing plans and not considered as a part of the new jobs | Additional jobs arising from RE development in Kerala considers only solar and wind installations (hydro and pumped hydro not considered in this analysis but can be studied further) | Studies and governance to include 6-10 persons for governance and ~18 studies to be conducted across sectors

Note: RE: Renewable Energy

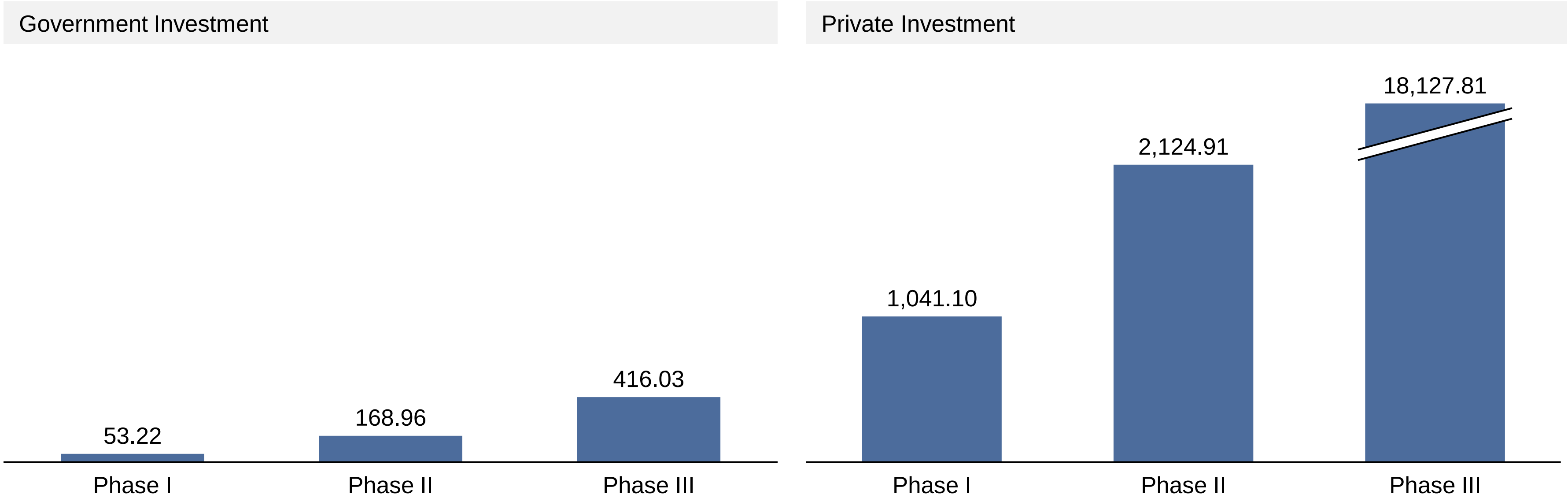
Source: Primary Interviews; Rhodium; HPCL; Research Articles; MEC+ analysis

Value in the valley is calculated

For each phase of the valley are the value is accounted with respect to the investments that will be made by the government and private players

Value of the Investments across the phases

In INR Crore



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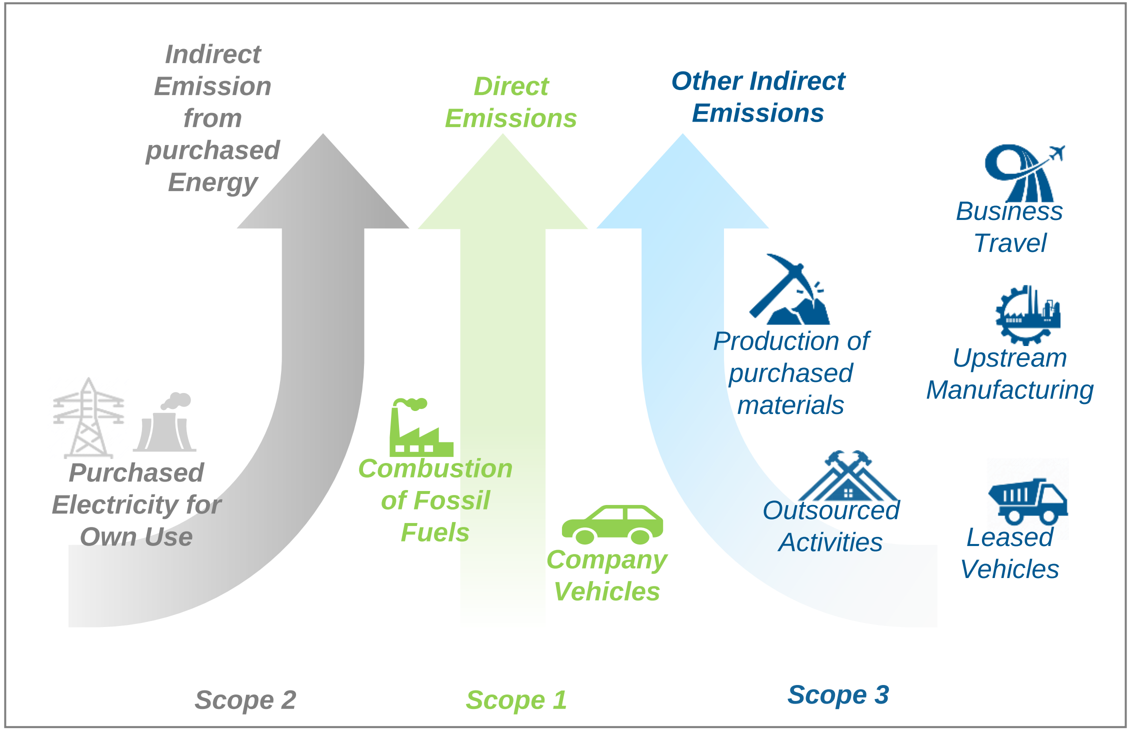
Note: RE: Renewable Energy
Source: MEC+ analysis

Carbon emissions can be accounted at 3 levels

Scope 1, 2 and 3; Only scope 1 emissions are considered for carbon abatement in the valley

Carbon Abatement Framework

Scopes of Emission



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The carbon abatement in the valley only considers the Scope 1 emissions that are abated due to direct replacement of fuel or feedstock

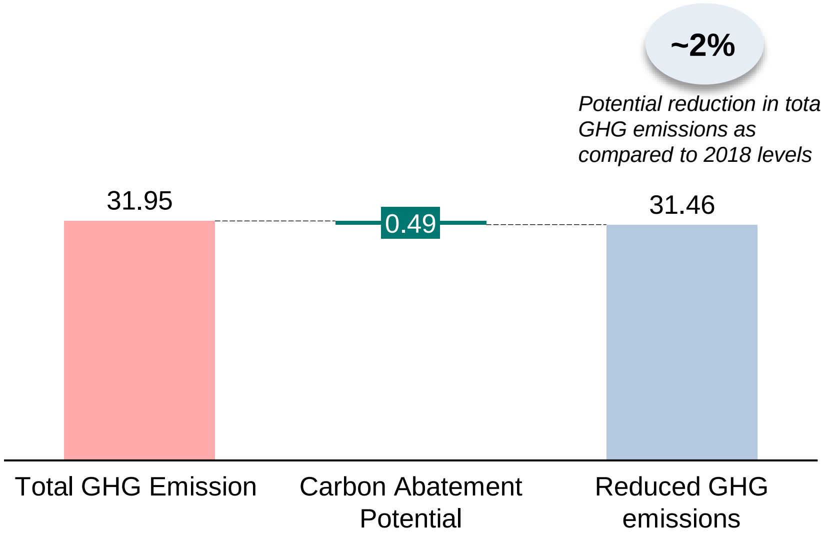
Source: Sustainable Procurement Platform; MEC+ analysis

The valley abates nearly 0.49 $MtCO_2e$ from the KL emissions

reducing the total emissions by ~2% and progressing to net zero goals in 2050

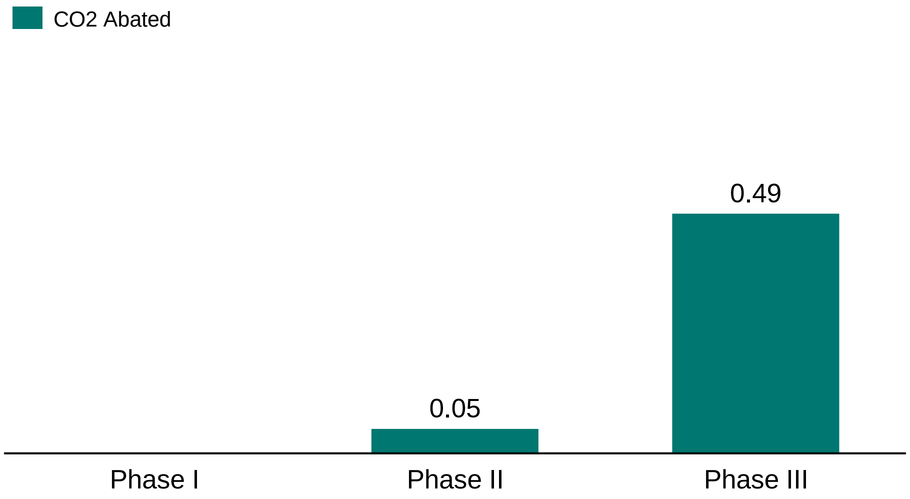
Net GHG emissions and reduction potential

$MtCO_2e$



CO_2 abatement potential (cumulative)

$MtCO_2e$



The valley leads to an abatement of 0.05 and 0.49 $MtCO_2e$ in Phase II and Phase III, respectively. In 2040 the valley has the potential to abate 1.7% of the total emissions in Kerala (2018 levels)

CO_2 abatement calculation only accounts for the direct prevention of CO_2 by replacing the existing fuel/feedstock with green hydrogen | For CO_2 abatement, other emissions (So_x, NO_x etc.) are not considered | Emissions during construction phase is also not considered | Detailed studies required for comprehensive potential mapping | Includes future CO_2 abated on deployment of green hydrogen buses and boats

Note: Comparisons based on 2018 GHG emission levels; MtCO2e: Million tons CO_2 Equivalent; GHG: Greenhouse Gases

Source: GHG Platform; MEC+ analysis

TOC

Sectional Summary

Kochi Hydrogen Valley – Design Choices

Anchor sectors in the valley; opportunities and challenges	• Demand for green hydrogen in Kerala is presently concentrated in 6 sectors (Refineries, Fertilizers, Road Transport, Water Transport, Chemicals and exports). Based on the demand, technology readiness, ease of adoption and centralised demand (except in road and water transport) these sectors are considered as anchor sectors for the valley • Other sectors contributing to less than 10% of the total demand are considered as a part of the innovation cluster. Innovation funds to be created for finding potential for scale-up and economic viability amongst these sectors • The valley has opportunities in the form of existence of multiple use-cases, central and state government willingness to support the valley and presence of Cochin Shipyard for H_2 vessel manufacturing know-how • The valley faces challenges in the form of concentration of entire sectoral demand under single player, untested nature of waterways and exports, price premiums on green hydrogen and technology bottlenecks
Factors impacting the adoption of green hydrogen across the sectors	• Economic case: Favorable economic case only for hydrogen buses in the valley in 2040 whereas refinery is a borderline case • Regulatory Support: Relatively higher regulatory support is visible in refinery through corporate 10% adoption target and within waterways for decarbonisation of waterways in the state • Technology Readiness: Across the value chain production of hydrogen is technologically mature with refineries and chemicals having a higher overall technology readiness due to the direct substitution of grey to green hydrogen in the process • Offtake Willingness: Overall offtake willingness is low to moderate in the valley with refineries having a relatively higher willingness due to their defined net zero goals, however, it is also subjected to premiums of green hydrogen

Source: MEC+ analysis

Sectional Summary

Kochi Hydrogen Valley – Design Choices

Supply side configuration

- The valley could be built in two configurations based on the electrolyser location and the inclusion of exports
- Configuration 1 is export oriented with a centralised electrolyser at Cochin Port and pipelines set-up between the port and BPCL, FACT. NH_3 conversion facility also to be set up at Port for exports
- Configuration 2 is domestic demand oriented with the electrolyser set up at BPCL and pipelines to FACT and trailer transport of hydrogen to port for refuelling
- Configuration 1 is selected as it offers a lower landed cost across most sectors if the trunk infrastructure is supported by the government
- Price premiums exist across all sectors, needing a total viability gap funding between INR 1,055 and INR 2,908 crores cumulatively in phase 2 and 3
- RE, electrolyser and storage costs are the biggest contributors in the investment costs and government support in these areas can reduce the burden on offtakers

Factors impacting the landed cost of green hydrogen in the valley

- The landed cost is sensitive to 3 major factors; RE plant location, banking provisions and utilisation of refuelling infrastructure
- The production cost can increase by ~46% in phase III if Kerala RE is used in place of India RE
- Availability of unrestricted banking (4000+ hours) can lower production costs by ~34% in Phase III, however, this would add stress to KSEB hence capping of banking at 1000 annual hours is suggested
- refuelling utilisation is sized to 100% utilisation as a lower utilisation rate (40%) can have costs higher by 140%

Source: MEC+ analysis

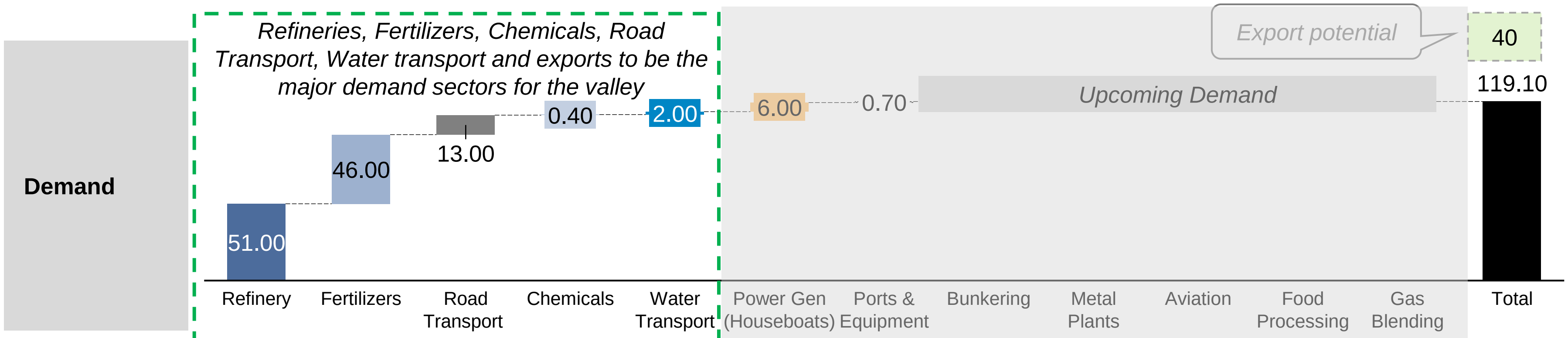
TOC

KL demand sector has a big head and a long tail

with 6 sectors being anchor off-takers (refinery, fertiliser, road transport, Water transport, chemicals and exports)

Kochi Valley | Demand Cluster

Sectors, Hydrogen Demand in kTPA



	Refinery	Fertilizers	Road Transport	Chemicals	Water Transport	Power Gen (Houseboats)	Ports & Equipment	Bunkering	Metal Plants	Aviation	Food Processing	Gas Blending
TRL	7-8	6-7	7-8	7-8	6	6	8-9	5-6	5	3-4	*NA*	7
Ease of Adoption	Substitute	Substitute	Convert	Substitute	Convert	Convert	Convert	Convert	Substitute	Convert	Substitute	Substitute
Demand Type	Central	Central	Central	Central	Distributed	Distributed	Distributed	Central	Central	Central	Distributed	Central

Refineries, fertilizers and chemicals use green hydrogen in their current processes. Road transport has high potential to decarbonise KL, waterways can drive traffic away from roads (reducing emissions) and the presence of Cochin Shipyard provides synergies for waterways. Export is an emerging use case and presence of two ports in KL provides synergies along with interests shown by private sector players

Source: MEC+ analysis

Opportunities and Challenges

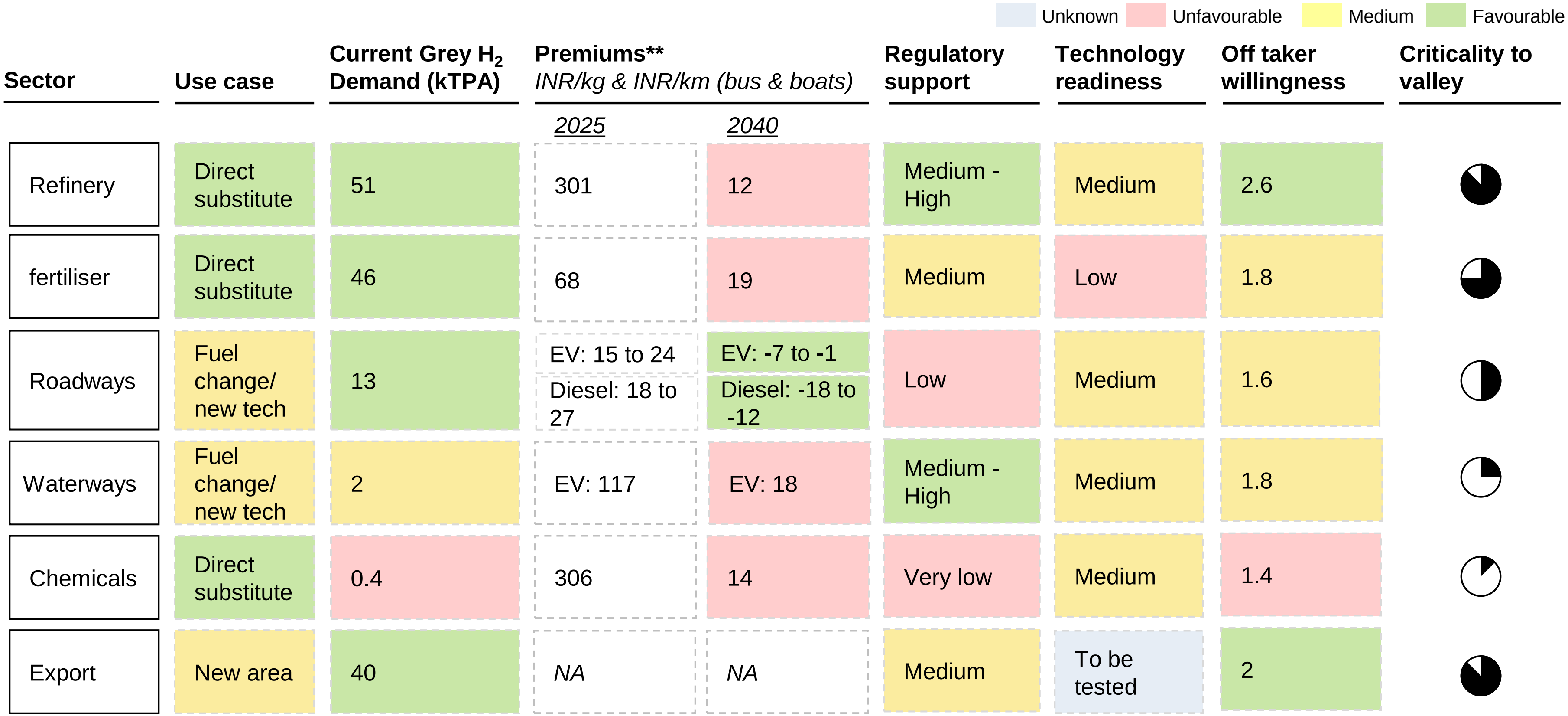
Of the Kochi Valley

Parameters	Opportunities	Challenges
Use-case	• **Existence of multiple use-cases** in the region. Opportunities for both **direct substitution** use cases like refineries and fertilizers and **new tech** like FCEVs	• **Use-cases like waterways and exports** does not exist currently and **are untested** hence emergence of demand depends on external factors as well
Demand	• Close to **120 kTPA potential demand with ~80% of the demand in direct use-cases** • Potential for demand from water transport and exports	• **Concentration of demand** sectors under single players in major sectors leading to concentration of risk, offtake stress and low willingness
Cost	• Kerala **can produce green H_2 with India best RE in 2040 coupled with incentives** reducing premiums, carbon costs (if present) can further make GH_2 competitive	• **Green H_2 price premium to remain** across most sectors even until 2040 leading to need for indirect support in terms of mandates, carbon tax etc
Regulatory Support	• Central **govt. focus on green hydrogen, announcement of incentives** and plans for the development of the sector, state policy also upcoming	• **Lack of well-defined decarbonisation targets and mandates** on industries hindering calls to action • Need for infrastructure development, standards etc
Technology Readiness	• **Opportunity to capitalise on the technology know-how developed by Cochin Shipyard** for developing H_2 vessels for building H_2 based water mobility	• **Technology bottlenecks** in offtake sectors like **utilisation of GH_2 at small scales** in fertiliser plants, **development of storage & transmission**

Source: MEC+ analysis

Refinery and Export are highly likely to adopt use of Green H_2

Out of the biggest 6 end-use cases, refinery and export have the highest propensity to adopt use of Green hydrogen



🟦 Unknown 🟥 Unfavourable 🟨 Medium 🟩 Favourable

Sector	Use case	Current Grey H_2 Demand (kTPA)	Premiums** *INR/kg & INR/km (bus & boats)*		Regulatory support	Technology readiness	Off taker willingness	Criticality to valley
			2025	*2040*				
Refinery	Direct substitute	51	301	12	Medium - High	Medium	2.6	◕
fertiliser	Direct substitute	46	68	19	Medium	Low	1.8	◕
Roadways	Fuel change/ new tech	13	EV: 15 to 24 Diesel: 18 to 27	EV: -7 to -1 Diesel: -18 to -12	Low	Medium	1.6	◑
Waterways	Fuel change/ new tech	2	EV: 117	EV: 18	Medium - High	Medium	1.8	◔
Chemicals	Direct substitute	0.4	306	14	Very low	Medium	1.4	◔
Export	New area	40	*NA*	*NA*	Medium	To be tested	2	◕

Note: Demand basis current (2025) demand potential ; **: Economic case comparison for landed cost for direct substitution with low-cost grey hydrogen/derivatives; TCO for mobility case comparison with diesel (at cost increase) and EV; TCO for road is a one off niche case

Source: MEC+ analysis

Economic case

Only switching buses to hydrogen fuel offers a net positive fuel cost in 2040, refinery and fertiliser is another borderline case

🟦 Unknown 🟥 Unfavourable 🟨 Medium 🟩 Favourable

Sector	Metrics	Comparative	Economic case comparisons
Refinery	Feedstock cost	Grey H_2	🟨 Premium in refinery sector against **low-cost grey hydrogen declines by 96% to INR 12/kg** in 2040
fertiliser	Feedstock cost	Grey NH_3	🟥 Premium in fertiliser sector against **low-cost grey ammonia declines by 72% to INR 19/kg** in 2040
Roadways	TCO	Diesel and EV	🟩 Long range FCEV buses expected to be competitive with **EV by 2040 by 4.5%** by being **INR 12/km** more **cost effective** than **EVs**. **HICE buses** also expected **to be competitive since 2040 by INR 7/km** more cost effective than EVs. Both H_2 techs to be competitive than diesel
Waterways	TCO	EV	🟥 Medium range FCEV vessels are expected to be competitive with EV towards 2040 however **premiums still exist at INR 18/km (decline by 85% in 2040)**, on development in refuelling infrastructure as well maturity in technology the costs can be brought down
Chemicals	Feedstock cost	Grey H2	🟥 Premiums in chemical sector against low-cost grey hydrogen **declines by 96% in 2040**. However, **current procurement costs of HOCL is significantly lower than grey hydrogen, weakening the economic case**
Export	No comparison done	No comparative	🟦 No comparative

Source: MEC+ analysis

Regulatory support

On the contrary, higher regulatory support is visible in refinery through corporate 10% adoption target and boats for decarbonisation of waterways in the state

🟦 Unknown 🟥 Unfavourable 🟨 Medium 🟩 Favourable

Sector	Regulatory support score	Commentary on regulatory support and clarity
Refinery	Medium - High	**Driver:** Plans for GH_2 mandates for all refineries at central level as well as GH_2 consumption target by BPCL at corporate level; defined timelines for decarbonisation goals at all levels **Inhibitor:** No state specific mandates for refinery/carbon emission reduction
fertiliser	Medium	**Driver:** Targets to substitute import based NH_3 with GNH_3 at central level; plans to set mandate for a min. percentage of GNH_3 at central level; competitive bidding for DAP & Urea fertiliser plants **Inhibitor:** No timelines for decarbonisation at FACT; no mandates
Roadways	Low	**Driver:** Decarbonisation goal of transport sector at central, state and local levels **Inhibitor:** Lack of mandates for GH_2; supporting environment for competing tech in EV; no clear subsidies/incentives for GH_2 uptake
Waterways	Medium - High	**Driver:** Central plans to launch H_2 based ferries; targets to reduce GHG emissions; funds allocated for green corridor on west coast canal; carbon neutral targets; manufacturing benefits for GH_2 vessel **Inhibitor:** Inhibitors present only in terms of lack of mandates and targets at state and local levels
Chemicals	Very low	**Driver:** Government plans to set up PLI for chemicals, no other specific drivers **Inhibitor:** Lack of mandates at all levels; no specific timelines for decarbonisation goals; no specific incentives for chemical sector
Export	Medium	**Driver:** Multiple proposals and developer interests in creating export hubs, NGHM targets **Inhibitor:** Distributed and unclear timelines of demand aggregation

Source: MEC+ analysis

Technology readiness

Production of green hydrogen is the only technologically mature part of the value chain across sectors; further in offtake, refinery & chemicals have relatively higher maturity due to direct fuel substitution

🟦 Unknown 🟥 Unfavourable 🟨 Medium 🟩 Favourable

Sector	Production	Conversion/ Storage	Transport	Offtake	Overall technology readiness
Refinery	🟩 8	🟩 NA	🟨 7-8	🟨 7	Technical readiness for technology shift from grey to green for Kochi refinery to be tested; currently pilots in regulated conditions – not scaled to regular operations
fertiliser	🟩 8	🟨 7-8	🟩 8-9	🟥 5	Feasibility and technical readiness for green scale NH_3 production via RE to be tested
Roadways	🟩 8	🟥 6	🟩 NA	🟨 6-9	Overall nascent sector due to new fuel, assets and refuelling tech to be tested; safety standards to be well established
Waterways	🟩 8	🟥 6	🟩 NA	🟥 5-6	New design for larger capacities to be developed and tested; pilots demonstrated in regulated environments at only demonstration level, not scaled operations
Chemicals	🟩 8	🟩 NA	🟩 NA	🟨 7	Green hydrogen purity maybe a challenge; to be tested
Export	🟩 8	🟥 5-6	🟩 NA	🟦 To be tested	Standards, certifications and verifications to be set according to global standards for export

Note: Refer sector deep-dives for further information on sector wise technology readiness and appendix for TRL definitions

Source: MEC+ analysis

Offtake willingness

Overall offtaker willingness is low to moderate in the valley on a score of 4, with refinery having relatively higher willingness

🟦 Unknown 🟥 Unfavourable 🟨 Medium 🟩 Favourable

Sector	Score	Offtake willingness score
Refinery	2.6	**Driver:** Plans for GH_2 mandates for all refineries at central level ;GH_2 consumption target by BPCL at corporate level; defined timelines for decarbonisation goals at all levels **Inhibitor:** No state specific mandates for refinery/carbon emission reduction
fertiliser	1.8	**Driver:** Targets to substitute import based NH_3 with GNH_3 at central level; plans to set mandate for min. percent of GHN_3 offtake at central level; competitive bidding for DAP & Urea fertiliser plants **Inhibitor:** Undefined decarbonisation timelines at FACT; no mandates
Roadways	1.6	**Driver:** Willingness to test pilot; decarbonisation steps taken in competitive tech.; govt. support for competitive tech – expectation in hydrogen as well; rise in diesel costs **Inhibitor:** Lack of mandates for GH_2; no direct use case of GH_2; high cost of new infra development
Waterways	1.8	**Driver:** Technology confidence due to Cochin Shipyard acting as a nexus for tech. development; focus on low carbon emission technologies; willing to test pilots **Inhibitor:** Long timelines for first operational boat/vessel; cost & operations of refuelling infrastructure
Chemicals	1.4	**Driver:** Technology maturity; direct hydrogen use case **Inhibitor:** No specific timelines for decarbonisation goals; no specific incentives for chemical sector; challenging financials; no adoption plans; no offtake timelines
Export	2	**Driver:** Global demand and requirement for green hydrogen/derivatives; strategic location and presence of 2 major ports; NGHM export plans and dialogue of GoI with several countries; NH_3 production **Inhibitor:** The opportunity cost of subsidies for local economy vs. export-oriented unit

Source: MEC+ analysis

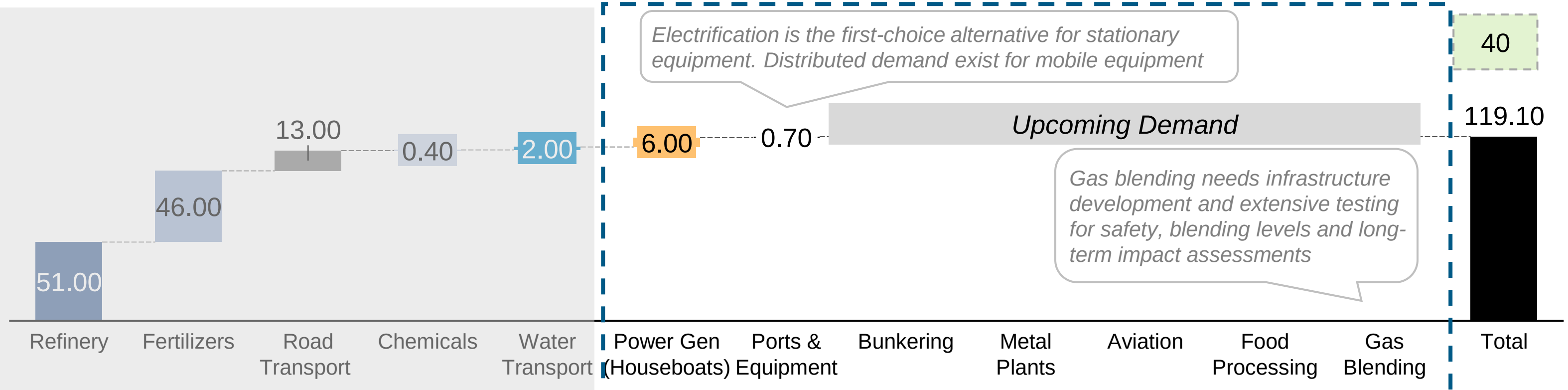
Other sectors contribute to less than 10% demand potential

in the valley currently and are proposed to be a part of the innovation fund

Kochi Valley | Innovation Cluster

Sectors, Hydrogen Demand in kTPA

Demand



Electrification is the first-choice alternative for stationary equipment. Distributed demand exist for mobile equipment

Gas blending needs infrastructure development and extensive testing for safety, blending levels and long-term impact assessments

	Refinery	Fertilizers	Road Transport	Chemicals	Water Transport	Power Gen (Houseboats)	Ports & Equipment	Bunkering	Metal Plants	Aviation	Food Processing	Gas Blending
TRL	7-8	6-7	7-8	7-8	6	6	8-9	5-6	5	3-4	*NA*	7
Ease of Adoption	Substitute	Substitute	Convert	Substitute	Convert	Convert	Convert	Convert	Substitute	Convert	Substitute	Substitute
Demand Type	Central	Central	Central	Central	Distributed	Distributed	Distributed	Central	Central	Central	Distributed	Central

Innovation fund in Kerala H_2 valley

Creation of innovation fund to test and evaluate the fringe sector contributing <10% of the demand in the valley, for finding potential for scale and economic viability

Source: Primary Interviews; Company Annual Reports; News Articles; MEC+ analysis

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There are two ways to configure the valley

basis the electrolyser location and whether export sector is part of the valley or not

Configuration options available for Green Hydrogen Valley in Kochi

Configuration options

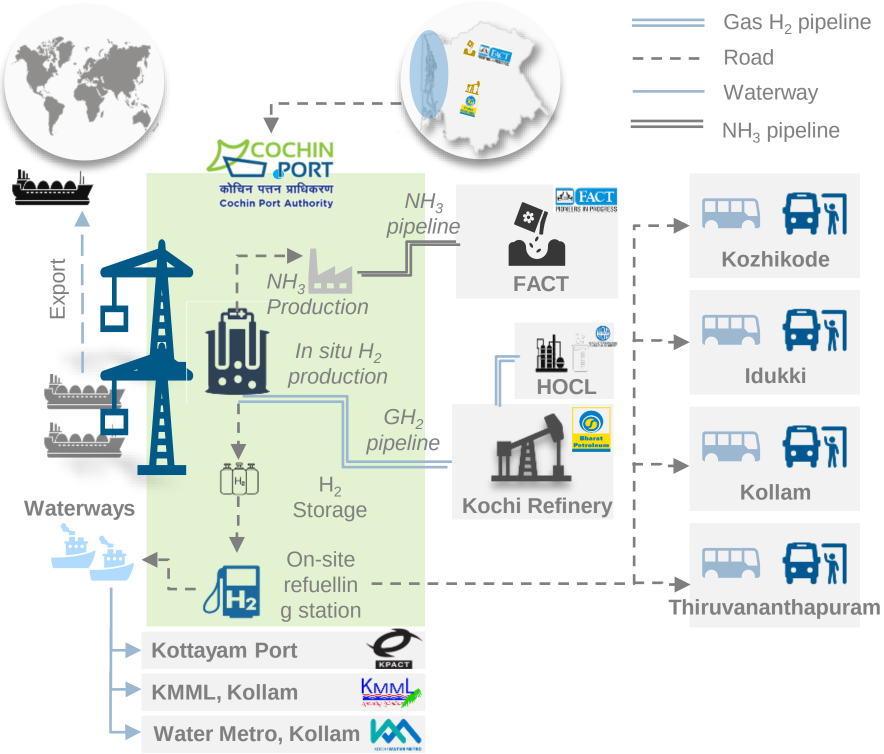
Configuration 1: Export oriented	Configuration 2: Domestic demand oriented
Round the clock Kerala and India RE	Round the clock Kerala and India RE
Centralised hydrogen production at Kochi port	Centralised hydrogen production at BPCL refinery, Kochi
Hydrogen to green ammonia conversion facility to be set up at the port premises	No storage or conversion facility required
New pipeline to be set up between the Kochi port and BPCL, FACT for hydrogen/ammonia transport	New pipeline to be setup between BPCL and FACT; Existing pipeline between BPCL and HOCL, H_2 trailers for transport between BPCL and Kochi port for refuelling stations
Central refuelling station at Kochi port for powering boats and buses	Central refuelling station at Kochi port for powering boats and buses

Source: MEC+ analysis

In configuration 1 electrolyser is placed at the port

with H_2 pipeline running to BPCL and LNH_3 pipeline running to FACT; the centralised refuelling infra is placed at the port itself

Kochi Green Hydrogen Valley | Total potential
Visualisation



RE	4.8 GW	*Cumulative RE required in the valley*
Electrolyser	0.9 GW	*Cumulative electrolyser deployment in the valley. centralised hydrogen production in Port area*
Pipeline	27 KM	*Pipeline laid between Cochin Port and BPCL for the transportation of H_2 (~12.4km) and Cochin Port to FACT for LNH_3 (~14.1 km)*
Refuel	800 Kg/day	*refuelling station and storage (1 day) set-up at Port. To fulfill the requirements of buses and boats*
Refinery	39.6 kTPA	*Green hydrogen transported from the Port to refinery to meet min. 60% of the refinery demand in phase III*
Fertiliser	12.3 kTPA	*Green hydrogen transported from the Port to refinery to meet min. 30% of the demand at FACT in Phase III*
Bus	0.2 kTPA	*FCEV and HICE buses to operate on long and medium distance routes. Valley to have 15 buses operating in phase III*
Boat	0.07 kTPA	*Hydrogen powered barges to operate from Kochi to Kottayam & KMML (WCC) and sea-going fast vessels on coastal route (Kochi-Kollam)*
Chemical	0.004 kTPA	*Chemicals (HOCL) to use min. 1% green hydrogen in phase III*
Export	40 kTPA*	*If export picks up, Green Ammonia to be manufactured (NH_3 production infra to be set up) at port and exported to Europe and Asia*

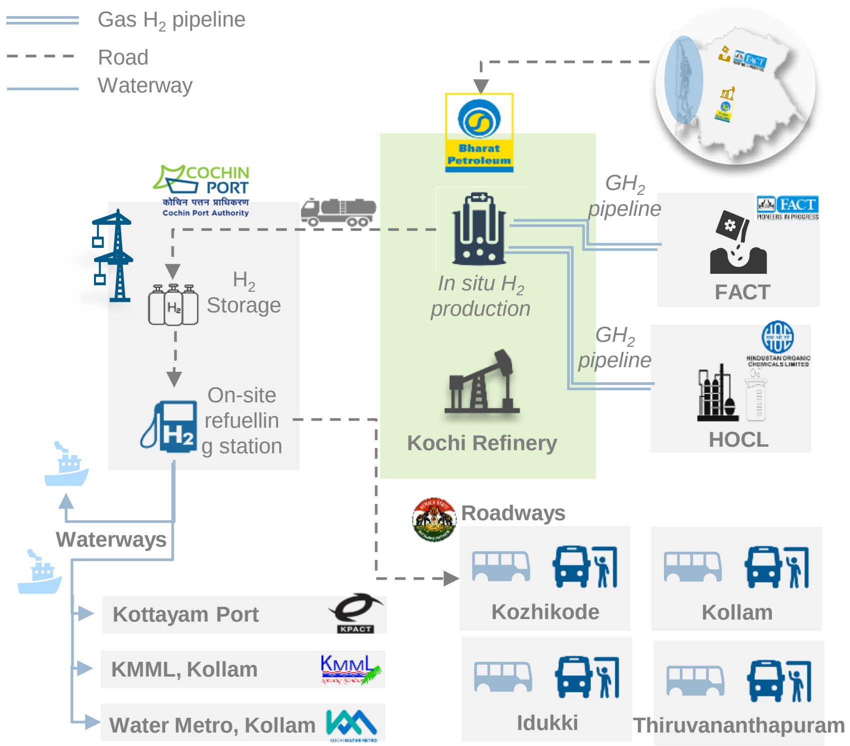
Note: *Green Hydrogen Requirement for Ammonia production; LNH_3: Liquid Ammonia
Source: MEC+ analysis

In configuration 2, electrolyser is placed at BPCL

with H_2 pipeline running to FACT and trailers running up to port for the refuelling infra structure

Kochi Green Hydrogen Valley | Total potential

Visualisation



Gas H_2 pipeline

Road

Waterway

Bharat Petroleum

COCHIN PORT

कोचिन पत्तन प्राधिकरण

Cochin Port Authority

H_2 Storage

On-site refuelling station

In situ H_2 production

Kochi Refinery

GH_2 pipeline

FACT

GH_2 pipeline

HOCL

Roadways

Kozhikode

Kollam

Idukki

Thiruvananthapuram

Waterways

Kottayam Port

KMML, Kollam

Water Metro, Kollam

RE	2.6 GW	*Cumulative RE required in the valley*
Electrolyser	0.52 GW	*Cumulative electrolyser deployment in the valley. centralised hydrogen production in Port area*
Pipeline	20.8 KM	*GH_2 Pipeline laid between BPCL and FACT (20.8 km) and existing pipeline between BPCL HOCL for the transportation of H_2*
Refuel	800 Kg/day	*refuelling station and storage (1 day) set-up at Port. To fulfill the requirements of buses and boats*
Trailer	1 trailer	*Hydrogen trailers for transporting H_2 from BPCL to Cochin port*
Refinery	39.6 kTPA	*Green hydrogen transported from the Port to refinery to meet min. 60% of the refinery demand in phase III*
Fertiliser	12.3 kTPA	*Green hydrogen transported from the Port to refinery to meet min. 30% of the demand at FACT in Phase III*
Bus	0.2 kTPA	*FCEV and HICE buses to operate on long and medium distance routes. Valley to have 15 buses operating in phase III*
Boat	0.07 kTPA	*Hydrogen powered barges to operate from Kochi to Kottayam & KMML (WCC) and sea-going fast vessels on coastal route (Kochi-Kollam)*
Chemical	0.004 kTPA	*Chemicals (HOCL) to use min. 1% green hydrogen in phase III*

Source: MEC+ analysis

Overall configuration 1 offers lower landed cost

for most sectors in the valley, if trunk infrastructure is supported by the government

Sector wise comparison of landed costs in 2040 with respect to trunk infrastructure support from govt.

INR/kg

- With trunk infrastructure **support refers to absorption of costs (refuelling, grid infra, pipeline and storage) by the government and only OPEX borne by developer**
- Without trunk infrastructure refers to **no cost absorption by the government**

Sectors	Case 1: With trunk infrastructure support from government		Case 2: Without trunk infrastructure support	
	Configuration 1	Configuration 2	Configuration 1	Configuration 2
Fertiliser (Green Ammonia)	**48.19**	**48.35**	**48.21**	**48.71**
Refinery	**214.45**	**213.02**	**215.97**	**213.02**
Road Transport	**294.42**	**314.10**	**413.59**	**448.18**
Water Transport	**294.42**	**314.14**	**413.59**	**449.19**
Chemicals	**215.97**	**216.62**	**218.05**	**218.14**
Export (Green Ammonia)				

Note: All landed costs are considered for Phase 3 of the valley, Electrolyser size for configuration 1 is 0.9 GW, whereas for configuration 2 it is 0.4 GW; Banking is considered(1000 hour yearly), Trunk Infrastructure considered: H_2 refuelling, Grid infra, pipelines and H_2 storage; only OPEX is considered as part of landed cost

Source: MEC+ analysis

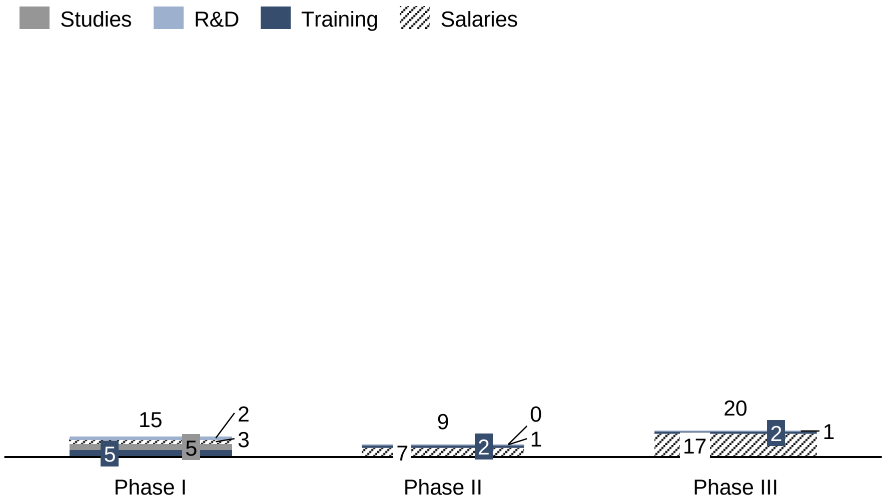
Investments in the valley is carried out by Council and Subsidiary

Council allocates funds for feasibility studies, R&D, training and manpower; Subsidiary allocates funds for infrastructure and offtake

Bifurcation of Government Spending

In INR Crore

COUNCIL



Investments by the council are towards feasibility studies in the different sectors, Research and development expenditure (for CDAC, CSIR and IIT Palakkad), training material, trainer training and salaries for the employees

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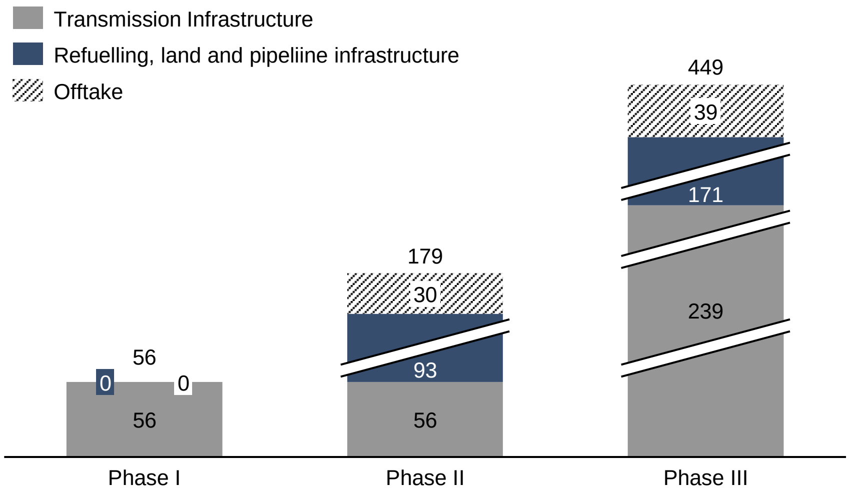


Subsidiary to spent on transmission infrastructure, pipeline infrastructure for H_2 and NH_3, land and refuelling stations and capex in offtake sectors like buses and boats

Note: Spent on R&D to include allocations to Cochin Shipyard; Salaries considered for 6,8 and 10 employees within council

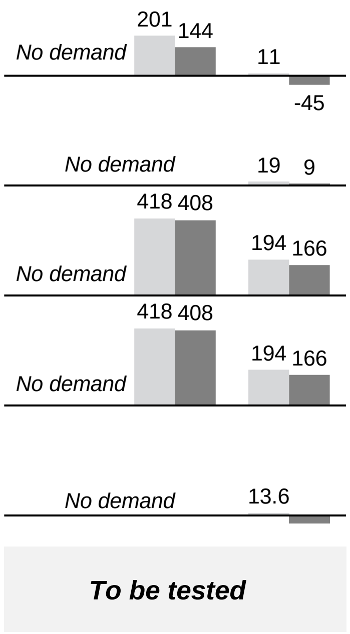
Source: Govt. of Kerala; MEC+ analysis

Premiums exist across all phases for low-cost fossil fuel

leading to a total viability gap for off-takers of INR 1055 and 2908 crores in different phases

Sector wise premiums of GH_2/GNH_3 with low and high-cost fossil fuel

INR/kg

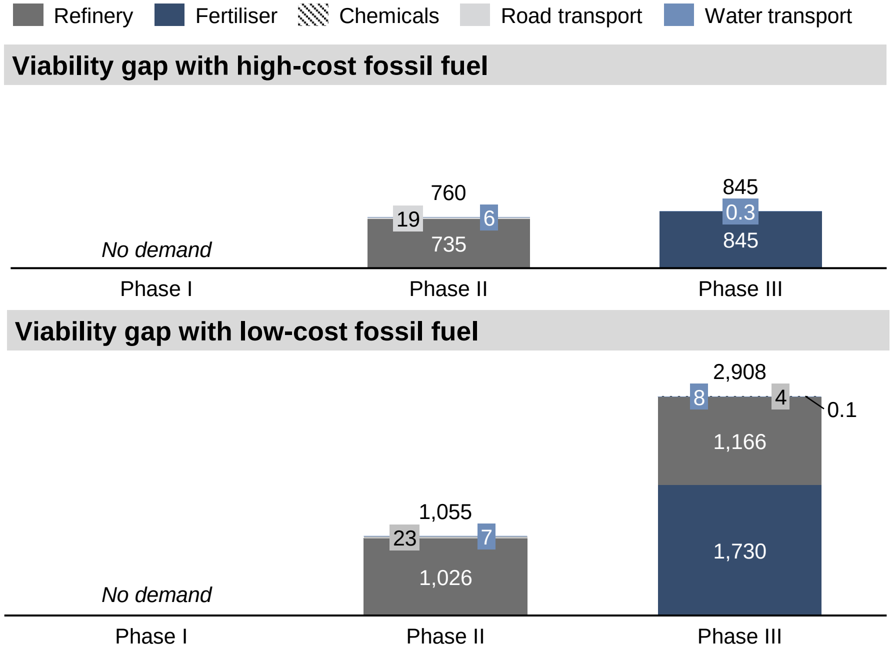


Sectors	Premiums (INR/kg) Phase I	 Phase II	 Phase III	Asset Life/ Contract Duration
Refinery	*No demand*	201 144	11 -45	**15 Years**
Fertiliser (Green Ammonia)	*No demand*		19 9	**15 Years**
Roadways	*No demand*	418 408	194 166	**10/15 Years**
Waterways	*No demand*	418 408	194 166	**20/15 Years**
Chemicals	*No demand*		13.6	**15 Years**
Export (Green Ammonia)	***To be tested***			***NA***

Sector wise viability gap through premiums

INR Cr

Viability gap for asset lifetime/contract duration (INR Cr)



Note: Viability gap has been calculated on premium of incumbent high CO2 emitting fuel vs green hydrogen/ammonia; Even though the premiums of road and water transport are high, the viability gap is low due to different fuel efficiencies of diesel vs hydrogen vehicles considered

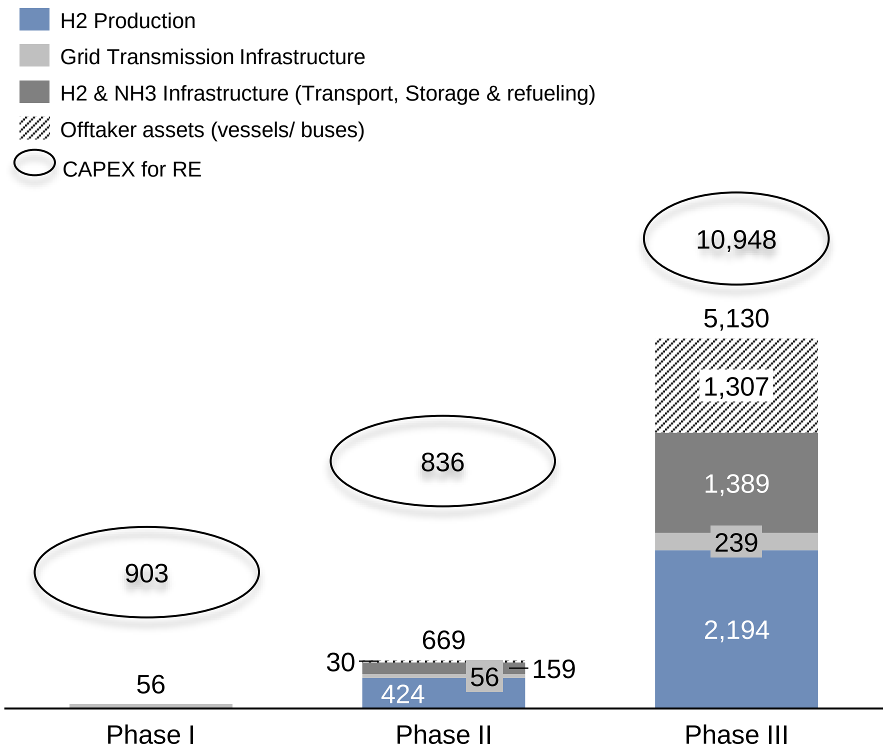
Source: MEC+ analysis

High viability gap exists in the total investments

with renewable energy, electrolyser and storage unit contributing the highest

Investment additions required in phase I, II, and III

INR Crore



Biggest contributing factors in the investment costs

RE, Electrolyser and storage account for ~90% of the investments

Renewable Energy	• Renewable energy accounts for around 70% of the total investment requirement in phase 3. Government can support the investments for renewable energy to bridge the viability gap
Electrolyser	• Of the rest of the investments, electrolyser accounts for around 10% of the total investments required. Government can support this viability gap by providing some equity funding for the electrolyser
Storage	• In the H_2 infrastructure, storage units holds for the maximum contribution. Overall, a storage unit accounts for 7% of the total investment costs needed which if supported by the government can reduce the viability gap

Note: Storage accounts for INR 1088 Cr in the H_2 and NH_3 Infra cost in phase III, investments are inclusive of land

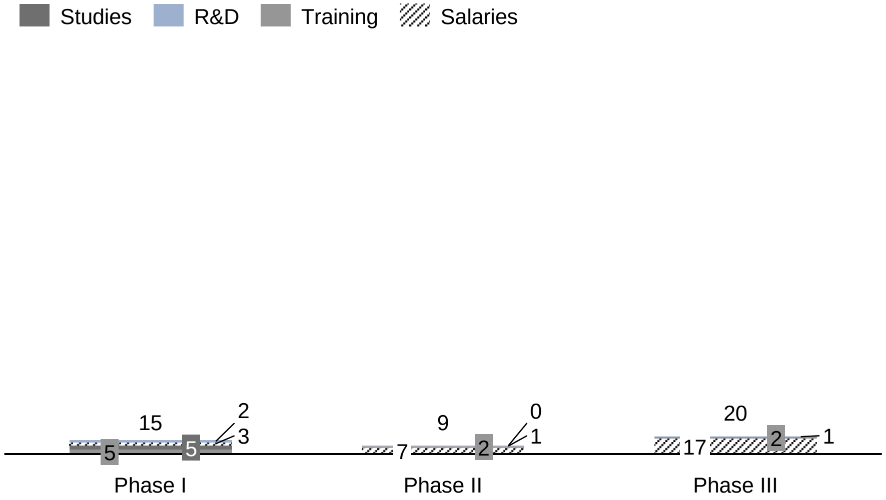
Source: Refer Appendix; MEC+ analysis

The government can reduce the burden on off-takers

by addressing the viability gaps created from RE, electrolyser and storage over and above the trunk infrastructure cost

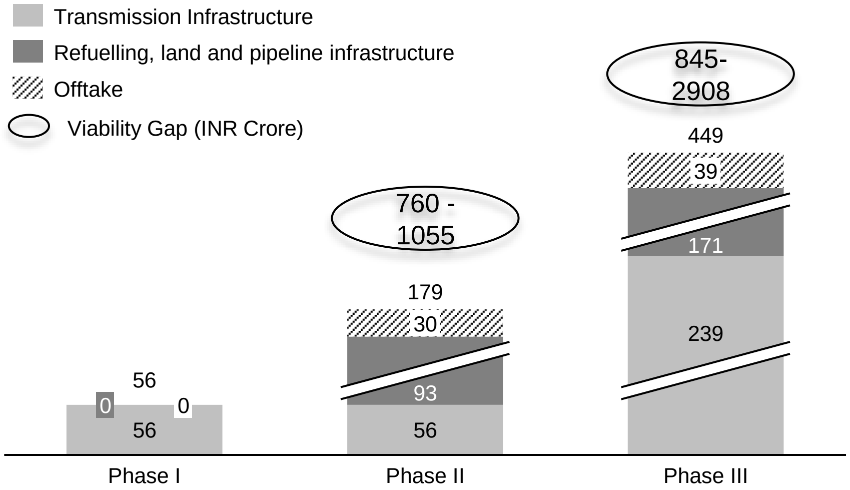
Bifurcation of Government Spending
In INR Crore

COUNCIL



Investments by the council are towards feasibility studies in the different sectors, Research and development expenditure (for CDAC, CSIR and IIT Palakkad), training material, trainer training and salaries for the employees

SUBSIDIARY



Subsidiary to spent on transmission infrastructure, pipeline infrastructure for H_2 and NH_3, land, refuelling stations and capex in offtake sectors like buses and boats

Note: Spent on R&D to include allocations to Cochin Shipyard; Salaries considered for 6,8 and 10 employees under the council

Source: Govt. of Kerala; MEC+ analysis

The landed cost is sensitive to largely 3 factors

and is significant as all the values discussed so far are sensitive to a specific configuration of landed cost

Three factors affecting landed cost of green hydrogen in the valley and selections made for Kerala

🟩 Favourable 🟥 Unfavourable

	RE plant location	Banking provision	utilisation of refuelling infrastructure
Description	• The **geographic location of the RE plant significantly impacts the cost**. Proximity to resources like solar, wind, etc. influences the energy input required for producing green hydrogen • **Higher CUF signifies better utilisation of RE resources**. It directly impacts the amount of electricity available for green hydrogen production. Selecting **locations with higher CUF ensures a more consistent and abundant energy supply, reducing the total systems cost**	• Banking provisions **allow for the management of energy flow and account for variations** in energy production and consumption • Integrating various sources, such as solar, wind, and traditional power generation, with **intermittent nature of availability, requires standardized procedures** • Adapting the grid infrastructure to accommodate bidirectional energy flow and storage requires **upgrading systems to handle distributed generation and storage integration requires significant capital and planning**	• **utilisation of refuelling infrastructure at scale positively impacts cost efficiency**. Higher utilisation rates of refuelling stations lead to better economies of scale, reducing the per-unit cost of hydrogen dispensed, making it more competitive • By **capitalizing on scale benefits**, the utilisation of refuelling infrastructure becomes a pivotal factor in reducing the landed cost of green hydrogen in the valley, **making it a more accessible and economically feasible energy solution**
Cases	🟩 **India RE**	🟩 **1000 hours banking**	🟩 **100% utilisation**
	🟥 Kerala RE	🟥 4000+ hours banking	🟥 80%, 60%, 40% utilisation

Source: MEC+ analysis

Location of RE plant

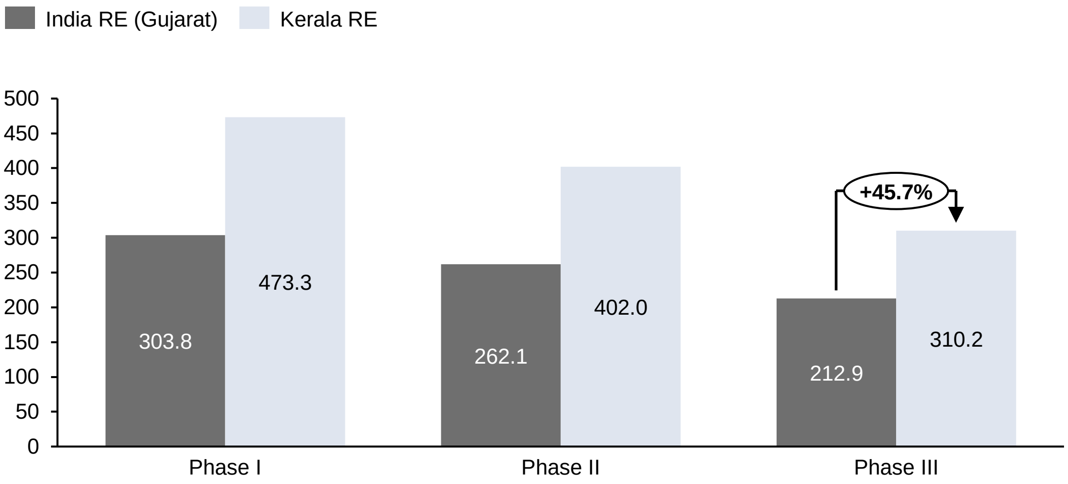
The production cost can vary by ~46% in Phase III if we were to use KL RE instead of India RE

Comparison of India and Kerala RE cost

- **Areas abundant in solar, wind, or hydroelectric resources allow for more efficient and cost-effective hydrogen production** due to readily available RE sources. E.g.: Rajasthan, Gujarat, benefit from vast land ideal for large-scale RE projects, thus reducing energy production costs
- Kerala's topography, with hilly terrain and unique weather patterns, affects the efficiency of solar and wind energy projects. **Variations in weather conditions can impact the reliability and consistency of energy generation, affecting overall production costs**
- While Kerala possesses significant RE potential, addressing the challenges associated with location constraints is essential to enhance the cost-effectiveness. **Strategic planning, innovative technologies, and supportive policies** are pivotal in harnessing Kerala's RE

Production cost of RE in India vs Kerala

INR/kg



- The production cost between India and Kerala RE varies by 43.6%, 23.4% and 35.6% in Phase I, II and III respectively
- Hence, it is suggested to source India's best resource renewable energy in phase-3 during scale up of the green hydrogen valley

Note: In Phase 1, Phase 2 the size of electrolyser taken is 50 MW, Phase 3 is 0.9 GW. Hourly Settlement is considered with 1000-hour yearly banking, Kerala Solar + pumped hydro is considered, For India RE, Gujarat Solar + Wind + Battery resource is considered

Source: MEC+ analysis

Banking provision

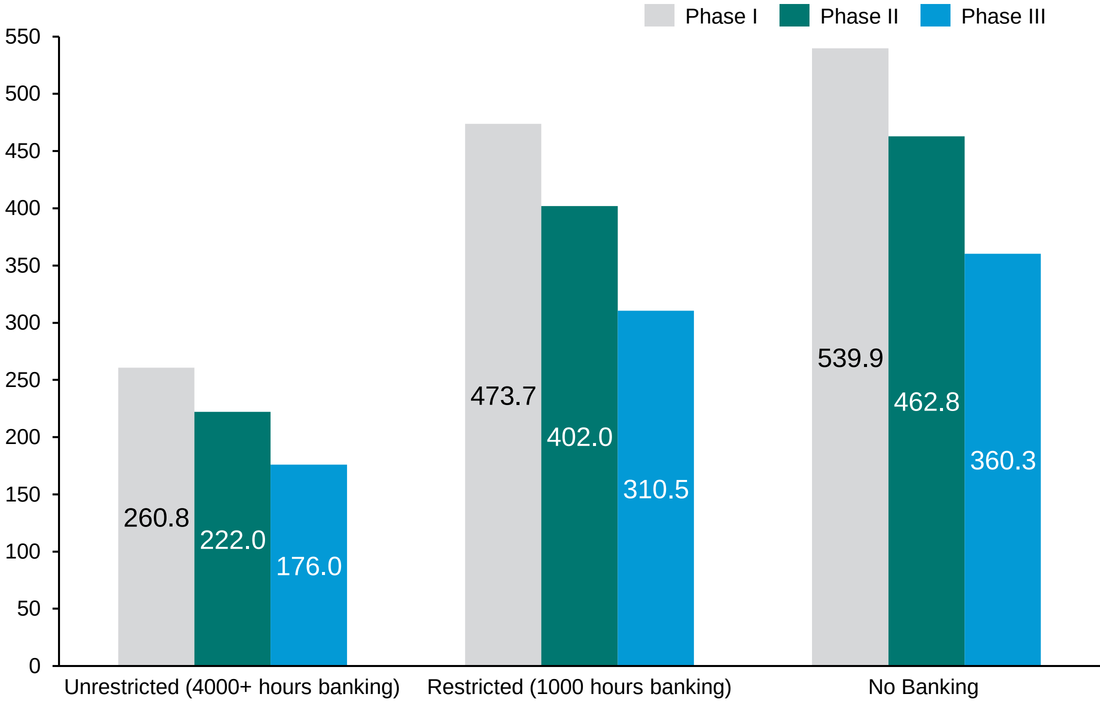
Availability of unrestricted banking can lower production costs by ~34% in Phase III, however, this is difficult for KSEB; and a no banking scenario is quite expensive, hence capping of banking at 1000 annual hours is suggested

Government regulations for ISTS charges

- Banking refers to arrangements or **provisions made for the storage, injecting, or withdrawal of excess or deficit energy** among different entities within the grid
- Selling surplus energy to the grid allows consumers access the gird for free during peak demand or low renewable output periods, but this requires **substantial grid upgrades** and **operational investment** from the discoms
- We have considered **three scenarios:** Restricted banking (1000 hours), Unrestricted banking (4000+ hours) and no banking
- Providing 4000 hours of banking for the Kerala State Electricity Board is challenging due to its current financial state (**EBITDA of -1000 crores in FY 2022-23**). However, completely forgoing banking would make green **H2 production very costly**. Hence, a compromise of 1000 hours of yearly banking is proposed to balance financial constraints with operational needs

GH_2 production costs for unrestricted vs restricted banking vs no banking in Kerala

INR/kg



Note: ISTS losses and Intra-state transmission charges are considered in the calculation, Natural gas price are considered at 10 USD/ MMBTU in 2025 and 12 USD/MMBTU in both 2030 and 2040; Plant configuration is Solar + pumped hydro based out of Kerala

Source: IGEF-MEC+ Model; PIB: ISTS Charges

refuelling infra utilisation

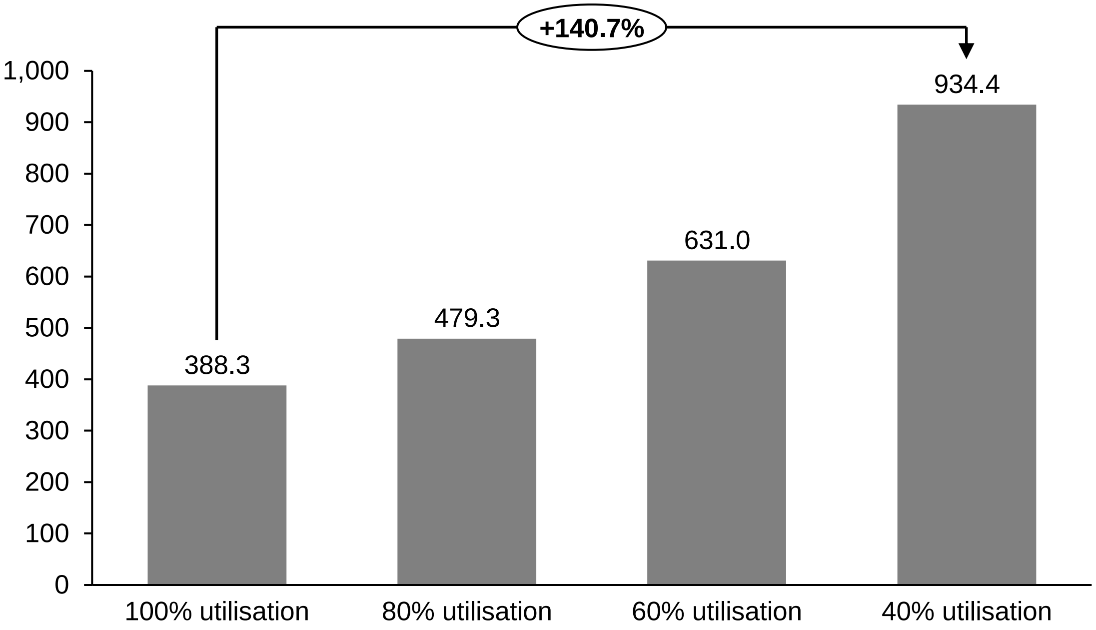
The landed costs is highly sensitive to refuelling infra utilisation, lower utilisation can have ~140% higher costs | refuelling infra has been sized to ensure 100% utilisation in all configurations

Refuelling infrastructure

- As the number of refuelling stations increases, **initial setup costs get distributed across a larger network**. This **decreases the per-unit cost** of establishing and operating each station, making the overall infrastructure more cost-efficient
- A higher utilisation of the refuelling would mean lower per unit costs whereas lower utilisation would mean high per unit costs for a fixed rate of return
- We have considered **4 scenarios** for arriving at refuelling costs: 40% utilisation, 60% utilisation, 80% utilisation and 100% utilisation

400 kg refuelling costs at different utilisation rates

INR/kg



Note: Cost of refuelling at a 400 kg hydrogen station is influenced by its utilisation rate. A fixed margin on the investment directly affects hydrogen (H_2) cost. The compressor energy is calculated 0.26 kWh/kg H_2, decreases with limited H_2 utilisation, the savings of which have also been considered

Source: MEC+ analysis

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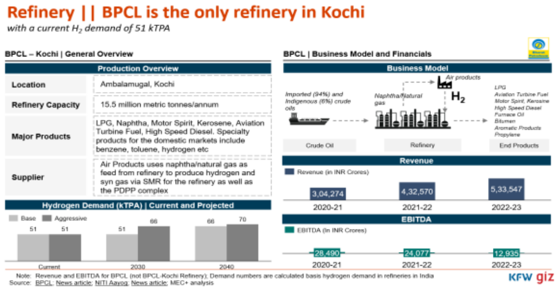
6 parameters were compared across sectors

We have compared 6 parameters across sectors to objectively analyse suitability for valley

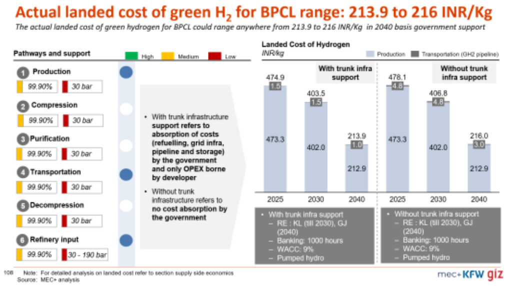
Parameters analysed across the 6 sectors



Refinery || BPCL is the only refinery in Kochi

with a current H_2 demand of 51 kTPA

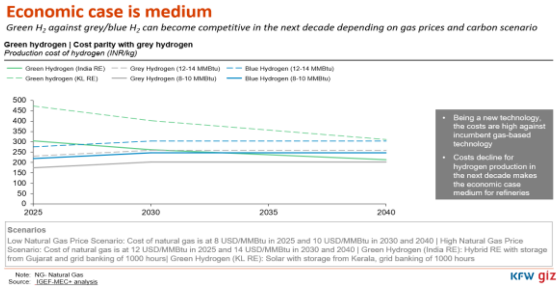
Off-taker profile and demand potential



Actual landed cost of green H_2 for BPCL range: 213.9 to 216 INR/Kg

The actual landed cost of green hydrogen for BPCL could range anywhere from 213.9 to 216 INR/Kg in 2040 basis government support

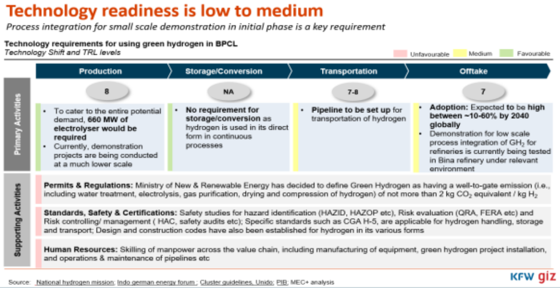
Supply side infrastructure requirement & TCO



Economic case is medium

Green H_2 against grey/blue H_2 can become competitive in the next decade depending on gas prices and carbon scenario

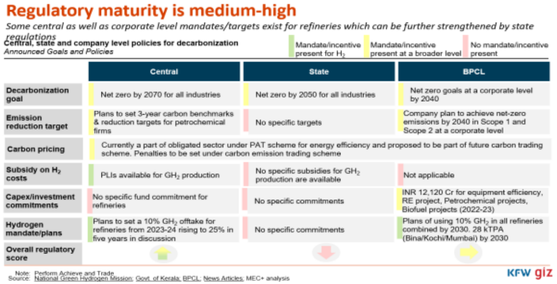
Economic case for adoption



Technology readiness is low to medium

Process integration for small scale demonstration in initial phase is a key requirement

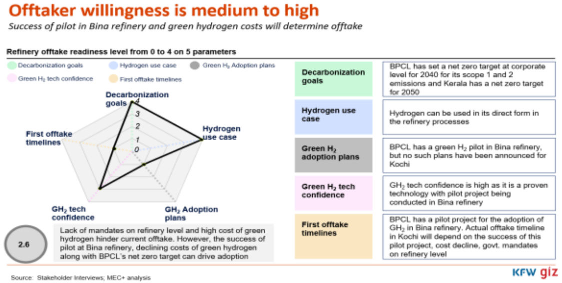
Technology readiness and adaptability



Regulatory maturity is medium-high

Some central as well as corporate level mandates/targets exist for refineries which can be further strengthened by state regulations

Regulatory Support and driver



Offtaker willingness is medium to high

Success of pilot in Bina refinery and green hydrogen costs will determine offtake

Off-taker readiness and considerations

Source: MEC+ analysis

TOC

REFINERY SECTOR

Image Credits

Refinery | BPCL is the only refinery in Kochi

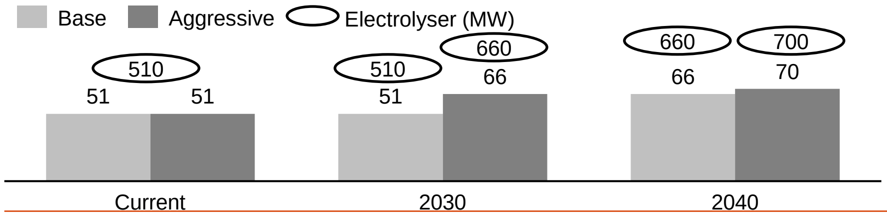
with a current H_2 demand of 51 kTPA

BPCL – Kochi | General Overview

Production Overview

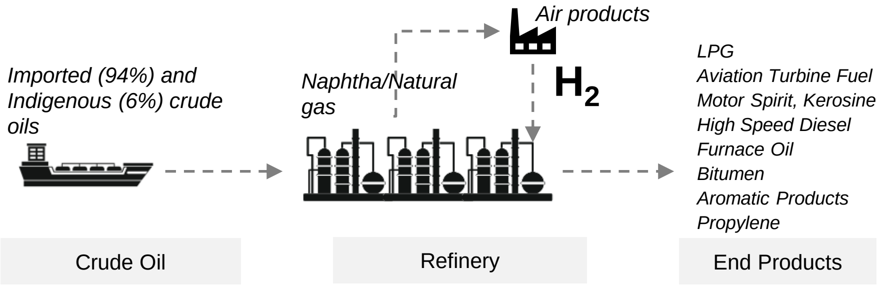
Location	Ambalamugal, Kochi
Refinery Capacity	15.5 million metric tons/annum
Major Products	LPG, Naphtha, Motor Spirit, Kerosene, Aviation Turbine Fuel, High Speed Diesel. Specialty products for the domestic markets include benzene, toluene, hydrogen etc
Supplier	Air Products uses naphtha/natural gas as feed from refinery to produce hydrogen and syn gas via SMR for the refinery as well as the PDPP complex

Hydrogen Demand (kTPA) | Current and Projected

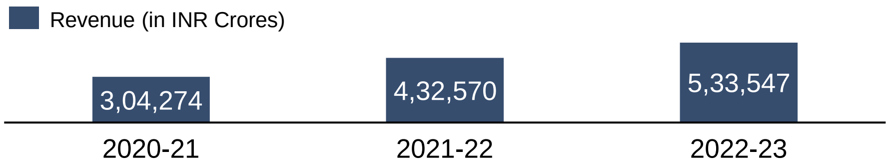


BPCL | Business Model and Financials

Business Model



Revenue



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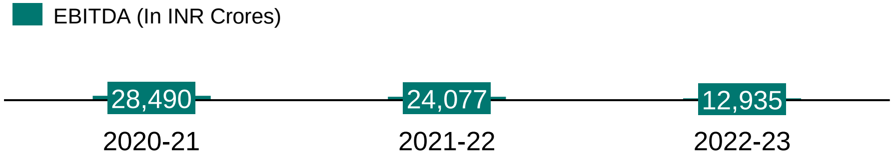


Note: Revenue and EBITDA for BPCL (not BPCL-Kochi Refinery); Demand numbers are projected basis hydrogen demand in refineries in India

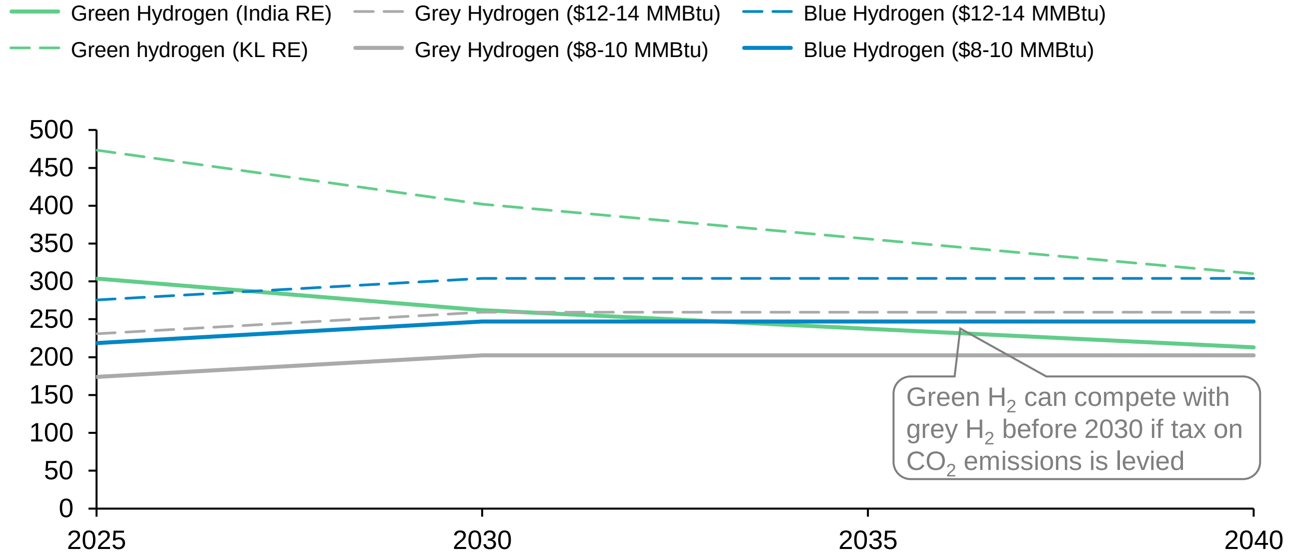
Source: BPCL; News article; NITI Aayog; MEC+ analysis

Economic case is medium

Green H_2 against grey/blue H_2 can become competitive in the next decade depending on gas prices and carbon scenario

Green hydrogen | Cost parity with grey hydrogen

Production cost of hydrogen (INR/kg)



Green H_2 can compete with grey H_2 before 2030 if tax on CO_2 emissions is levied

- Being a new technology, the costs are high against incumbent gas-based technology
- Costs decline for hydrogen production in the next decade makes the economic case medium for refineries

Scenarios

Low Natural Gas Price Scenario: Cost of natural gas is at 8 USD/MMBtu in 2025 and 10 USD/MMBtu in 2030 and 2040 | High Natural Gas Price Scenario: Cost of natural gas is at 12 USD/MMBtu in 2025 and 14 USD/MMBtu in 2030 and 2040 | Green Hydrogen (India RE): Hybrid RE from Gujarat and grid banking of 1000 hours| Green Hydrogen (KL RE): Solar with pumped hydro storage from Kerala, grid banking of 1000 hours

Note: NG- Natural Gas

Source: IGEF-MEC+ analysis

Actual landed cost of green H_2 for BPCL range: 213.9 to 216 INR/Kg

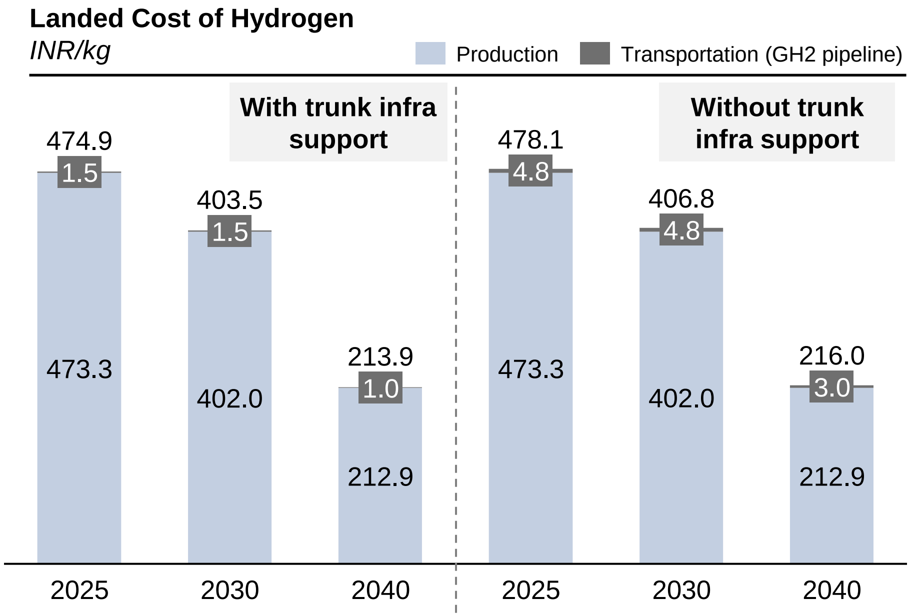
The actual landed cost of green hydrogen for BPCL could range anywhere from 213.9 to 216 INR/Kg in 2040 basis government support

Pathways and support 🟩 High 🟨 Medium 🟥 Low

1	**Production**	🟨 *99.90%*	🟥 *30 bar*	●
2	**Compression**	🟨 *99.90%*	🟥 *30 bar*	○
3	**Purification**	🟨 *99.90%*	🟥 *30 bar*	○
4	**Transportation**	🟨 *99.90%*	🟥 *30 bar*	●
5	**Decompression**	🟨 *99.90%*	🟥 *30 bar*	○
6	**Refinery input**	🟨 *99.90%*	🟥 *30 - 190 bar*	●

- With trunk infrastructure **support refers to absorption of costs (refuelling, grid infra, pipeline and storage) by the government and only OPEX borne by developer**
- Without trunk infrastructure refers to **no cost absorption by the government**

Landed Cost of Hydrogen
INR/kg



- With trunk infra support
  - RE : KL (till 2030), GJ (2040)
  - Banking: 1000 hours
  - WACC: 9%
  - Pumped hydro

- Without trunk infra support
  - RE : KL (till 2030), GJ (2040)
  - Banking: 1000 hours
  - WACC: 9%
  - Pumped hydro

Note: For detailed analysis on landed cost refer to section supply side economics
Source: MEC+ analysis

Regulatory maturity is medium-high

Some central as well as corporate level mandates/targets exist for refineries which can be further strengthened by state regulations

Central, state and company level policies for decarbonisation
Announced Goals and Policies

🟩 Mandate/incentive present for H_2 🟨 Mandate/incentive present at a broader level 🟥 No mandate/incentive present

	Central	State	BPCL
Decarbonisation goal	🟨 Net zero by 2070 for all industries	🟨 Net zero by 2050 for all industries	🟨 Net zero goals at a corporate level by 2040
Emission reduction target	🟨 Plans to set 3-year carbon benchmarks & reduction targets for petrochemical firms	🟥 No specific targets	🟨 Company plan to achieve net-zero emissions by 2040 in Scope 1 and Scope 2 at a corporate level
Carbon pricing	🟨 Currently a part of obligated sector under PAT scheme for energy efficiency and proposed to be part of future carbon trading scheme. Penalties to be set under carbon emission trading scheme		
Subsidy on H_2 costs	🟩 PLIs available for GH_2 production	🟥 No specific subsidies for GH_2 production are available	🟥 Not applicable
Capex/investment commitments	🟥 No specific fund commitment for refineries	🟥 No specific commitments	🟨 INR 12,120 Cr for equipment efficiency, RE project, Petrochemical projects, Biofuel projects (2022-23)
Hydrogen mandate/plans	🟩 Plans to set a 10% GH_2 offtake for refineries from 2023-24 rising to 25% in five years in discussion	🟥 No specific commitments	🟩 Plans of using 10% GH_2 in all refineries combined by 2030. 28 kTPA (Bina/Kochi/Mumbai) by 2030
Overall regulatory score	⬆	⬇	➡

Note: Perform Achieve and Trade
Source: National Green Hydrogen Mission; Govt. of Kerala; BPCL; News Articles; MEC+ analysis

Technology readiness is low to medium

Process integration for small scale demonstration in initial phase is a key requirement

Technology requirements for using green hydrogen in BPCL

Technology Shift and TRL levels

🟥 Unfavourable 🟨 Medium 🟩 Favourable

	Production	Storage/Conversion	Transportation	Offtake
Primary Activities	8	NA	7-8	7
	🟩 • To cater to the entire potential demand, **660 MW of electrolyser would be required** • Currently, demonstration projects are being conducted at a much lower scale	🟩 • **No requirement for storage/conversion** as hydrogen is used in its direct form in continuous processes	🟨 • **Pipeline to be set up** for transportation of hydrogen	🟨 • **Adoption:** Expected to be **high between ~10-60% by 2040 globally** • Demonstration for low scale process integration of GH_2 for refineries is currently being tested in Bina refinery under relevant environment

Supporting Activities

🟥 **Permits & Regulations:** Permits required to setup a pipeline for transportation of green hydrogen; setting up a centralised electrolyser; regulations required to define green hydrogen aligned with the central policies

🟥 **Standards, Safety & Certifications:** Safety studies for hazard identification (HAZID, HAZOP etc), Risk evaluation (QRA, FERA etc) and Risk controlling/ management (HAC, safety audits etc); Specific standards such as CGA H-5, are applicable for hydrogen handling, storage and transport; Design and construction codes have also been established for hydrogen in its various forms

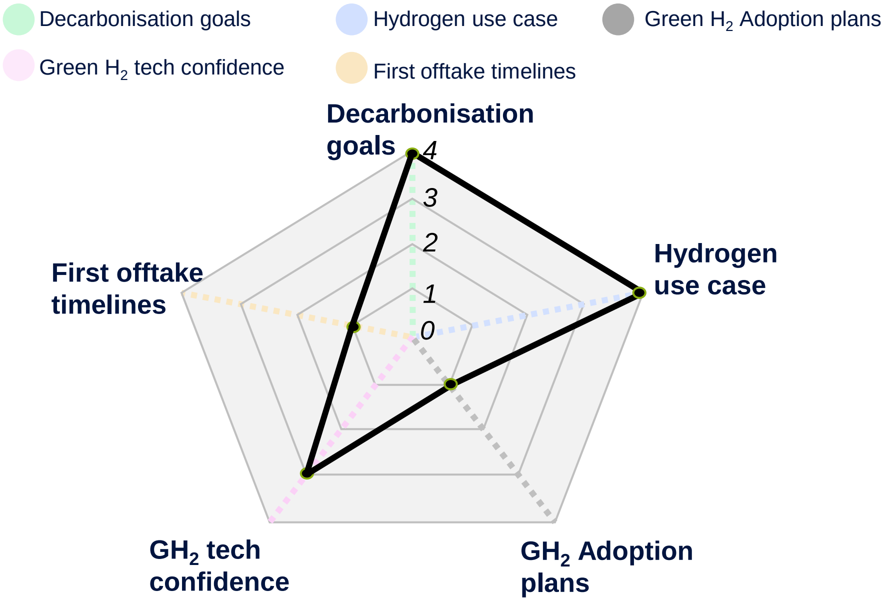
🟥 **Human Resources:** Skilling of manpower across the value chain, including manufacturing of equipment, green hydrogen project installation, and operations & maintenance of pipelines etc.

Source: National hydrogen mission; Indo German energy forum ; Cluster guidelines, Unido; PIB; MEC+ analysis

Offtaker willingness is medium to high

Success of pilot in Bina refinery and green hydrogen costs will determine offtake

Refinery offtake readiness level from 0 to 4 on 5 parameters



2.6

Lack of mandates on refinery level and high cost of green hydrogen hinder current offtake. However, the success of pilot at Bina refinery, declining costs of green hydrogen along with BPCL's net zero target can drive adoption

Decarbonisation goals	BPCL has set a net zero target at corporate level for 2040 for its scope 1 and 2 emissions and Kerala has a net zero target for 2050
Hydrogen use case	Hydrogen can be used in its direct form in the refinery processes
Green H_2 adoption plans	BPCL has a green H_2 pilot in Bina refinery, but no such plans have been announced for Kochi
Green H_2 tech confidence	GH_2 tech confidence is high as it is a proven technology with pilot project being conducted in Bina refinery
First offtake timelines	BPCL has a pilot project for the adoption of GH_2 in Bina refinery. Actual offtake timeline in Kochi will depend on the success of this pilot project, cost decline, govt. mandates on refinery level

Source: Stakeholder Interviews; MEC+ analysis

Adoption of green hydrogen in refineries can be fast tracked

by addressing concerns for new process integration and creating refinery level mandates

Hydrogen offtake in Refineries
Drivers and Inhibitors

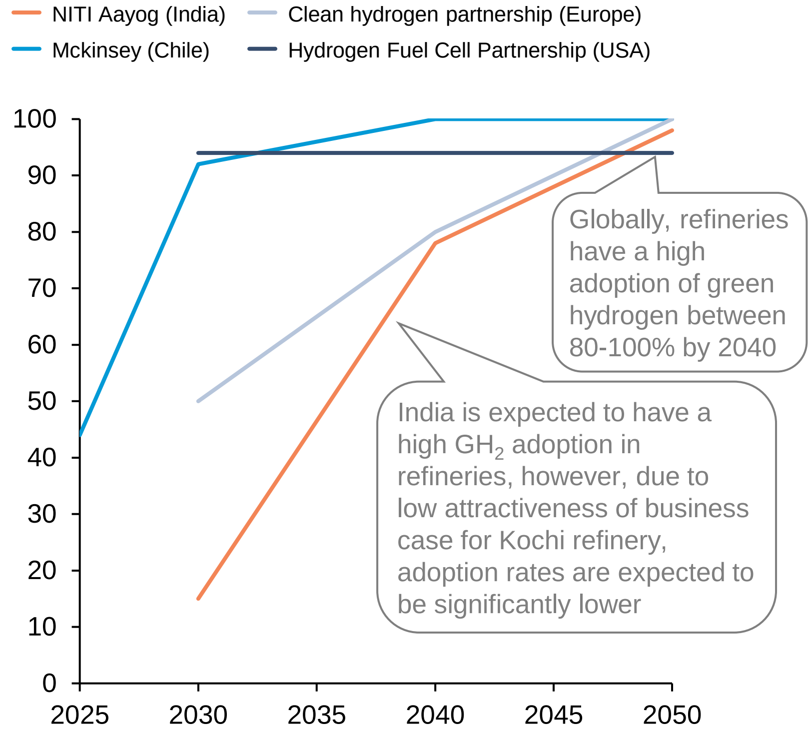
	GH_2 based hydrogen production has high technology maturity, cost competitiveness in the next decade and easy process integration	***Require government intervention on subsidy and infrastructure set up***
Economic	• Green hydrogen would be cost competitive with grey hydrogen towards 2030	• Stranded assets in the industrial gas complex for current hydrogen production
Regulations	• The central government plans to set a 10% GH_2 **offtake** for refineries • BPCL plans to use **10% GH_2 combined in all its refineries by 2030**	• **No regulations for** creation of demand in terms of **mandates, penalties** • **No regulations for** creation of green hydrogen in terms of **investments**
Technical	• Current **pilot demonstration** in Bina refinery and **studies at company level** conducted	• New integration for Kochi Refinery for new setup • Set up of new pipeline will require feasibility to be conducted
Offtaker willingness	• BPCL has a net zero target for 2040 and adoption of green hydrogen is crucial for this target	• BPCL already has a GH_2 pilot in its Bina refinery. Currently no plans and timelines have been outlined for offtake in Kochi

Note: TRL: Technology Readiness Level
Source: BPCL; News Articles; MEC+ analysis

Adoption of Green H_2 in refineries are very high globally by 2040

driven by self-targets and business case, it is expected to be between 5-40 kTPA in 2030 to 2040

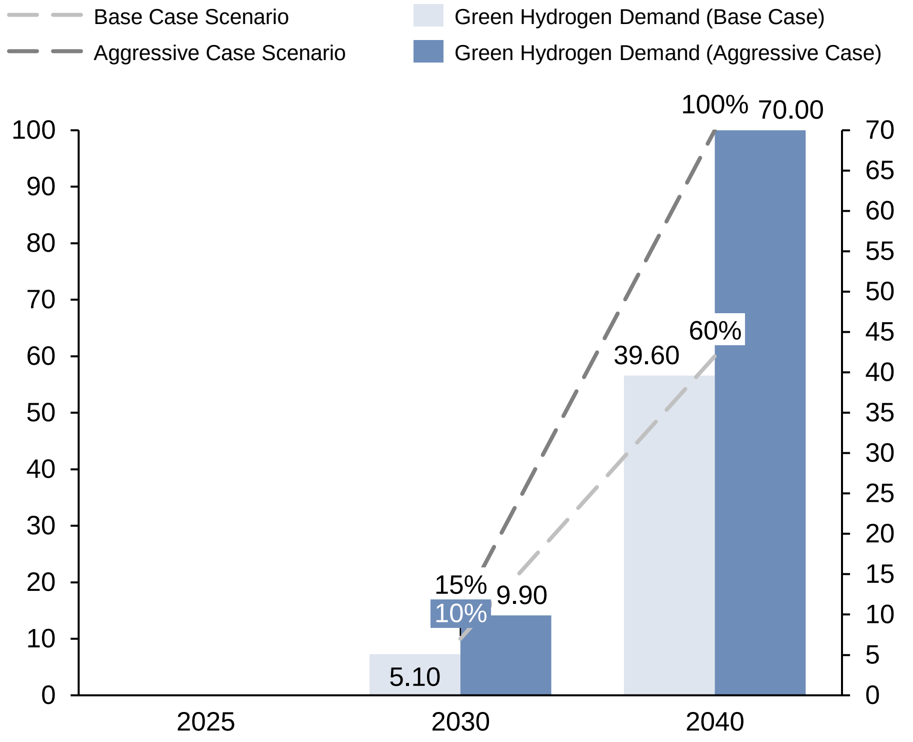
Adoption rate of hydrogen in refinery
% of total demand



Globally, refineries have a high adoption of green hydrogen between 80-100% by 2040

India is expected to have a high GH_2 adoption in refineries, however, due to low attractiveness of business case for Kochi refinery, adoption rates are expected to be significantly lower

Expected adoption rates for refinery in the valley
As % of total demand and demand in kTPA



Note: Base and Aggressive cases are considered based on net zero targets of Kerala
Source: NITI Aayog; HFCP; McKinsey; Clean Hydrogen Partnership; MEC+ analysis

FERTILISER SECTOR

Image Credits

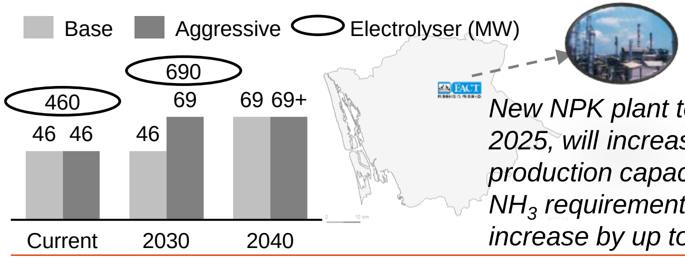
Fertiliser || FACT Kochi is the only fertiliser producer in Kerala

requiring 46 kTPA of Hydrogen

FACT | General Overview

Production Overview	
Location	*FACT has two units in Kerala namely Udyogmandal complex & Ambalamugal complex*
Production Capacity	*280.5 kTPA NH_3 capacity (at 90-95% utilisation)*
Major Products	*NPK Fertilizers and Chemicals: (FACTAMFOS 20:20:0:13), Ammonium Sulphate, Caprolactam Sulphuric Acid, Anhydrous Ammonia, Phosphoric Acid, Sulphur Dioxide etc.*
Customers	*Sales in Kerala and PAN India (Including: Maharashtra, West Bengal, Gujarat, Odisha and Bihar)*

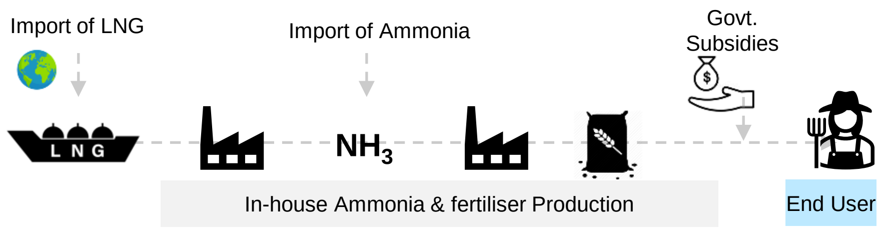
Hydrogen Demand (kTPA) | Current and Projected



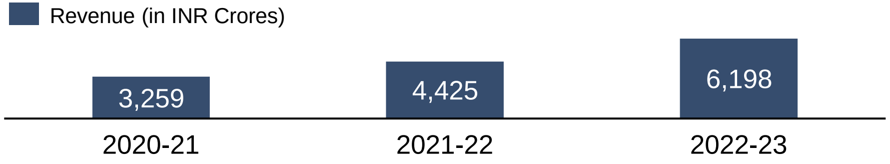
New NPK plant to be set up by 2025, will increase the total production capacity by 50% and NH_3 requirement is expected to increase by up to 50% by 2030

FACT | Business Model & Financials

Business Model



Revenue



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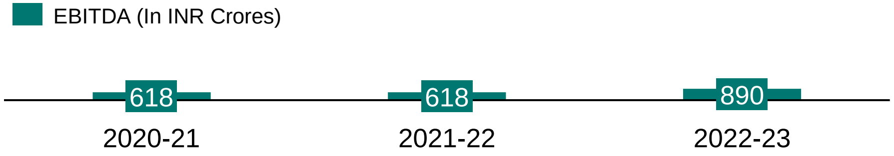


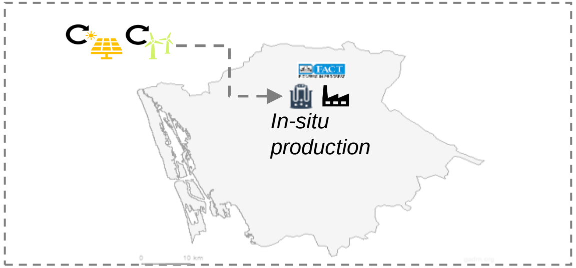
Note: Approx 60-70 TPD NH_3 equivalent of hydrogen is consumed in chemicals production (~12 TPD Green H_2);

Source: FACT Annual Reports; Stakeholder Interviews; MEC+ analysis

Decarbonisation | Different pathways for fertilizers

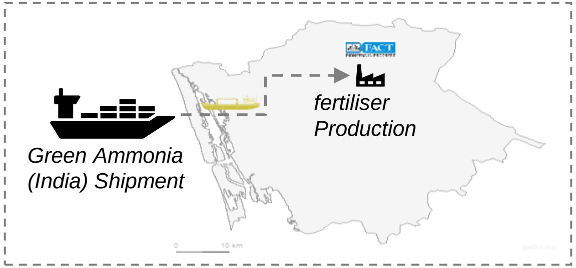
Available Pathways

1 In-situ Production of Green Hydrogen and Ammonia for Captive Consumption



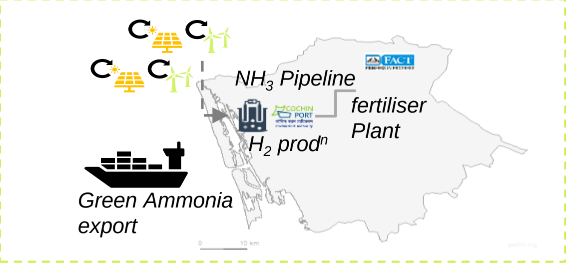
- In this pathway, green hydrogen will be produced in-situ at the FACT premises, N_2 will be sourced through air seperation units and storage will be set-up if required
- Output would be integrated with the ammonia produciton unit (based on results from the technical assessments)
- **This pathway ensures control over supply however plant size based on H_2 adoption would be small (need technical assessment)**

2 Green Ammonia Shipments from Rest of India



- In this pathway, green ammonia will be shipped from rest of Inida to Cochin Port and then delivered to FACT through barges
- This green ammonia would be used to manufacture complex fertilizers at FACT
- **This pathway requires additional transportation infrastructure and development of port infrastructure**

3 Ex-situ Production of Green Hydrogen and Ammonia for Captive Consumption and Exports



- In this Pathway, green H_2 and NH_3 are produced at centrally at port
- Ammonia is transported to FACT through pipelines
- This pathway allows for scaled production of ammonia as export is also a use-case leading to feasible NH_3 plant sizes
- **This pathway ensures feasible NH_3 plant sizes and co-located hydrogen and ammonia production not requiring expensive H_2 pipelines**

Note: Prod^n: Production; Currently minimum size of ~100kTPA NH_3 plant would be required for ammonia production process technology

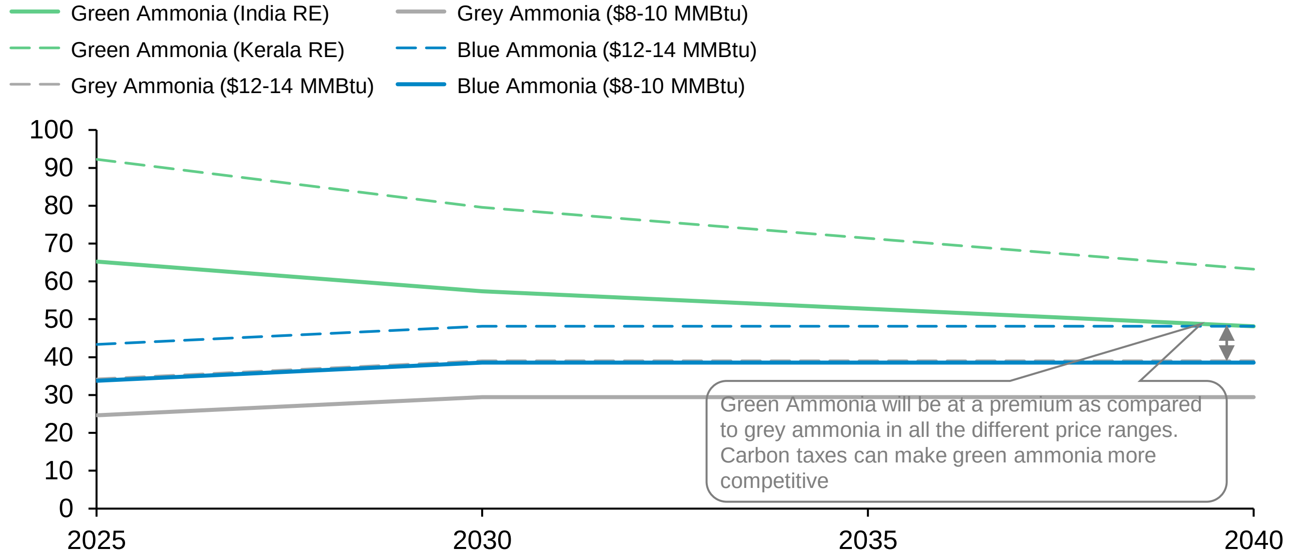
Source: MEC+ analysis

Economic case is low

On comparison with grey ammonia, green ammonia is at price premium excluding carbon taxes scenario across all phases

Green Ammonia | Cost parity with grey ammonia

Production cost of ammonia per kg (INR/kg)



Green Ammonia will be at a premium as compared to grey ammonia in all the different price ranges. Carbon taxes can make green ammonia more competitive

- Being a new technology, the costs are high against incumbent gas-based technology
- Fertiliser is a subsidised sector and plants are optimised to achieve maximum throughput – additional green H_2 costs can increase subsidy burden

Scenarios

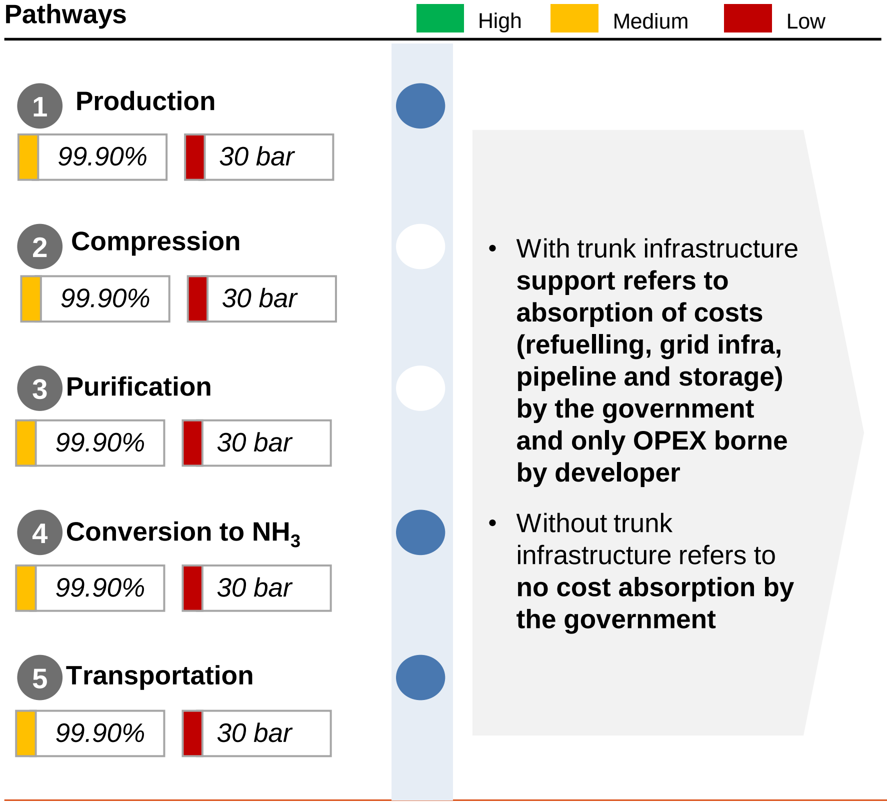
Low Natural Gas Price Scenario: Cost of natural gas is at 8 USD/MMBtu in 2025 and 10 USD/MMBtu in 2030 and 2040 | High Natural Gas Price Scenario: Cost of natural gas is at 12 USD/MMBtu in 2025 and 14 USD/MMBtu in 2030 and 2040 | Green Ammonia (India RE): Hybrid RE from Gujarat and grid banking of 1000 hours| Green Ammonia (KL RE): Solar with Pumped hydro storage from Kerala and grid banking of 1000 hours

Note: NG- Natural Gas

Source: IGEF-MEC+ Model

Cost of Green Ammonia is in a close range

The cost of green ammonia comprises of NH_3 conversion & transportation cost leading to a cost of 48.20 INR/Kg in 2040



Pathways

🟩 High 🟨 Medium 🟥 Low

1 **Production** ●
🟨 99.90% 🟥 30 bar

2 **Compression** ○
🟨 99.90% 🟥 30 bar

3 **Purification** ○
🟨 99.90% 🟥 30 bar

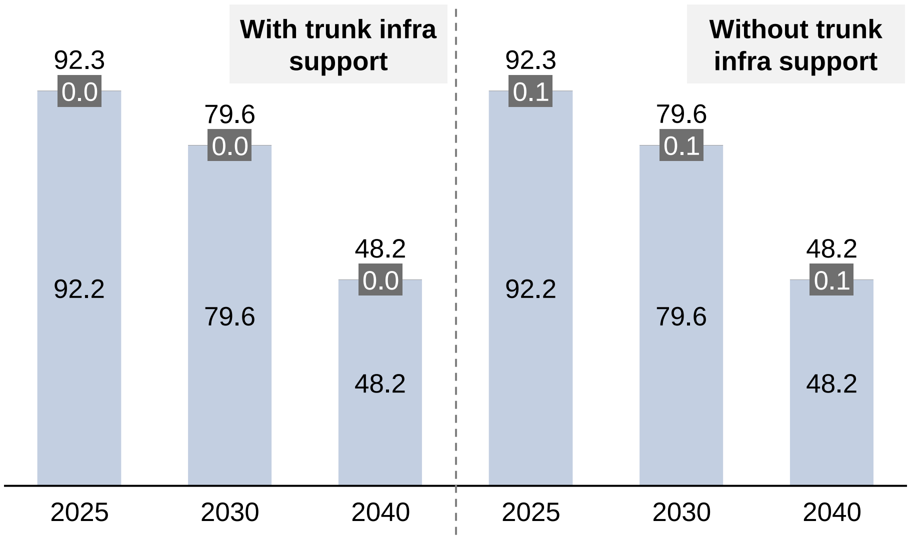
4 **Conversion to NH_3** ●
🟨 99.90% 🟥 30 bar

5 **Transportation** ●
🟨 99.90% 🟥 30 bar

- With trunk infrastructure **support refers to absorption of costs (refuelling, grid infra, pipeline and storage) by the government and only OPEX borne by developer**
- Without trunk infrastructure refers to **no cost absorption by the government**

Landed Cost of Ammonia

INR/kg



- With trunk infra support
  - RE : KL (till 2030), GJ (2040)
  - Banking: 1000 hours
  - WACC: 9%
  - Pumped hydro

- Without trunk infra support
  - RE : KL (till 2030), GJ (2040)
  - Banking: 1000 hours
  - WACC: 9%
  - Pumped hydro

Note: NH_3 transport through pipeline is a mature technology & is done in significant scale as such per unit cost of ammonia is low; For detailed analysis on landed cost refer to section supply side economics

Source: IGEF-MEC+ Model; MEC+ analysis

Policy maturity is medium

Support at central level exists for DAP & urea-based plants but no mandates exist for fertiliser sector in Kerala as of now

Central, state and company level policies for decarbonisation
Announced Goals and Policies

🟩 Mandate/incentive present for H_2
🟨 Mandate/incentive present at a broader level
🟥 No mandate/incentive present

	Central	State	FACT
Decarbonisation goal	🟨 Net zero by 2070 for all industries	🟨 Net zero by 2050 for all industries	🟥 Plans present but no fixed timelines defined yet
Emission reduction target	🟨 No targets are announced	🟥 No targets announced yet	🟥 Plans present but no fixed timelines defined yet
Carbon pricing	🟨 Currently a part of obligated sector under PAT scheme for energy efficiency and proposed to be part of future carbon trading scheme. Penalties to be set under carbon emission trading scheme		
Subsidy on H_2 costs	🟩 PLIs available for green hydrogen production	🟥 No subsidies are available	🟥 Not applicable
Capex/investment commitments	🟥 2 plants each for production of Green H_2 based Urea & DAP to be set up via competitive bidding	🟥 No specific incentives	🟥 Plans to setup 6 MW solar for captive consumption
Hydrogen mandate/plans	🟩 Plan for 5% offtake from 2023-24 rising to 20% in 5 years. Substitute NH_3 based fertiliser imports with domestic green NH_3 based fertilizers	🟥 No mandates	🟥 No mandates/plans
Overall regulatory score	↗	↓	↓

Note: NH_3: Ammonia; PAT: Perform Achieve and Trade Scheme; SIGHT Scheme in place for green hydrogen production incentives
Source: National Green Hydrogen Mission; Govt. of Kerala; News Articles; FACT; MEC+ analysis

Technology readiness is low to moderate

Green NH_3 prod. using RE based green H_2 needs large scale demonstrations and tech development for small-scale plants

Technology requirements for using green hydrogen in FACT

Technology Shift and TRL levels

🟥 Unfavourable 🟨 Medium 🟩 Favourable

	Production	Storage/Conversion	Transportation	Offtake
	8	7-8	8-9	5
Primary Activities	🟩 • To cater to the total demand, **690 MW of electrolyser would be required** • Currently, demonstration projects are being conducted at a much lower scale	🟨 • **Storage:** Not required • **Conversion:** NH_3 conversion needs large scale demonstrations & small-scale plant designs (addressing challenges in performance and non-steady operations)	🟩 • **NH_3 Pipeline:** Pipeline is required to transport NH_3 from port to FACT • The global transportation of ammonia by pipeline is already a well-developed technology	🟥 • **Process integration:** The impact on NPK and DAP production processes for utilising GH_2 at low scale is untested

Supporting Activities

🟥 **Permits & Regulations:** Ministry of New & Renewable Energy has decided to define Green Hydrogen as having a well-to-gate emission (i.e., including water treatment, electrolysis, gas purification, drying and compression of hydrogen) of not more than 2 kg CO2 equivalent / kg H_2); **Permits for ammonia production and handling at ports; permission for setting up a pipeline for transport**

🟥 **Standards, Safety & Certifications:** Safety studies for hazard identification (HAZID, HAZOP etc), Risk evaluation (QRA, FERA etc) and Risk controlling/ management (HAC, safety audits etc); Specific standards such as IS 660 (1963), EN 378 are applicable for ammonia handling, storage and transport; Design and construction codes are also present for ammonia

🟥 **Human Resources:** Employees need skill development for new processes & areas, high-level experts are vital for setting up the electrolyser and green ammonia plant, creating standard protocols and guidelines, need expertise in radiography, non-destructive testing in deployment of pipelines

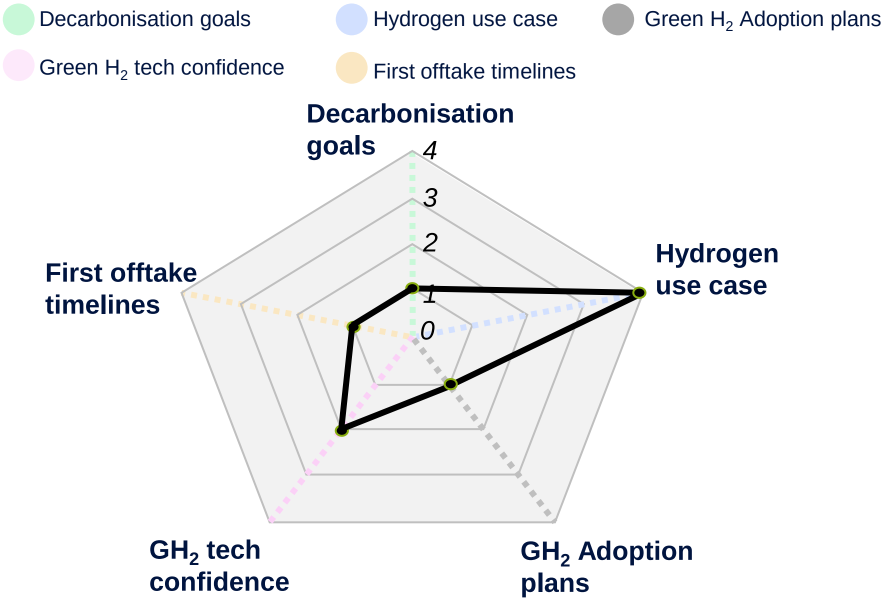
Note: TRL for ammonia production varies between 5-9 globally considering factors like scale, variability of RE etc

Source: Indo German energy forum; PIB; Cluster guidelines, Unido; Joule; IEA; The Royal Society; MEC+ analysis

Off-taker willingness is medium

Need decarbonisation targets and capex investments for green hydrogen conversion

Fertiliser offtake readiness level from 0 to 4 on 5 parameters



1.8

CAPEX for new unit to test green hydrogen conversion to ammonia, sunk cost of existing unit and lack of mandates

Decarbonisation goals	FACT has taken steps towards decarbonisation via RE integration (Rooftop RE), plans more RE (Floating Solar - 6MW), however **feedstock-based CO_2 emission reduction do not have a fixed timeline**
Hydrogen use case	Direct use case for substitution of grey ammonia to green ammonia exists. However, willingness to uptake will be basis development in technology, mandates and cost competitiveness of green ammonia
Green H_2 adoption plans	Current plans limited to import substitution. Future willingness to uptake basis cost competitiveness exists. Adoption to depend on govt. mandates
Green H_2 tech confidence	Tech. in demonstration stage. Need proven technology providers. Some process changes required for small scale demonstration and stranded assets are a challenge
First offtake timelines	No fixed timelines set. Cost declines and govt. mandates can drive adoption in 2030, but final product (fertiliser) is subsidised which may impact mandate creation

Source: Stakeholder interviews; MEC+ analysis

GH_2 tech and economics are not becoming favorable for adoption

government interventions on these can support unlock the demand

Hydrogen offtake in Fertilizers

Drivers and Inhibitors

	GH_2 based fertiliser provide medium technology maturity, cost competitiveness in the next two decades, and import substitution	***Require government intervention on subsidy, asset depreciation, and infrastructure***
Economic	• Green ammonia could become competitive with grey ammonia in a scenario where carbon emissions are taxed	• Price sensitivity of green hydrogen/ammonia for fertiliser manufacturing • Additional CAPEX requirement for new unit
Regulations	• Targets to substitute imports of ammonia • Plans for setting up green H_2 and green NH_3 plants through competitive bidding	• No clear mandates • No pilots suggested for NPK based fertilisers in NGHM • No clear goals for decarbonisation or adoption of green ammonia at state or company level
Technical	• Studies being carried out for small scale green ammonia produciton plants globally	• No studies done on a company/state level for integration of green ammonia into current process/new green ammonia plants
Offtaker willingness	• Initial plans for import substitution • Possibility of green H_2 use in chemicals division • Offtaker willingness to study new technology	• No defined timelines for decarbonisation exist • Need for technology and integrators • Clarity on the future of stranded assets

Note: TRL – Technology Readiness Level; NGHM: National Green Hydrogen Mission; BAU: Business as Usual

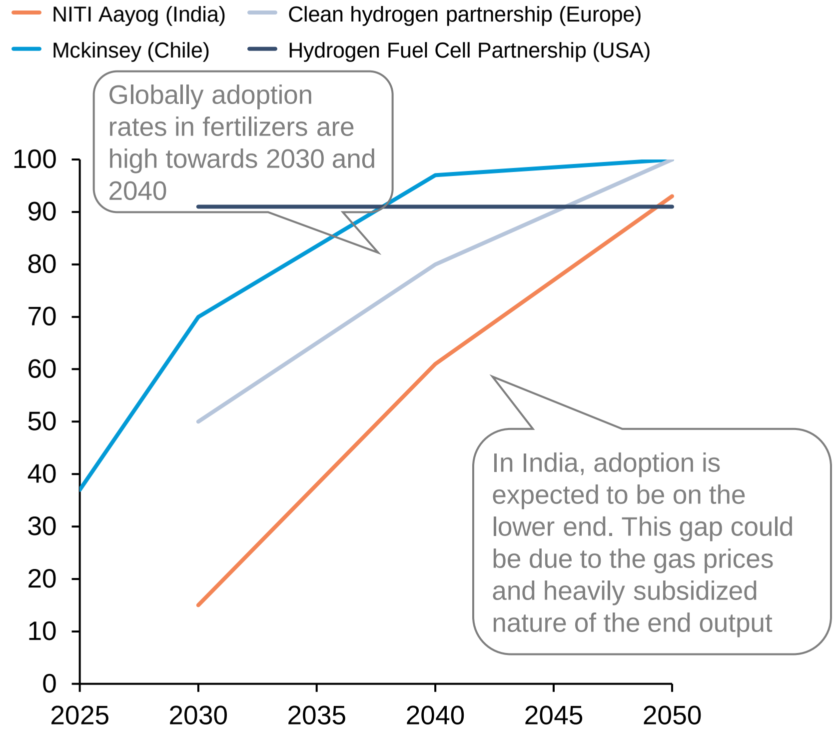
Source: National Green Hydrogen Mission; Interviews; Frazer-Nash; MEC+ analysis

Adoption of Green H_2 in fertilizers are high globally towards 2040

adjusting for the adoption in Kerala the Green H_2 demand is expected in range 18% to 36% of the total demand in 2040

Adoption rate of hydrogen in fertiliser units

% of total demand

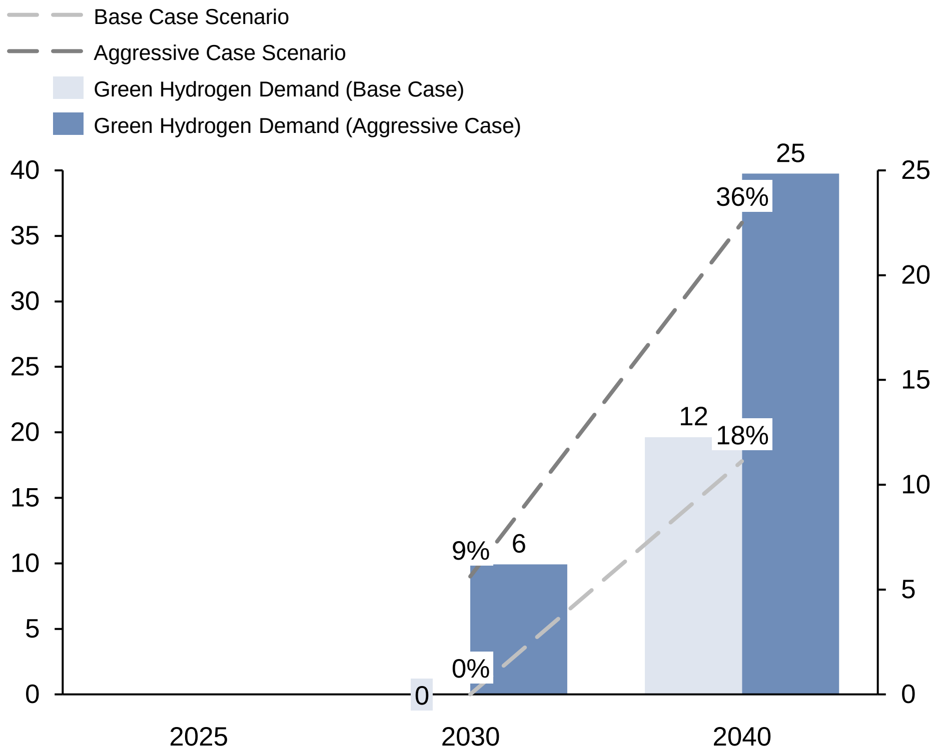


Globally adoption rates in fertilizers are high towards 2030 and 2040

In India, adoption is expected to be on the lower end. This gap could be due to the gas prices and heavily subsidized nature of the end output

Expected adoption rates for fertilizers in the valley

As % of total demand and demand in kTPA



Note: Base and Aggressive cases are considered based on the high/low natural gas prices and price premiums for grey ammonia, net zero targets of Kerala and valley specific parameters; a 10-year expansion plan lag is considered in base case – potential demand: 2030(46 kTPA) and 2040 (69 kTPA)

Source: NITI Aayog; McKinsey; HFCP; Clean Hydrogen Partnership; MEC+ analysis

ROAD TRANSPORT

Image Credits

4 competing technologies exist in mobility use case

for low/no emission technologies in buses

Types of zero emission technologies for buses

	Retrofitted HICE	Hydrogen ICE	Hydrogen FCEV	Electric
	H_2	H_2	H_2	H_2
Driving Range (km)	280-300 km (30 kg tank)	280-300 km (30 kg tank)	350-500 km (30-40 kg tank)	250 Kms (260 kWh Battery)
Refuelling Time	20-30 minutes	20-30 minutes	20-30 minutes	90 minutes (Fast Charging)
Load (for maximum efficiency)	Medium to high	Medium to high	Low to medium	Low
Capex (INR)	0.1-0.3 Crore*	0.7-0.8 Crore	2 Crore	1.1 Crore
Infrastructure Requirement	H_2 distribution and refuelling infrastructure	H_2 distribution and refuelling infrastructure	H_2 distribution and refuelling infrastructure	Charging Infrastructure and grid upgrades
Technology readiness level (heavy duty vehicles)	5-6	6-7	8-9	9
Commercial readiness in India	Preliminary development ○	Pilots demonst. in trucks ○	Pilots being conducted ◔	Multiple tenders awarded ◑

Note: *CAPEX for retrofitted ICE: Development phase = 0.3 crore, Deployment phase = 0.1-0.2 crore

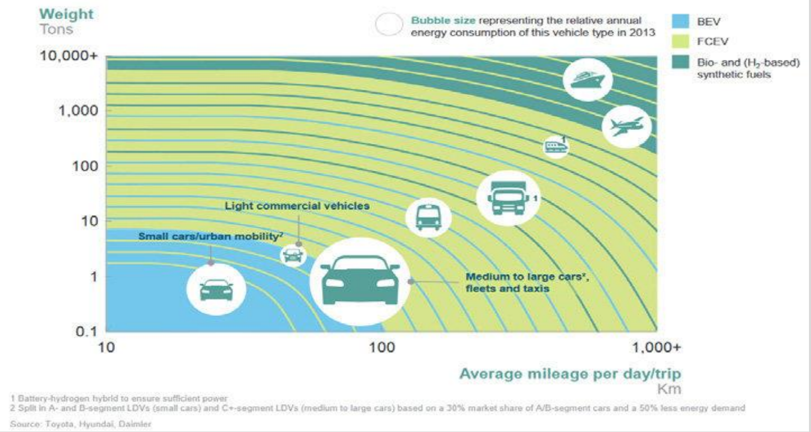
Source: Green hydrogen industrial cluster guidelines; H_2IQ; NREL; Primary; MEC+ analysis

Globally, heavy duty transport makes a strong case for hydrogen

In Kerala, KSRTC is the largest state-run bus operator providing anchor fleet for H_2 offtake

Mobility feasibility for hydrogen, battery electric vehicles

Global landscape of transport segments and suitable technology



1 Battery-hydrogen hybrid to ensure sufficient power
2 Split in A- and B-segment LDVs (small cars) and C+-segment LDVs (medium to large cars) based on a 30% market share of A/B-segment cars and a 50% less energy demand

Source: Toyota, Hyundai, Daimler

- **Electrification will make strongest case for small cars and light commercial vehicles since they run on a short range**
- **Hydrogen will be preferred for heavy duty vehicles such as buses, trucks, trains (hybrid) as they have longer range and need shorter refuelling time to avoid loss of business**

Current operators in Kerala

Selected operator

	Private Buses	Public Buses (KSRTC)	Trucks
Ownership status	Privately owned fleet	State owned fleet	Separation of fleet ownership and operator
Type of operations	Multiple small players operating in fragments	Concentrated operations in South Kerala	Multiple small players operating in fragments
Scalability of operations	**Low** as each player has a small fleet	**High** as KSRTC owns all the buses	**Low** as each player has a small fleet

- **KSRTC will be the best suited operator for running a pilot on hydrogen offtake:**
- **It operates a fleet of ~5600 buses**
- **It has concentrated operations on routes running from Kochi to Trivandrum and dominates operations in the southern region**
- **There is scope for scalability as all the fleet is owned by the government**

Source: Hydrogen Council; Primary interviews; MEC+ analysis

KSRTC operates a fleet of 5600 buses in Kerala

With total potential hydrogen demand of 43 kTPA divided between long- and short-range buses where demand can be anchored for 13 kTPA of long-range buses

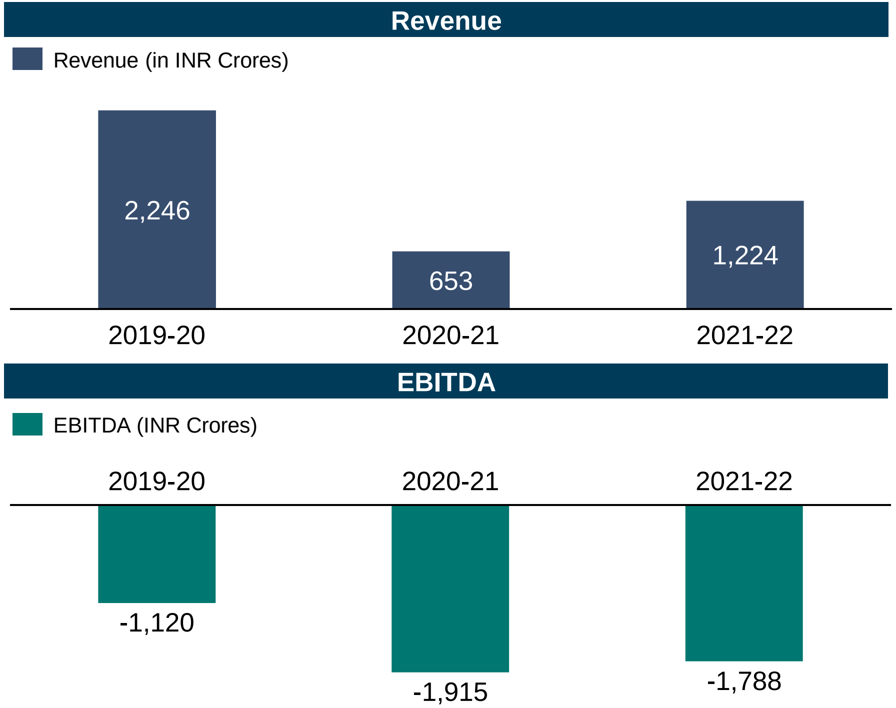
KSRTC operations in Kerala

⬭ MW electrolyser

Fleet size*	5,600	5,656	5,713	5,770
	2023	2025	2030	2040
Fuel consumption (lakh litres)	3.95	3.99	4.03	4.07
	2023	2025	2030	2040

Type of fleet	1,000	4,600
	Long range	Short range
Potential GH_2 consumption (kTPA)	13 130	30 300
	Long range	Short range
Routes covered	KSRTC has high coverage in southern Kerala covering routes from Kochi to Trivandrum	
Distance (km)/day	An average of ~16 lakh kms is operated on a daily basis	

Financial performance of KSRTC



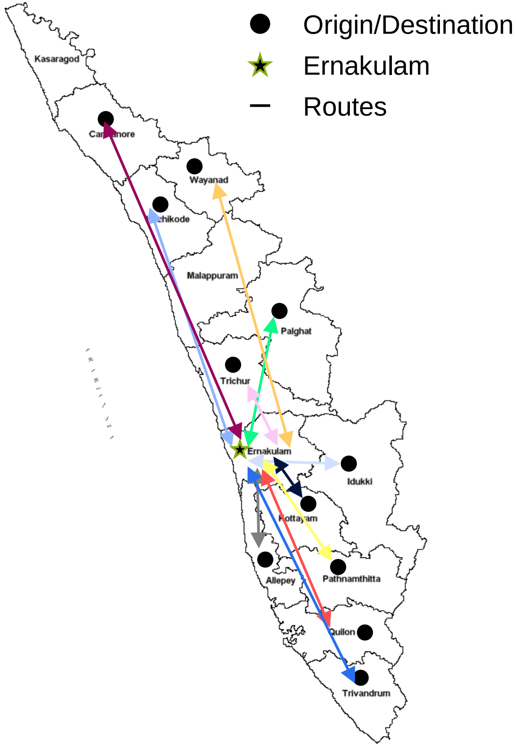
Note: Potential demand for GH_2 has been estimated for 1000 buses on 1 refuelling of a 40 kg tank for 330 days; *Fleet size is based on estimates applying a CAGR of 1%

Source: KSRTC financial data; Review of public enterprises in Kerala; Primary interviews; MEC+ analysis

From Ernakulam, 11 long inter-city routes span serving ~300 buses

Of the 1000 long range buses, ~300 buses run through Ernakulam over inter-city routes with a potential of 3.96 kTPA

KSRTC: Major Intercity Routes from Kochi



Inter-city routes, distances, traffic and ecologically sensitive zones

	Route	Round Trip (km)*	Traffic**	Ecological Sensitivity
●	Ernakulam to Kannur	536	2	🟥
●	Ernakulam to Kozhikode	352	11	🟥
●	Ernakulam to Palakkad	258	5	🟥
●	Ernakulam to Thrissur	148	48	🟥
●	Ernakulam to Idukki	246	19	🟩
●	Ernakulam to Kottayam	138	76	🟥
●	Ernakulam to Alappuzha	120	17	🟥
●	Ernakulam to Pathanamthitta	246	7	🟩
●	Ernakulam to Kollam	282	12	🟥
●	Ernakulam to Thiruvananthapuram	418	37	🟥

Note: *Round trip distances < 250 kms can be run on EV, Round trip distances of >250-500 kms are suitable for hydrogen; **Refers to number of buses/day basis website

Source: Website; Primary interviews; MEC+ analysis

In order to convert these routes, 3 essential elements are needed

Hydrogen production, set up of refuelling infrastructure and deployment of hydrogen buses are key to convert the potential demand

Infrastructure requirements for converting bus routes to hydrogen bus routes

Hydrogen production

Production of H_2

Compression

Purification

Production of green hydrogen via electrolysis. A key input required for mobility use case of hydrogen is compression of H2 molecules as well as high purity at 99.999% (for FCEV specifically).

Refuelling

Refuelling infra

Setup of refuelling infra along the routes to ensure continuous supply of hydrogen to the buses

Offtake

Hydrogen bus

Procurement and deployment for HFCEV and HICE buses for offtake over the long-range routes

Source: MEC+ analysis

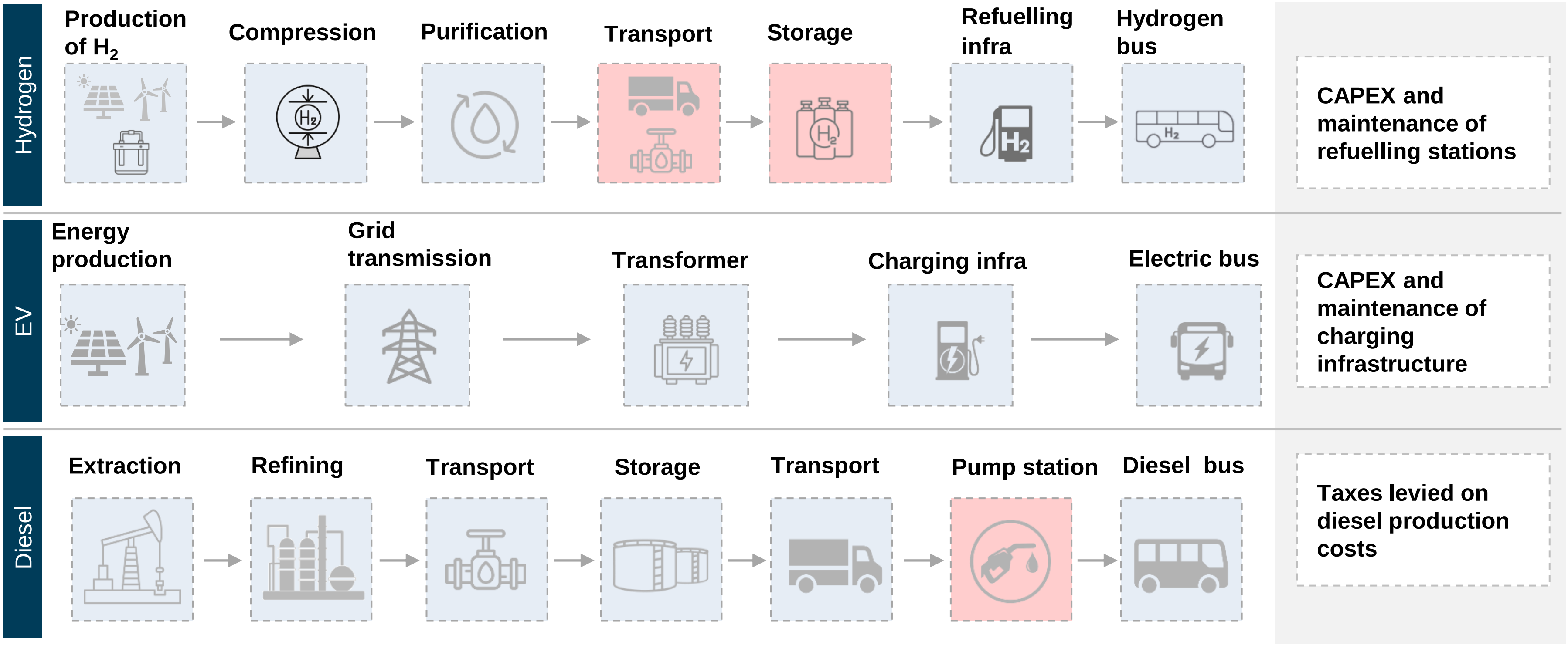
To assess demand conversion economically, we've calculated TCO

We have compared incumbent fuels as well as competitive technologies for TCO calculation over 5-7 value chain elements

🟦 Included in TCO 🟥 Not included in TCO

Infrastructure requirements for various technologies and their inclusions for TCO analysis

Relative additional costs



Hydrogen

Production of H_2 🟦 → Compression 🟦 → Purification 🟦 → Transport 🟥 → Storage 🟥 → Refuelling infra 🟦 → Hydrogen bus 🟦

CAPEX and maintenance of refuelling stations

EV

Energy production 🟦 → Grid transmission 🟦 → Transformer 🟦 → Charging infra 🟦 → Electric bus 🟦

CAPEX and maintenance of charging infrastructure

Diesel

Extraction 🟦 → Refining 🟦 → Transport 🟦 → Storage 🟦 → Transport 🟦 → Pump station 🟥 → Diesel bus 🟦

Taxes levied on diesel production costs

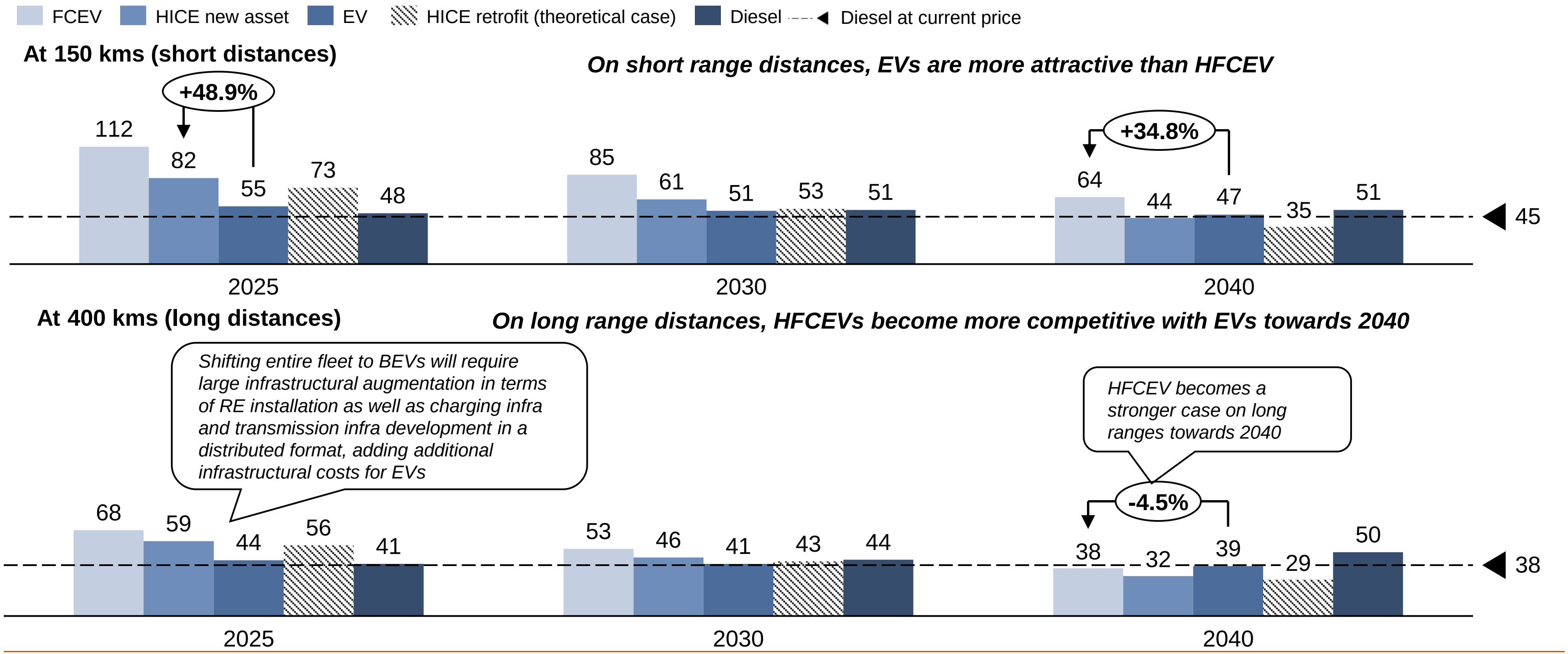
Source: MEC+ analysis

Economic |HICE emerges as most competitive fuel technologically

On comparing EV with H_2, HFCEV becoming stronger for longer ranges towards 2040

Total cost of ownership analysis at different distances

INR/km



On short range distances, EVs are more attractive than HFCEV

On long range distances, HFCEVs become more competitive with EVs towards 2040

Shifting entire fleet to BEVs will require large infrastructural augmentation in terms of RE installation as well as charging infra and transmission infra development in a distributed format, adding additional infrastructural costs for EVs

HFCEV becomes a stronger case on long ranges towards 2040

Note: Cost of GH_2 considered is at 0 tax value; Assumptions: We have considered a fleet of 10 buses for TCO calculation to run over 400km and have full utilisation of a 400kg refuelling station; In EVs the range of 400 km is expected to be covered in between 2 buses; one refuelling for H_2

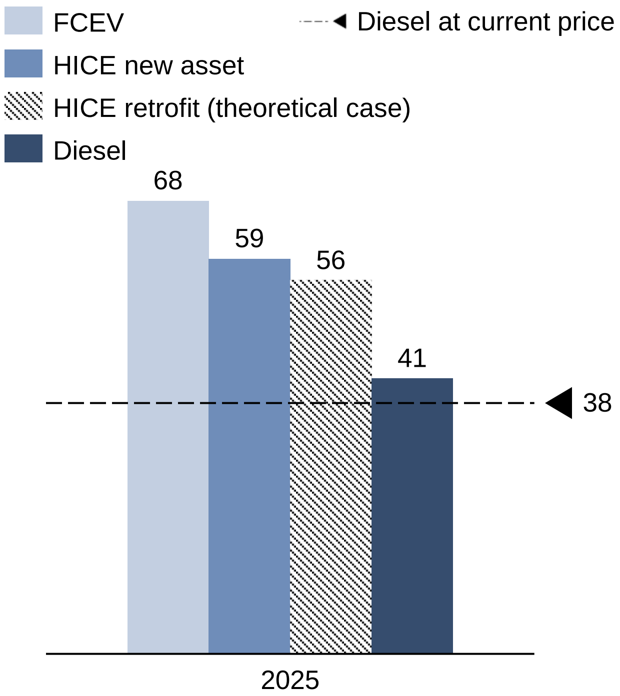
Source: MEC+ analysis

Economic | In next decade, diesel & hydrogen can be comparable

if investment support is provided for the cost and maintenance of the bus as well as refuelling

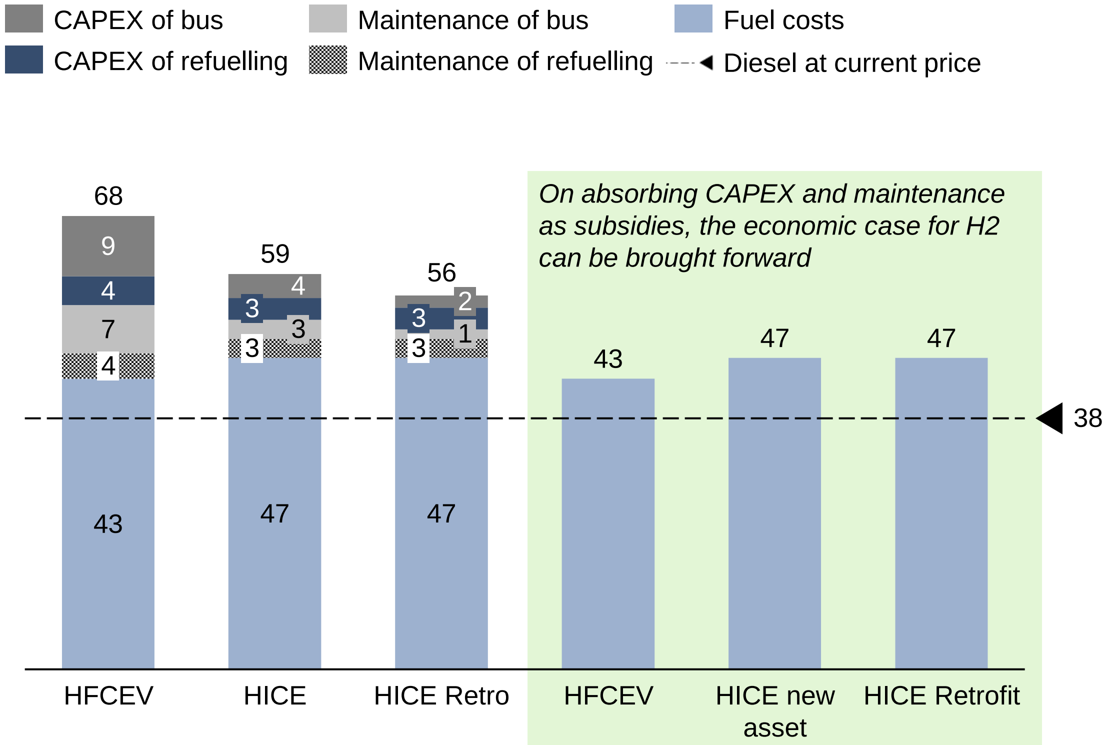
Total cost of ownership analysis at 400 km

INR/km



Factor wise TCO for buses in 2025

INR per factor/km



On absorbing CAPEX and maintenance as subsidies, the economic case for H2 can be brought forward

Note: Cost of green hydrogen considered is at 0 tax value; diesel prices are expected to rise from INR 100 to INR 147; one refuelling is considered for H_2 buses

Source: MEC+ analysis

The results are based on 100% utilisation of 400 kg refuelling infra

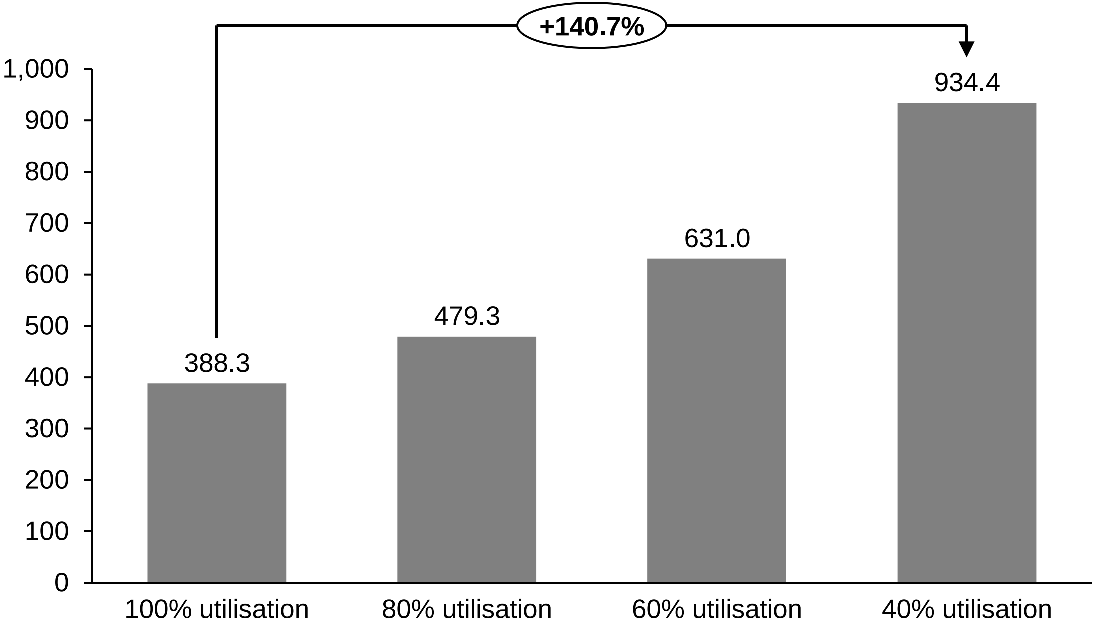
The landed costs is highly sensitive to refuelling infra utilisation, lower utilisation can have ~140% higher costs | refuelling infra has been sized to ensure 100% utilisation in all configurations

Refuelling infrastructure

- As the number of refuelling stations increases, **initial setup costs get distributed across a larger network**. This **decreases the per-unit cost** of establishing and operating each station, making the overall infrastructure more cost-efficient
- A higher utilisation of the refuelling would mean lower per unit costs whereas lower utilisation would mean high per unit costs for a fixed rate of return
- We have considered **4 scenarios** for arriving at refuelling costs: 40% utilisation, 60% utilisation, 80% utilisation and 100% utilisation

400 kg refuelling costs at different utilisation rates

INR/kg



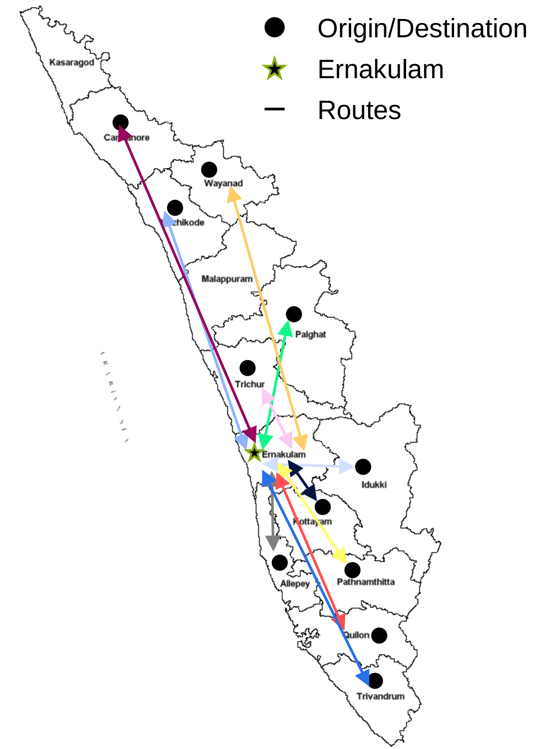
Note: Cost of refuelling at a 400 kg hydrogen station is influenced by its utilisation rate. A fixed margin on the investment directly affects hydrogen (H_2) cost. The compressor energy is calculated 0.26 kWh/kg H_2, decreases with limited H_2 utilisation, the savings of which have also been considered

Source: MEC+ analysis

Economically assessed, 4 routes appear most attractive for pilots

11 intercity routes run from Ernakulam, of which based on distance, traffic and ecological sensitivity 4 routes seem attractive

KSRTC: Major Intercity Routes from Kochi



Inter-city routes, distances, traffic and ecologically sensitive zones

🟩 Attractive 🟥 Not attractive
▣ Selected

	Route	Round Trip (km)*	Traffic**	Ecological Sensitivity
●	Ernakulam to Kannur	536 🟥	2 🟥	🟥
●	Ernakulam to Kozhikode	352 🟩	11 🟩	🟥
●	Ernakulam to Palakkad	258 🟩	5 🟥	🟥
●	Ernakulam to Thrissur	148 🟥	48 🟥	🟥
●	Ernakulam to Idukki	246 🟩	19 🟩	🟩
●	Ernakulam to Kottayam	138 🟥	76 🟥	🟥
●	Ernakulam to Alappuzha	120 🟥	17 🟥	🟥
●	Ernakulam to Pathanamthitta	246 🟩	7 🟥	🟩
●	Ernakulam to Kollam	282 🟩	12 🟩	🟥
●	Ernakulam to Thiruvananthapuram	418 🟩	37 🟩	🟥

Note: *Round trip distances < 250 kms can be run on EV, Round trip distances of >250-500 kms are suitable for hydrogen; **Refers to number of buses/day basis website

Source: Website; Primary interviews; MEC+ analysis

H_2 costs could range anywhere from 294 to 414 INR/kg in 2040

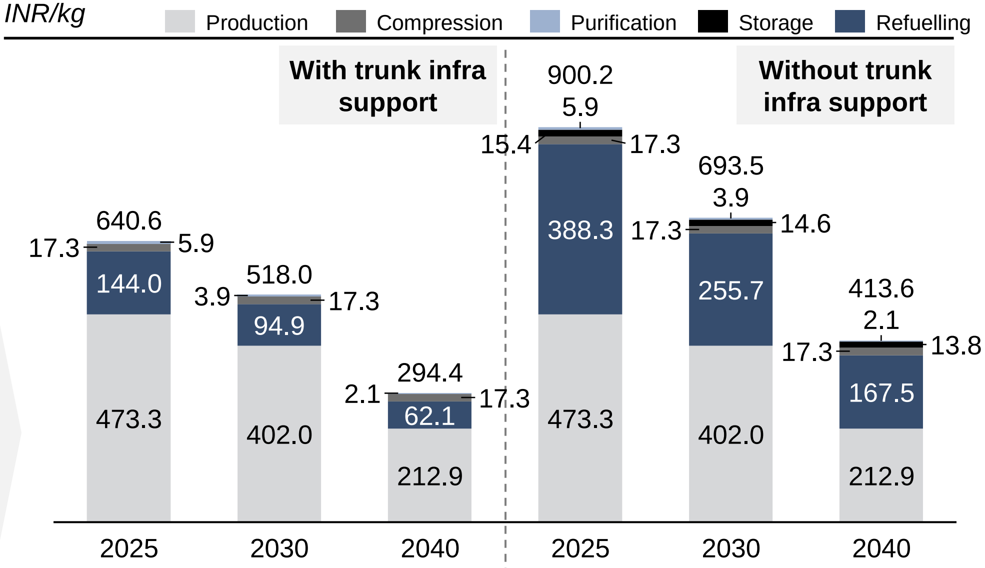
with refuelling station having highest cost contribution after production

Pathways 🟩 High 🟨 Medium 🟥 Low

1 Production	🟨 *99.90%*	🟥 *30 bar*	●
2 Compression	🟨 *99.90%*	🟩 *200 bar*	●
3 Purification	🟩 *99.999%*	🟩 *200 bar*	●
4 Transportation	🟩 *99.999%*	🟩 *200 bar*	○
5 Onsite Storage	🟩 *99.999%*	🟩 *200 bar*	●
6 Refuelling Station (compression/dispenser)	🟩 *99.999%*	🟩 *350 bar*	●

- With trunk infrastructure **support refers to absorption of costs (refuelling, grid infra, pipeline and storage) by the government and only OPEX borne by developer**
- Without trunk infrastructure refers to **no cost absorption by the government**

Landed Cost of Hydrogen



- With trunk infra support
  - RE : KL (till 2030), GJ (2040)
  - Banking: 1000 hours
  - WACC: 9%
  - refuelling storage cost absorbed by the govt, only OPEX considered

- Without trunk infra support
  - RE : KL (till 2030), GJ (2040)
  - Banking: 1000 hours
  - WACC: 9%
  - Storage cost included

Note: Refuelling includes compression and dispensing of hydrogen till 350 Bar for 1 tpd plant; H_2 buffer storage pathway is not used; For detailed analysis on landed cost refer to section supply side economics

Source: IGEF-MEC Model; MEC+ analysis

Regulation maturity is low

Currently no specific regulations with specific timelines for offtake of hydrogen exist for transport sector in Kerala or centrally inhibiting the uptake of green hydrogen

Central, state and company level policies for decarbonisation
Announced Goals and Policies

🟩 Mandate/incentive present for H_2
🟨 Mandate/incentive present at a broader level
🟥 No mandate/incentive present

	Central	State	KSRTC
Decarbonisation goal	🟨 Net zero by 2070 for all industries	🟨 Net zero by 2050 for all industries	🟨 Net zero goals at a corporate level by 2040
Emission reduction target	🟥 Reduction targets using EV (30% electric LDV sales by 2030	🟥 Emission reductions by deploying 1 million EVs on road by 2022	🟥 Reduction by adoption of EV in the entire fleet of KSRTC by 2025, however currently 117 buses operate
Carbon pricing	🟥 No carbon mandates		
Subsidy on H_2 costs	🟥 Competing tech such as EVs have received subsidies/waivers etc		
Capex/investment commitments	🟥 CAPEX/Investments in EVs have been made		
Hydrogen mandate/plans	🟥 No hydrogen mandates are present		
Overall regulatory score	↓	↓	↓

Note: ACC: Advanced Chemistry Cell
Source: Decarbonising transport 2023; EV policy; News article; ICCT: BS-VI norms; PIB; E-Amrit; Mercom; Tender KSRTC; News article; MEC+ analysis

Technology readiness is medium

Technology demonstration for various hydrogen-based buses exists in controlled environment

Technology requirements for using green hydrogen in KSRTC

Technology Shift and TRL levels

🟥 Unfavourable 🟨 Medium 🟩 Favourable

Primary Activities

Production	Storage/Conversion	Refuelling station	Offtake
8	6	6-7	6-9
🟩	🟥	🟥	🟨
• To cater to the potential demand, **130 MW of electrolyser would be required** • Demonstration projects at this scale are being conducted globally	• **Storage:** Storage in refuelling stations for buses exists at controlled scale in isolated environments through demonstrations • **Conversion:** Not required	• **Refuelling station:** To cater to annual demand, refuelling station of 400 kg/day to setup • Demonstration projects for being conducted at very initial level	• **Offtake:** FCEV buses are at a TRL of 8-9 with successful demos undertaken whereas for HICE and retrofit HICE exist at concept level for buses

Supporting Activities

🟥 **Permits & Regulations:** Permits required for setting up refuelling at port or over the routes, permits for entering of buses in port, permits required for procurement of HFCEV and HICE buses

🟥 **Standards, Safety & Certifications:** For hydrogen fuelled road transport, international standards such as CEN/TC268 give quality specifications for fuel cells. Further, Indian and international standards such as IS/ISO 13985 : 2006, IS17268 : 2020, EN 17127 are present for refuelling stations; specific and stringent safety and standards required specifically in state and centrally

🟥 **Human Resources:** Skilling of manpower across the value chain, including manufacturing of buses, Green Hydrogen project installation, and operations & maintenance, skill development for H_2 bus operations, refuelling station operations

Note: TRLs are based on pilot projects being conducted in India by companies such as Reliance, IOCL etc

Source: PIB; Standards and certifications, IIT Madras; Cluster guidelines, Unido; MEC+ analysis

Technology demonstrations in progress

Various technology demonstrations for HFCEV and HICE buses in various stages are currently in progress in India

Technology requirements for using green hydrogen in KSRTC

Technology Shift and TRL levels

Retrofitted ICE

No demonstration has been seen in buses presently

Hydrogen ICE

Cummins and Tata Motors have signed a Memorandum of Understanding (MoU) to collaborate on the design and development of low and zero-emission propulsion technology solutions for commercial vehicles in India, including hydrogen-powered internal combustion engine

Hydrogen FCEV

Currently companies such as IOCL; Olectra & Bharat Benz in collaboration with Reliance; and Tata Motors have **launched pilot hydrogen FCEV buses** in India

Electric

Several companies have manufactured and launched EVs on a **commercial scale** in India for various applications including public transportation, commercial fleet operations etc

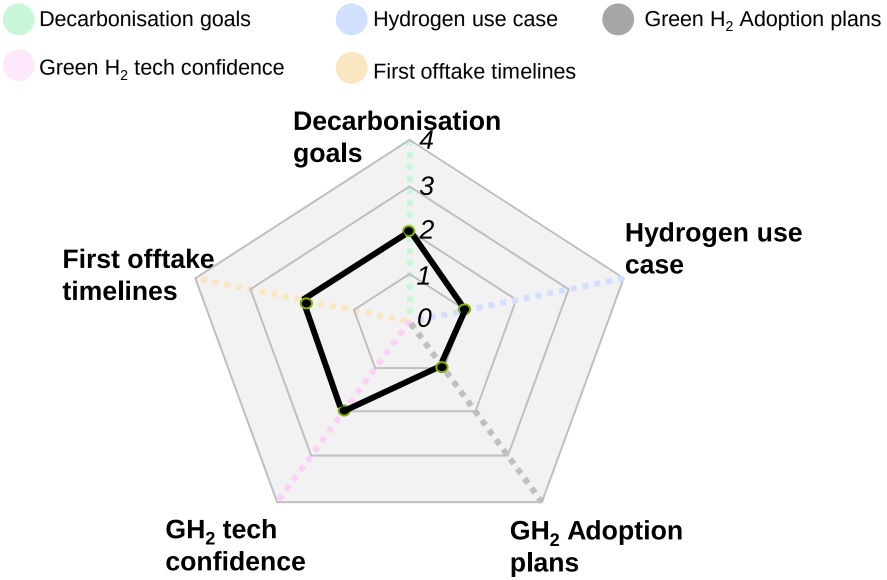
Note: The players listed are not exhaustive

Source: Hydrogen ICE; IOCL; Reliance & Olectra; Tata Motors; Reliance & Bharat Benz; EV bus; Ashok Leyland; MEC+ analysis

Off-taker willingness is low to medium

willingness and openness for green hydrogen uptake is relatively lower for the transport sector

Road transport offtake willingness level from 0 to 4 on 5 parameters



1.6

Lack of mandates, high cost of green hydrogen, procurement of new assets and set up of infrastructure hinder offtake. However, Kerala's net zero target, high TRL and possible support from govt can drive adoption

Decarbonisation goals	KSRTC has deployed EV buses for decarbonisation of its fleet; no goals specific to H_2 have been announced but Kerala has a net zero target for 2050
Hydrogen use case	H_2 does not have a direct use and will require huge expenditure in terms of new assets, infrastructure set up etc. H_2 is suitable for specific markets only
Green H_2 adoption plans	No adoption plans as mandates, regulations and targets are not present. Adoption will depend on support provided by the government
Green H_2 tech confidence	refuelling infrastructure is a potential challenge; high costs of new assets in the fleet
First offtake timelines	No timelines have been outlined by KSRTC; Willingness to test pilot given government support in terms of infrastructure and bus CAPEX

Source: Stakeholder Interviews; MEC+ analysis

Currently only technology readiness acts as a driver for H_2 offtake

The lack of regulations, poor economics and medium off-taker willingness inhibit hydrogen uptake

Hydrogen offtake in Buses

Drivers and Inhibitors

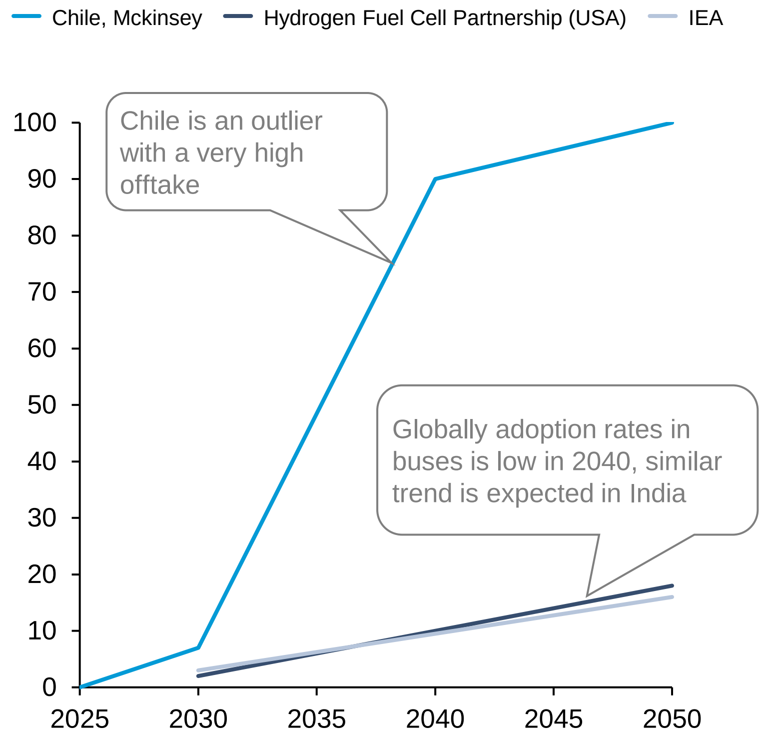
	GH_2 based hydrogen production provide high technology maturity, cost competitiveness in the next decade and is suitable for long ranges	***Require government intervention on subsidy and infrastructure set up (bus & refuelling)***
Economic	• Hydrogen buses will make a strong case for long ranges (400 kms) given initial support from the government	• **New assets (buses) and infrastructure (refuelling)** would be required inhibiting adoption. Government support will be needed initially
Regulations	• **No drivers** present at central, state, self level for hydrogen	• No regulations for demand creation in terms of mandates, targets, penalties • No regulations for creation of supply in terms of incentives and subsidy
Technical	• There are 3 types of H_2 technology available: HICE, Retrofitted HICE, FCEV • TRL of FCEV is between 8-9 showcasing that the technology is successfully demonstrated	• **Commercial feasibility is yet to be tested** • Cost competitive technologies such as HICE, Retrofitted HICE have a low TRL and their usage has not been demonstrated yet
Offtaker willingness	• **No drivers present** for hydrogen offtake for KSRTC presently	• **Offtaker willingness is low** at 1.6 on parameters including decarbonisation goals, hydrogen use case, adoption plans, tech confidence and offtake timelines

Source: Stakeholder Interviews; MEC+ analysis

Adoption of Green H_2 in Buses are Low to Medium demand in 2040

Basis these, on applying global adoption rates of H_2 for buses, a low to medium demand in 2040 of 0.12 kTPA and 0.2 kTPA offtake in India under the base scenario emerges

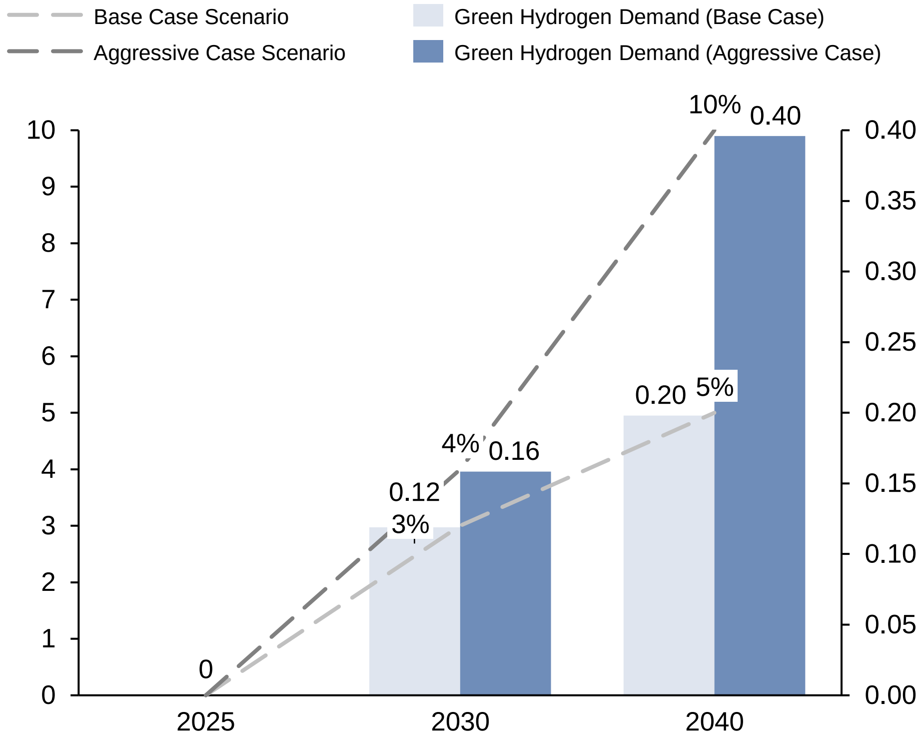
Adoption rate of hydrogen in buses
% of total demand



Chile is an outlier with a very high offtake

Globally adoption rates in buses is low in 2040, similar trend is expected in India

Expected adoption rates for buses in the valley
As % of total demand and demand in kTPA



Note: Base and Aggressive cases are considered based on net zero targets of Kerala and valley specific parameters for 300 long range buses operating from Kochi

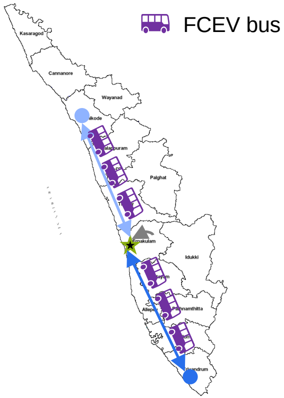
Source: HFCP; IEA ; McKinsey; MEC+ analysis

As a pilot, 6 buses of FCEV, and 3 buses of HICE are proposed

to run on the selected routes in Phase II

Valley Phase II: FCEV buses

2026 to 2030

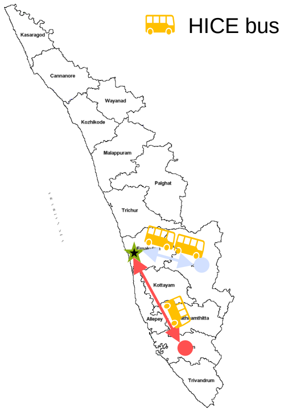


Green Hydrogen Adoption	3% based on the results of the technical assessments and studies

- After Phase I of studies and assessments, the results should be used for initial deployment of **6 FCEV bus each in the 2 proposed routes** Ernakulam to Kozhikode and Ernakulam to Thiruvananthapuram
- This phase will prove the cost competitiveness of green hydrogen and will clear the path for large scale adoption in the third phase of the valley

Valley Phase II: FCEV buses

2026 to 2030



Green Hydrogen Adoption	3% based on the results of the technical assessments and studies

- After Phase I of studies and assessments, the results should be used for initial deployment of **3 HICE bus each in the 2 proposed routes** Ernakulam to Idukki and Ernakulam to Kollam
- This phase will prove the cost competitiveness of green hydrogen and will clear the path for large scale adoption in the third phase of the valley

Source: MEC+ analysis

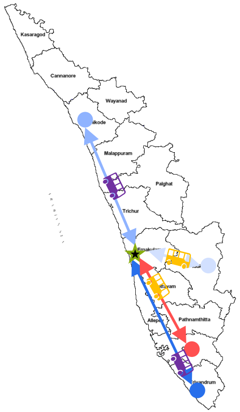
The best suited technology from phase II

will be deployed on a larger scale in Phase III

Valley Phase III

2030 to 2040

HICE bus FCEV bus



0.2 KTPA demand

Green Hydrogen Adoption	5%

- With green hydrogen infrastructure established, further cost declines and now a tested technology (from Phase II), large scale deployment can be conducted on the same routes
- We propose total **10 FCEV buses on Ernakulam to Kozhikode and Ernakulam to Thiruvananthapuram and 5 HICE buses on Ernakulam to Idukki and Ernakulam to Kollam**

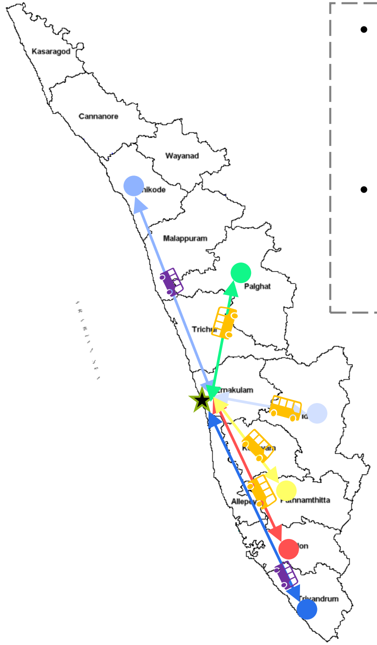
Upside of the valley

Post 2040

HICE bus FCEV bus

Green Hydrogen Adoption	100%

- Post 2040 we propose running all 91 buses operating a distance of > 250 kms on hydrogen owing to low cost of green hydrogen and achieving Kerala's net zero target
- 2 additional routes have been added: Ernakulam to Pathanamthitta and Ernakulam to Palakkad



1.2 KTPA demand

Source: MEC+ analysis

WATER TRANSPORT

Image Credit

Kerala can operate vessels in inland waterways and coastal routes

with current operations limited to specific stretches in inland waterways

Global Feasibility

Unavoidable

- Fertiliser
- Refinery
- Methanol
- Shipping
- Chemical
- Long haul train
- E-fuels
- Long haul truck
- Coastal & inland vessels
- Local ferries
- Short haul aviation
- Light aviation
- Rural trains
- H_2FC cars
- 2-3 wheelers

Uncompetitive

- Shipping is the most competitive sector
- Coastal & inland vessel have moderate use case; local ferries have low case

Waterways | Operational landscape in Kerala

Type of Operation	Passenger Operations		Cargo Operations (Inland)		Shipping
Operator	**Kochi Water Metro**	**KSWTD**	**KSINC**	**Other Operators***	*Shipping has lower TRLs and is highly dependent on global development hence expected to come post 2040; further, bunkering demand is kept under innovation cluster as a part of upcoming demand*
Operations	Kochi	Kerala	Kochi	Distributed	
Ownership	Kerala Govt. & KMRL	Kerala Govt.	Kerala Govt.	Private Owned	
Current operations and plans	Passenger transport in Kochi; plans for multiple in KL	Passenger transport in different KL clusters	Cargo, passenger and tourism in Kochi; Plans for KMML barges	Movement of cargo mainly in the Kochi area	
Current volume and future volume	**No current H_2 demand**; visible demand of **~1.9 kTPA**	No current and visible demand	**No current H2 demand**; visible demand of **~0.1 kTPA**	*Highly distributed*	

- Current cargo operations are focussed on Kochi and passenger transport is confined to small clusters within districts, IWAI the development and regulatory body for the inland waterways and KMB oversees the coastal ports, coastal shipping is a potential opportunity currently unexplored

Note: *Other operators are representative (non-exhaustive); PPP: Public Private Partnership; KMML: Kerala Metals and Minerals Ltd; IWAI: Inland Waterways Authority of India ; KMB: Kerala Maritime Board

Source: Liebreich Associates; MEC+ analysis

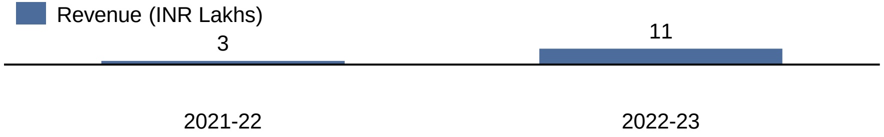
Kochi Water Metro can drive the integration of waterways

A pioneer in sustainable technology and operations, the Kochi Water Metro can play a potential role in the integration of waterways by deploying sea-going vessels connecting metros in different cities

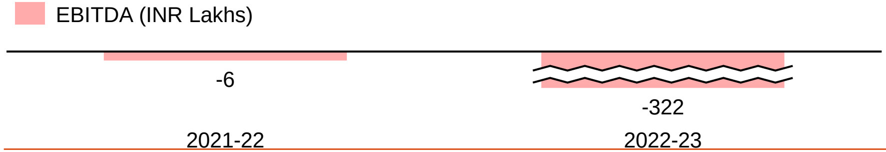
Kochi Water Metro | Operational Profile

Type of Operation	Rapid Passenger Transit
Fuel Used	Electric powered (Diesel back-up)
Vessels	120 kWh LTO battery powered. Order placed for 23 boats (10 delivered) out of total 78 boats planned
Operational Area	Currently operational in two routes, plans to connect 38 jetties (76 kms total route length)

Financials | Revenue

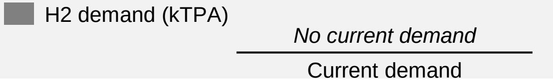


Financials | EBITDA



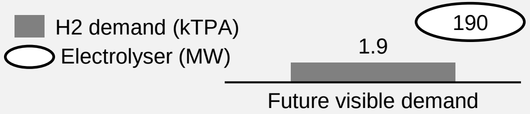
Current Operations of Kochi Water Metro

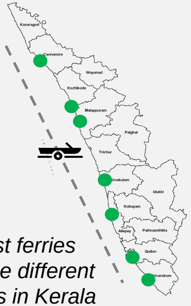
- Envisaged as a modern water transport system **connecting the islands to the Greater Kochi region**
- Commenced operations in April 2023
- On activating the full envisioned capacity, it will have a **fleet of 78 boats** connecting the **38 jetties** across **15 routes**



Potential Role of KWML in Kochi Valley

- The Kerala government aims to **expand the Water Metro Model** to **5-6 cities**
- KWML intends to **link these cities** via **sea routes**, connecting inland waterways to sea
- Kochi Water Metro aims to introduce a **H_2 fuel-cell sea vessel service** capable of up to 25-30 knots





Sea-going fast ferries connecting the different metro clusters in Kerala

Note: KWML: Kochi Water Metro Limited

Source: KWML AR-23; Interviews; MEC+ analysis

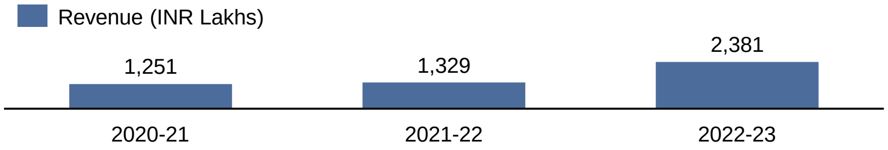
KSINC can drive cargo movement across cities for KMML & KPACT

KSINC is an established operator of barges and other inland-water crafts in Kochi; potential to deploy and operate hydrogen powered barges for cargo movement across cities for KMML & KPACT

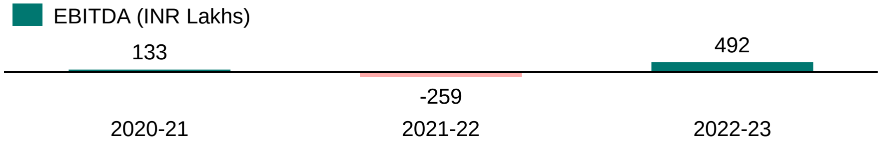
KSINC | Operational Profile

Type of Operation	Cargo, Passenger and Tourism
Fuel Used	Diesel
Vessels	Diesel Powered Barges, Roll-on Roll-offs (RoRo), bunkering and tourist cruise vessels
Operational Area	Operations in and around Kochi with cargo operations at Cochin Port and FACT plants

Financials | Revenue

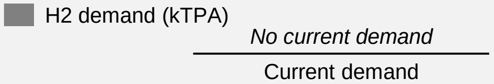


Financials | EBITDA



Current Operations of Kochi Water Metro

- KSINC operates vessels for cargo, bunkering, passenger, and tourism
- KSINC performs vessel docking, repairs, and constructs inland crafts
- Established owners and operators of inland vessels in Kerala water ways



Barges from Cochin Port to FACT

Bunkering at Cochin Port

Sagararani cruise for tourism

RoRo in Kochi

Potential Role of KWML in Kochi Valley

	Kollam	**Kottayam**
Distance*	~260 kms	~170 kms
Cargo	FO, Chemicals	Container
Partner	KMML	KPACT

KSINC can operate hydrogen-powered IWT barges between Kochi & KMML for raw materials & fuels, & between Kochi and Kottayam Port for container transport.

Note: *Roundtrip distance; KSINC: Kerala Shipping and Inland Navigation Corporation Ltd; KMML: Kerala Minerals and Metals Ltd; IWT: Inland Water Transport; KPACT:Kottayam Port and Container Terminal; FO: Furnace Oil

Source: KSINC-AR; KMML; Kottayam Port; Interviews; MEC+ analysis

To create this H_2 marine economy, 3 essential elements are needed

Hydrogen production, set up of refuelling infrastructure and deployment of hydrogen boats are key to establish the potential demand

Infrastructure requirements for creating a new hydrogen marine economy in Kochi/Kerala

Hydrogen production

Production of H_2

Compression

Purification

Production of green hydrogen via electrolysis. A key input required for mobility use case of hydrogen is compression of H2 molecules as well as high purity at 99.999% (for FCEV specifically).

Refuelling

Refuelling infra

Setup of refuelling infra along the routes to ensure continuous supply of hydrogen to the boats

Offtake

Hydrogen boats

Procurement and deployment for new HFCEV boats for offtake over proposed routes from Kochi under water metro and KSINC

Source: MEC+ analysis

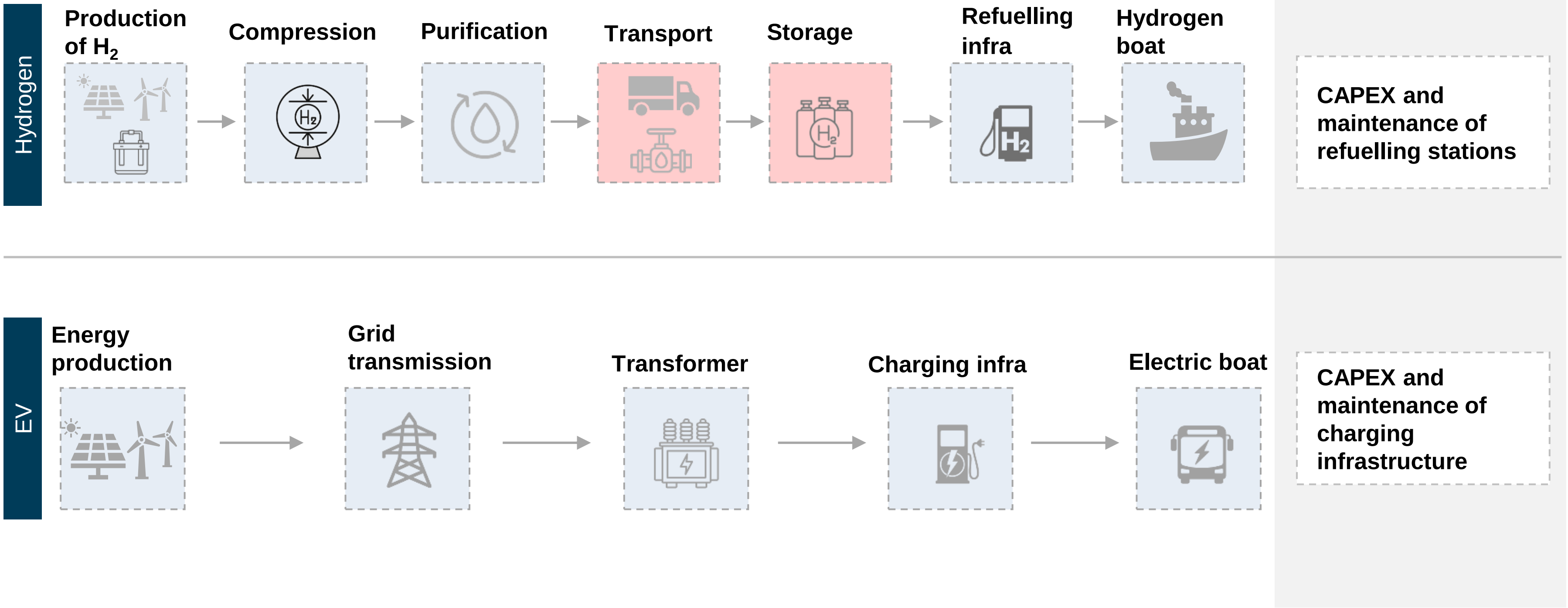
To assess demand conversion economically, we’ve calculated TCO

We have compared no emission competitive technologies for TCO calculation over 5-7 value chain elements

🟦 Included in TCO 🟥 Not included in TCO

Infrastructure requirements for various technologies and their inclusions for TCO analysis

Relative additional costs



Hydrogen

- **Production of H_2** 🟦 →
- **Compression** 🟦 →
- **Purification** 🟦 →
- **Transport** 🟥 →
- **Storage** 🟥 →
- **Refuelling infra** 🟦 →
- **Hydrogen boat** 🟦

CAPEX and maintenance of refuelling stations

EV

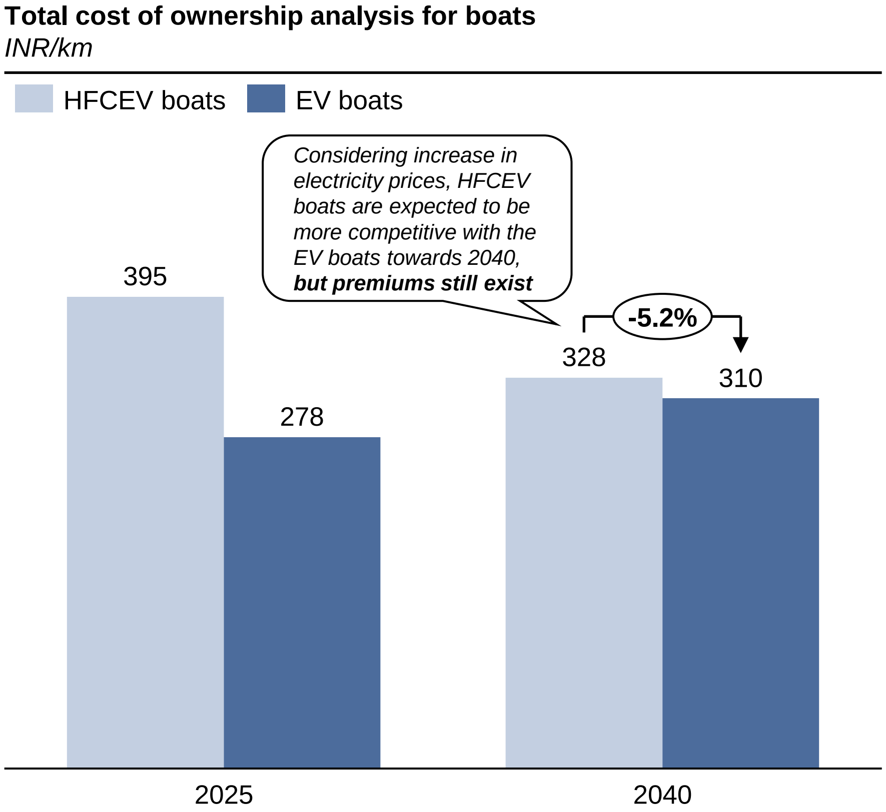
- **Energy production** 🟦 →
- **Grid transmission** 🟦 →
- **Transformer** 🟦 →
- **Charging infra** 🟦 →
- **Electric boat** 🟦

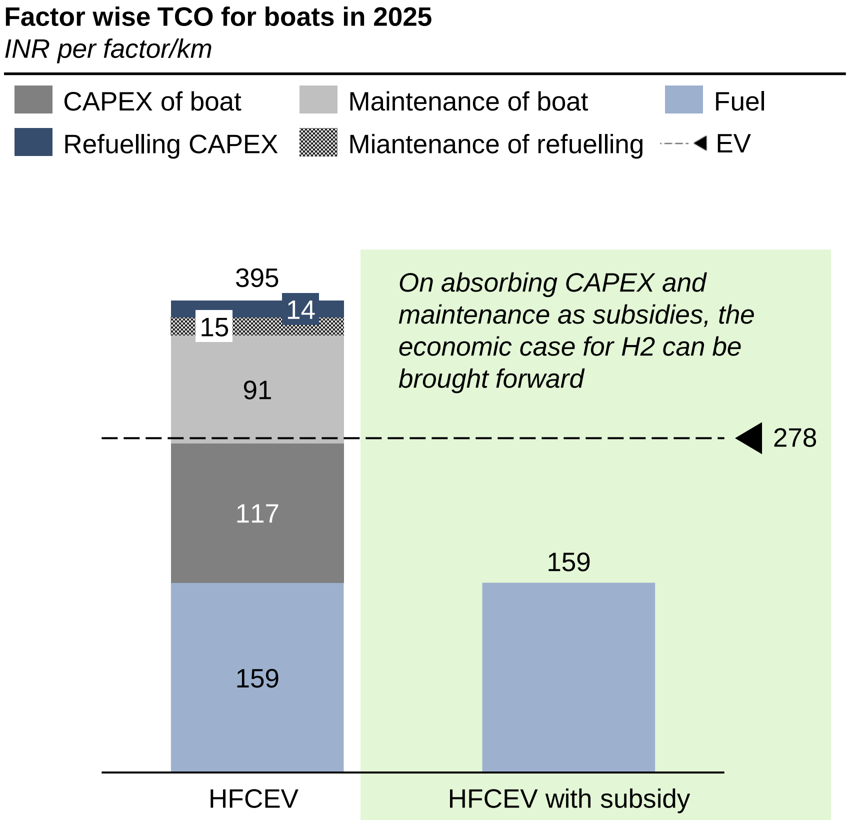
CAPEX and maintenance of charging infrastructure

Source: MEC+ analysis

Economic case is low-medium

Government support over vessels and refuelling infrastructure in the initial years for the pilot can strengthen the case for waterways in Kochi





Note: OPEX at 3% for boats; OPEX for refuelling declining from 7% to 2%; 4 boats considered over a distance of 200 km; 1 refuelling station and 4 chargers; 80 kg tank of H_2 for 1 boat; H_2 boat cost INR 20 Cr and EV boat INR 10 Cr

Source: MEC+ analysis

For water transport H_2 costs ranges from 294.4 to 413.6 INR/Kg

For water transport, hydrogen costs could range anywhere from 294.4 to 413.6 INR/Kg in 2040 with refuelling station having highest cost contribution after production

Pathways

🟩 High 🟨 Medium 🟥 Low

1 Production
🟨 99.90% 🟥 30 bar

2 Compression
🟨 99.90% 🟩 200 bar

3 Purification
🟩 99.99% 🟩 200 bar

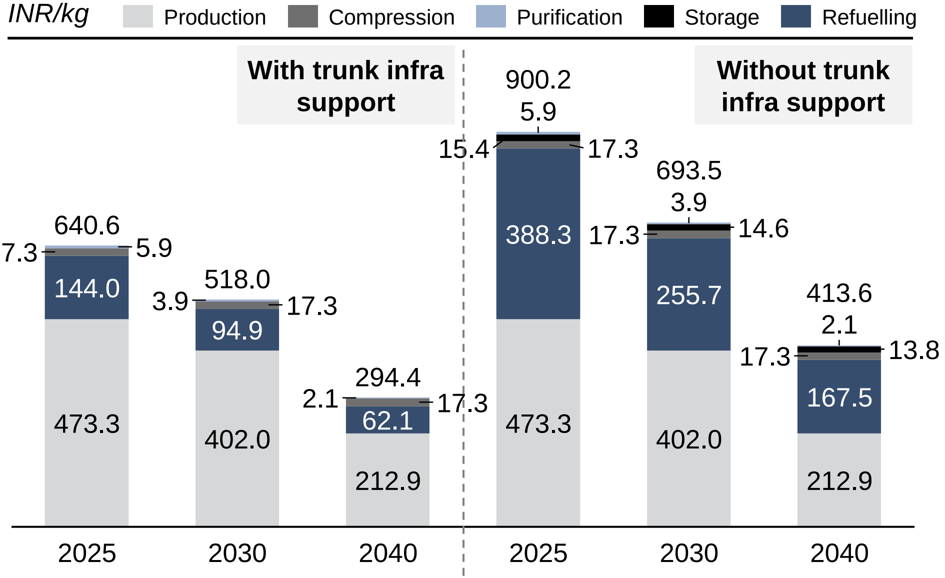
4 Transportation
🟩 99.99% 🟩 200 bar

5 Onsite Storage
🟩 99.99% 🟩 200 bar

6 Refuelling Station (compression/dispenser)
🟩 99.99% 🟩 350 bar

- With trunk infrastructure **support refers to absorption of costs (refuelling, grid infra, pipeline and storage) by the government and only OPEX borne by developer**
- Without trunk infrastructure refers to **no cost absorption by the government**

Landed Cost of Hydrogen



- With trunk infra support
  - RE : KL (till 2030), GJ (2040)
  - Banking: 1000 hours
  - WACC: 9%
  - refuelling storage cost absorbed by the govt, only OPEX considered

- Without truck infra support
  - RE : KL (till 2030), GJ (2040)
  - Banking: 1000 hours
  - WACC: 9%
  - refuelling storage cost included

Note: For detailed analysis on landed cost refer to section supply side economics
Source: MEC+ analysis

Policy maturity is medium-high

Central and state level plans for investments in decarbonisation of waterways as well as pilots for green vessels drive regulatory support for Kochi Waterways

Central, state and company level policies for decarbonisation

Announced Goals and Policies

🟩 Mandate/incentive present for H_2

🟨 Mandate/incentive present at a broader level

🟥 No mandate/incentive present

	Central	State	KWML/KSINC
Decarbonisation goal	🟨 Multiple initiatives specified in (2030) and Amrit kaal Vision (2047)	🟩 Plans to transform West Coast canal into green economic corridor	🟨 KWML targets to be carbon neutral. Timelines to be fixed soon
Emission reduction target	🟩 Targets to reduce GHG emissions – 30% in 2030 and 70% in 2047	🟥 No specific targets for inland waterways or coastal shipping	🟥 No specific targets
Carbon pricing	🟥 Not present at inland/coastal level	🟥 No Mandates	
Subsidy on H_2 costs	🟨 Ships using cleaner fuels may be incentivized through queue priority or rebate in berth dues	🟥 Not specified	
Capex/investment commitments	🟩 Govt. to support 30% of project cost for green vessels. To launch 20 pilot vessels (**including H_2 ferry**, tugs.	🟩 **INR 2400 crores** allocated for west coast canal transformation	🟥 KSINC; initial plans to convert to LNG barges**;** studies done by Kottayam Port for H_2 barges
Hydrogen mandate/plans	🟥 No mandates announced	🟥 Not Specified	🟩 Not applicable
Overall regulatory score	↗	↗	↘

Note: 2008 GHG emissions as reference level; KWML: Kochi Water Metro Rail Ltd

Source: PIB; Maritime Amrit kaal Vision 2047; ET-Infra; ET-EW; TME; MEC+ analysis

Technology readiness is medium

Technology demonstration for various hydrogen-based vessels exists in controlled environment

Technology requirements for using green hydrogen in Vessels

Technology Shift and TRL levels

🟥 Unfavourable 🟨 Medium 🟩 Favourable

	Production	Storage/Conversion	Refuelling	Offtake
	8	6	6-7	5-6
Primary Activities	🟩 • To cater to the demand, **20 MW of electrolyser would be required** • Demonstration projects at this scale are being conducted globally	🟩 • **Storage:** Storage in refuelling stations for boats exists at controlled scale in isolated environments through demonstrations • **Conversion:** Not required	🟨 • **Refuelling station:** To cater to annual demand, refuelling station of 400 kg/day to setup • Demonstration projects for being conducted at very initial level	🟨 • **Process integration:** FCEV boats are at a TRL of 6 with demos in relevant environment while HICE boats have a lower TRL of 5 • **Vessel manufacturing: CSL has proven tech & expertise in manufacturing GH_2 vessels**

Supporting Activities

🟥 **Permits & Regulations:** Ministry of New & Renewable Energy has decided to define Green Hydrogen as having a well-to-gate emission (i.e., including water treatment, electrolysis, gas purification, drying and compression of hydrogen) of not more than 2 kg CO2 equivalent / kg H_2; **regulations and permits for vessel manufacturing; permits required for setting up a refuelling station**

🟥 **Standards, Safety & Certifications:** For hydrogen fuelled transport, international standards such as CEN/TC268 give quality specifications for fuel cells. Further, Indian and international standards such as IS/ISO 13985 : 2006, IS17268 : 2020, EN 17127 are present for refuelling stations; stringent standards required as public is involved; vessel manufacturing

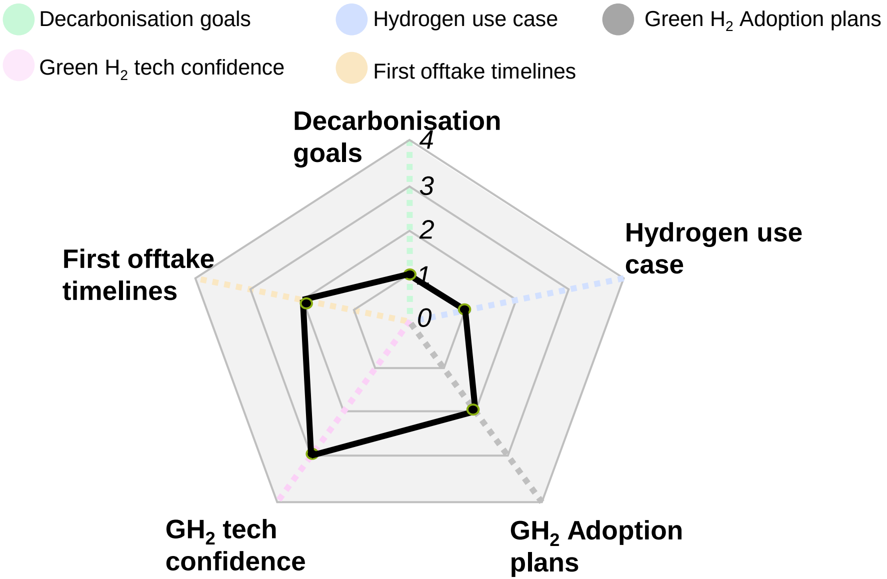
🟥 **Human Resources:** Skilling of manpower across the value chain, including manufacturing of equipment, Green Hydrogen project installation, and operations & maintenance

Source: PIB; Standards and certifications, IIT Madras; Cluster guidelines Unido; MEC+ analysis

Offtaker willingness is low to medium

Willingness to test the pilots can be strengthened by maturing technology developments and addressing refuelling infrastructural challenges

Waterways readiness level from 0 to 4 on 5 parameters



Decarbonisation goals	Off takers have views on decarbonisation but no timelines, two-way focus on carbon reduction; shift from road to waterways and use of alternate fuels in operations
Hydrogen use case	Currently there is no direct use case of hydrogen present
Green H_2 adoption plans	Interest shown in water-based cargo movement (by beneficiaries) and operators are willing for pilots if adequate support is given by the government
Green H_2 tech confidence	Technology is in prototype/beginning demonstration stage, hydrogen related projects at Cochin Shipyard is leading to stronger tech confidence
First offtake timelines	No fixed timelines. Adoption to depend on refuelling infrastructure availability, operational and technical feasibility (based on studies) and capex incentives

1.8

Lack of mandates, clearly defined decarbonisation goals as well as challenges in refuelling infrastructure and new tech for vessels lowers the willingness, however, the off takers are keen on conducting pilots for the same making boats a peculiar demand case

Source: Stakeholder Interviews; MEC+ analysis

Cochin Shipyard and Government can drive offtake for waterways

Technology expertise from Cochin Shipyard and support from the government on infrastructure can drive the offtake for waterways in Kochi

Hydrogen offtake in Vessels

Drivers and Inhibitors

	Technology maturity from Cochin Shipyard, decarbonisation goals, central support for pilots can drive waterways sector in Kochi	***Require government intervention on subsidy and infrastructure set up***
Economic	• Government support on CAPEX of vessels and refuelling infrastructure can drive the economic case	• High costs capital as well as operational costs of the vessels • **Low scale prospective demand** inhibiting economies of scale
Regulations	• **Targets for decarbonisation** exist at central level • Central **policies for deployment** of pilot green hydrogen vessels exist	• Lack of **clearly defined timelines** for decarbonisation goals • Lack of established demand
Technical	• Cochin Shipyard's current H_2 vessel projects and positioning as a **leading shipyard** improves **tech confidence** in the valley for fuel cell manufacturing	• Lack of expertise in **operations and maintenance** of hydrogen fuel-cell based vessels • **Refuelling infrastructure** might be a challenge
Offtaker willingness	• **Willingness to test pilots** with government support • Past studies and proposals conducted for H_2 based vessels	• **Uncertainty on future plans** for development of infrastructure

Source: Stakeholder Interviews; MEC+ analysis

Total anticipated demand from waterways is ~2 kTPA of green H_2

which could have a potential upside basis the development of infrastructure and traffic

Total Demand generated from Waterways

Demand in kTPA

Barge Operations Potential Demand

Proposal is to run hydrogen powered barges from **Kochi to Kottayam** and **Kochi to Kollam**. Based on the success of the pilots and demand arising on WCC, barges can be increased

Kottayam Port

Number of Boats	1 barge
Roundtrip Distance	170 Kms (Kochi to Kottayam)
Hydrogen Consumption	68 kgs (80kg tank with 200kms range)*
Operational Days	330 Days
Hydrogen Demand	**0.02 kTPA**

Kochi to KMML

Number of Boats	2 barges (HCL and Furnace Oil)
Roundtrip Distance	260 Kms (Kochi to KMML)
Hydrogen Consumption	104 kgs (80kg tank with 200kms range)
Operational Days	183 Days
Hydrogen Demand	**0.04 kTPA**

Kochi Water Metro – Sea going vessels potential demand

The proposal is to run sea-going vessels connecting the different water metros of the states. And, In lines with the Kerala govt. Vision to introduce **100 boats running on clean fuels**. The total boats potential for this operation would be **50**

Number of Boats	50 Boats
Roundtrip Distance	260 Kms (Kochi Metro to Kollam Metro)
Hydrogen Consumption	104 kgs (80kg tank with 200kms range)
Operational Days	365 Days
Hydrogen Demand	**1.9 kTPA of green hydrogen**

- Total demand arising from waterways is **2 kTPA**, with majority of the demand depending on the operations of **Kochi Water Metro sea-going vessels**
- The actual potential of the waterways in Kerala would depend on multiple factors like the **completion of works in the WCC, conversion of traffic from roadways, development of H_2 vessels etc**

Note: Demand is calculated through high-level estimations as it is bottom up, further studies required to ascertain total demand; WCC: West Coast Canal

*: Range estimations have been made basis input of 40 kg tank of boats running over 100 km, hydrogen consumption per roundtrip considered

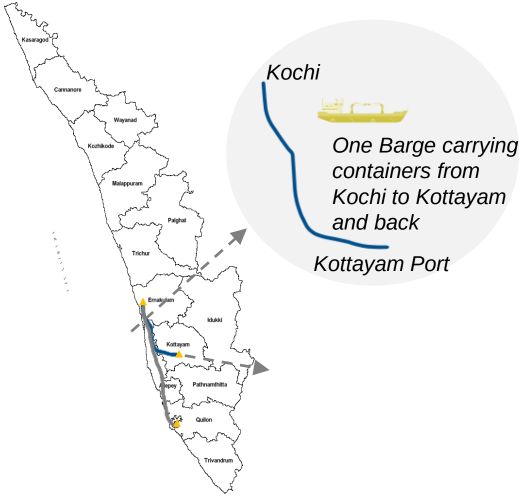
;Source: Primary interviews; Kerala Govt.; MEC+ analysis

Phase wise development of waterways in Kochi

Phase wise demand from Waterways
Phase I

- Hydrogen based vessels with **larger tank capacity** and **higher ranges in 1 refuelling** need to be developed
- Phase I to focus on **the development of hydrogen powered sea-going vessels and hydrogen powered barges**
- Studies need to be conducted to ascertain the **technical feasibility** of operating sea-going vessels and barges
- The inland waterway stretch from Kochi to Kollam is also expected to be ready in this phase

Phase wise demand from Waterways
Phase II



Kochi

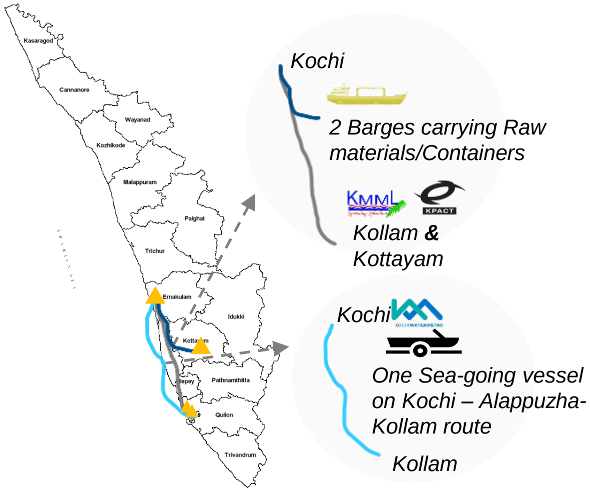
One Barge carrying containers from Kochi to Kottayam and back

Kottayam Port

Green Hydrogen Demand	**0.015 kTPA**

- One pilot barge to operate from Kochi to Kottayam Port
- This could be further scaled in the next phase if the traffic improves

Phase wise demand from Waterways
Phase III



Kochi

2 Barges carrying Raw materials/Containers

Kollam & Kottayam

Kochi

One Sea-going vessel on Kochi – Alappuzha-Kollam route

Kollam

Green Hydrogen Demand	**0.074 kTPA**

- 2 barges in total. New barge to operate from Kochi to KMML. Kochi to Kottayam to operate more frequently basis demand
- Kochi Metro to run a pilot sea-going vessel from Kochi to Kollam

Note: Demand is calculated through high-level estimations, further studies required to ascertain total demand

Source: MEC+ analysis

CHEMICALS SECTOR

Image credits

In Kochi, chemical sector is concentrated under HOCL

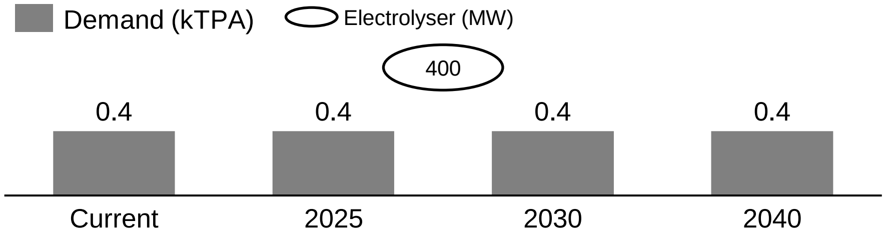
with a current demand of 0.4 kTPA of hydrogen

HOCL – Kochi | General Overview

Production Overview

Location	Ambalamugal, Kochi
Production Capacity	40 KTPA (Phenol); 25 KTPA (Acetone); 5.2 KTPA (Hydrogen peroxide)
Major Products	Phenol, Acetone and **Hydrogen Peroxide where hydrogen is used directly**
Customers	Major customers contributing >50% of revenue in FY 2022-23 include: Pooja petrochemicals, Ramesh Kumar Sonkamal Enterprises P Ltd, Ponpure Chemical India Pvt Ltd

Grey to Green Hydrogen Demand* (kTPA) | Current and Projected

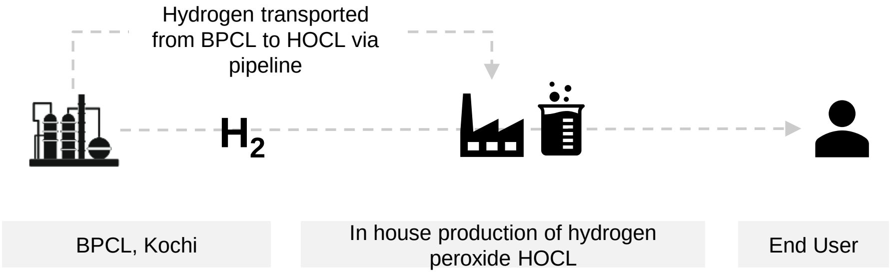


HOCL | Business Model & Financials

Revenue and EBITDA

HINDUSTAN ORGANIC CHEMICALS LIMITED

Business Model for Hydrogen Offtake



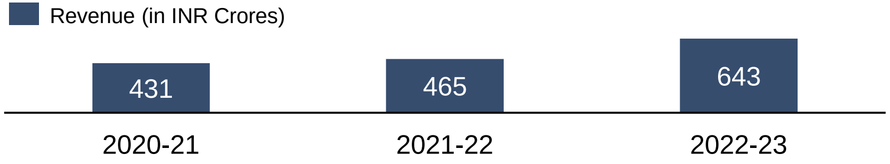
Hydrogen transported from BPCL to HOCL via pipeline

BPCL, Kochi

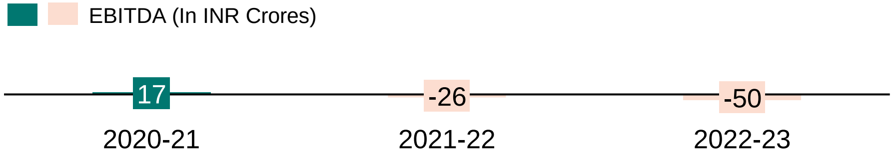
In house production of hydrogen peroxide HOCL

End User

Revenue



EBITDA



Note: No expansion plans have been announced yet, hence, demand is considered to stay consistent over the years; Hydrogen is used only for production of hydrogen peroxide

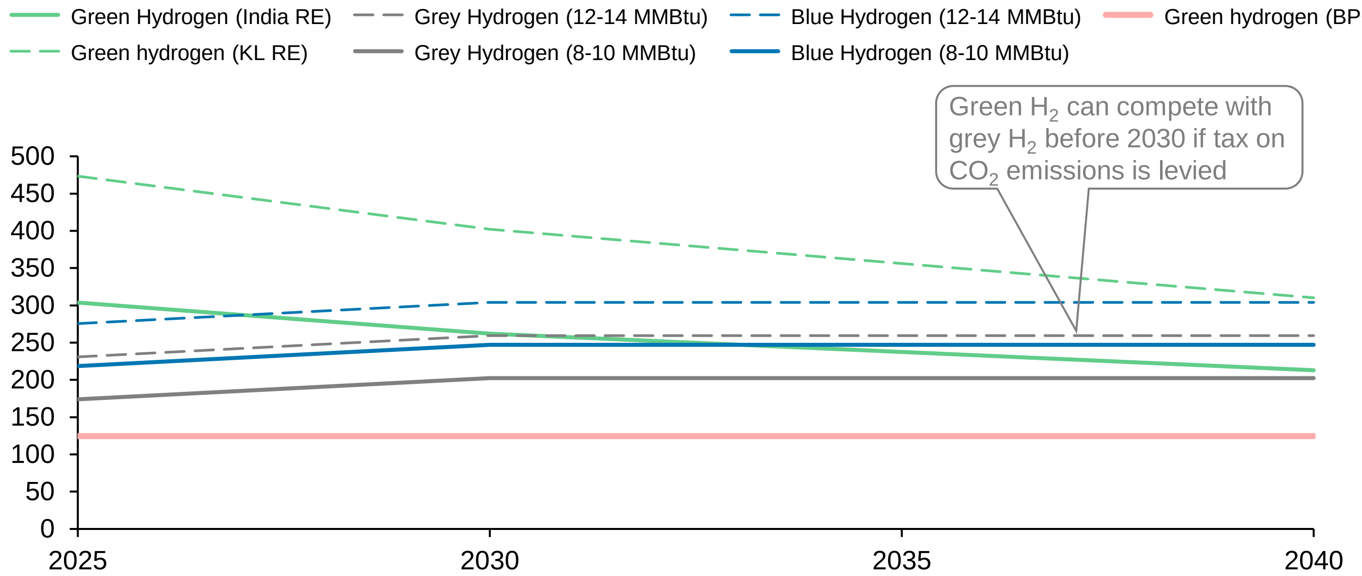
;Source: HOCL; Annual report 2022-23; Annual report 2021-22; MEC+ analysis

Economic case is low

Business case for chemical plants has low attractiveness as HOCL procures its current hydrogen from BPCL at a price of ~ INR 125/kg

Green hydrogen | Cost parity with grey hydrogen

Landed cost of hydrogen per kg



Green H_2 can compete with grey H_2 before 2030 if tax on CO_2 emissions is levied

- **Being a new technology, the costs are high against incumbent gas-based technology**
- **Currently, HOCL receives green hydrogen from BPCL at a very low cost of ~1.5 USD (INR 124.5)**

Scenarios

Low Natural Gas Price Scenario: Cost of natural gas is at 8 USD/MMBtu in 2025 and 10 USD/MMBtu in 2030 and 2040 | High Natural Gas Price Scenario: Cost of natural gas is at 12 USD/MMBtu in 2025 and 14 USD/MMBtu in 2030 and 2040 | Green Hydrogen (India RE): Hybrid RE from Gujarat and grid banking of 1000 hours| Green Hydrogen (KL RE): Solar with Pumped hydro storage from Kerala and grid banking of 1000 hours

Source: IGEF-MEC+ Model; MEC+ Analysis

Landed cost of green H_2 for HOCL range: 216 to 218.1 INR/kg

In-situ production of H_2 and onsite storage of hydrogen are major drivers of landed cost with costs ranging from 216 to 218.1 INR/kg in 2040

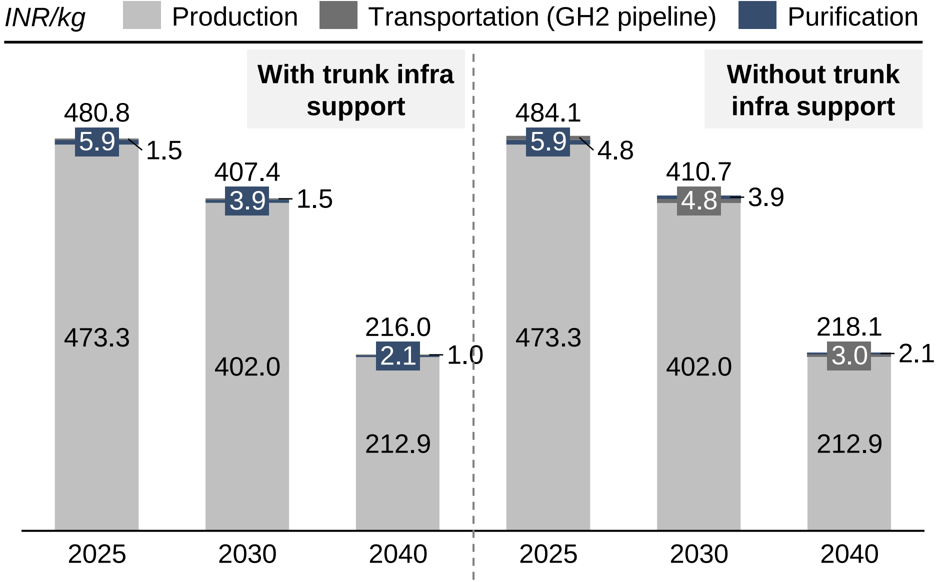
Pathways 🟩 High 🟨 Medium 🟥 Low

1 Production	🟨 *99.90%*	🟥 *30 bar*	●
2 Compression	🟩 *99.99%*	🟥 *30 bar*	●
3 Purification	🟩 *99.99%*	🟥 *30 bar*	○
4 Transportation	🟩 *99.99%*	🟥 *30 bar*	●
5 Decompression	🟩 *99.99%*	🟥 *30 bar*	○
6 Chemicals input	🟨 *99.90%*	🟥 *30 - 190 bar*	●

- With trunk infrastructure **support refers to absorption of costs (refuelling, grid infra, pipeline and storage) by the government and only OPEX borne by developer**
- Without trunk infrastructure refers to **no cost absorption by the government**

Landed Cost of Hydrogen

INR/kg



- With trunk infra support
  - RE : KL (till 2030), GJ (2040)
  - Banking: 1000 hours
  - WACC: 9%
  - Pumped hydro

- Without truck infra support
  - RE : KL (till 2030), GJ (2040)
  - Banking: 1000 hours
  - WACC: 9%
  - Pumped hydro

Note: For detailed analysis on landed cost refer to section supply side economics

Source: IGEF-MEC+ Model; MEC+ analysis

Policy maturity is very low

No mandates or emission targets exist for chemical plants in Kerala or centrally, inhibiting uptake of green hydrogen

Central, state and company level policies for decarbonisation
Announced Goals and Policies

🟩 Mandate/incentive present for H_2
🟨 Mandate/incentive present at a broader level
🟥 No mandate/incentive present

	Central	State	HOCL
Decarbonisation goal	🟨 Net zero by 2070 for all industries	🟨 Net zero by 2050 for all industries	🟥 No goal announced yet
Emission reduction target	🟥 Targets are yet to be announced		
Carbon pricing	🟨 Currently a part of obligated sector under PAT scheme for energy efficiency and proposed to be part of future carbon trading scheme. Penalties to be set under carbon emission trading scheme		
Subsidy on H_2 costs	🟩 PLIs available for GH_2 production	🟥 No specific subsidies are available	🟥 Not defined
Capex/investment commitments	🟥 No investment outlay has been announced yet		
Hydrogen mandate/plans	🟥 No investment outlay has been announced yet No mandates are present		
Overall regulatory score	↓	↓	↓

Note: PAT: Perform Achieve and Trade
Source: PIB; News article; MEC+ analysis

Technology readiness is moderate to high

Chemical sector in Kochi requires minimal technology intervention as direct substitution of green hydrogen is possible

Technology requirements for using green hydrogen in HOCL

Technology Shift and TRL levels

🟥 Unfavourable 🟨 Medium 🟩 Favourable

	Production	Storage/Conversion	Transportation	Offtake
	8	NA	NA	7
Primary Activities	🟩 • To cater to the demand, **4 MW of electrolyser would be required** • Demonstration projects are being conducted at this scale globally	🟩 • **No storage or conversion required** as hydrogen is used in direct form	🟨 • **Transportation:** Pipeline for transportation already exists from BPCL to HOCL. Tests for pipeline from port to BPCL to be conducted	🟨 • The technology has received approval for projects in Odisha by ReNew in 2023 and is **soon to be demonstrated in controlled relevant environment**

Supporting Activities

🟥 **Permits & Regulations:** Ministry of New & Renewable Energy has decided to define Green Hydrogen as having a well-to-gate emission (i.e., including water treatment, electrolysis, gas purification, drying and compression of hydrogen) of not more than 2 kg CO2 equivalent / kg H_2

🟥 **Standards, Safety & Certifications:** Safety studies for hazard identification (HAZID, HAZOP etc), Risk evaluation (QRA, FERA etc) and Risk controlling/ management (HAC, safety audits etc); Specific standards such as CGA H-5, are applicable for hydrogen handling, storage and transport; Design and construction codes have also been established for hydrogen in its various forms

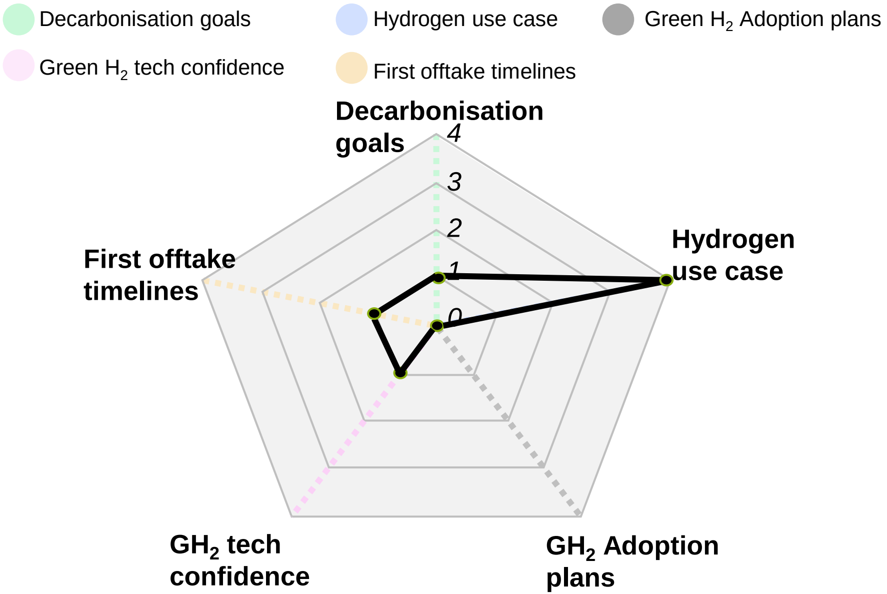
🟥 **Human Resources:** Skilling of manpower across the value chain, including manufacturing of equipment, Green Hydrogen project installation, and operations & maintenance

Source: National hydrogen mission; Indo German energy forum ; News article; Cluster guidelines, Unido; MEC+ analysis

Offtaker willingness is low

High price sensitivity due to low economic case impacts green hydrogen offtake

Chemical offtake readiness level from 0 to 4 on 5 parameters



Decarbonisation goals	HOCL does not have defined timelines for decarbonisation, but Kerala has a net zero target for 2050 that will require decarbonisation of all the sectors
Hydrogen use case	Hydrogen used in its direct form for production of hydrogen peroxide
Green H_2 adoption plans	No adoption plans as mandates, regulations and targets are not present. Adoption will depend on support provided by the government or mandates created
Green H_2 tech confidence	No technology shift or infrastructure challenges are seen as grey hydrogen will be substituted with green hydrogen, however, cost of Green H_2 is a challenge
First offtake timelines	No timelines have been outlined by HOCL. Cost declines and government support/mandates can drive adoption

1.4

Direct substitution makes the case high, however, high price sensitivity and hinders offtake. Government support would be crucial to drive adoption

Source: Stakeholder Interviews; MEC+ analysis

Green H_2 technology and economics to become favorable by 2030

for adoption as government interventions on these can support in unlocking the demand

Hydrogen offtake in Chemicals

Drivers and Inhibitors

	GH_2 based hydrogen production has high technology maturity, cost competitiveness in the next decade and easy process integration	***Require government intervention on subsidy and infrastructure set up***
Economic	• Green hydrogen would be cost competitive with high cost grey hydrogen towards 2030	• **Highy price sensitivity** of product • **Challenging financials** • Low cost grey hydrogen supply from BPCL
Regulations	• **No drivers** present at central, state, self level	• **No regulations for demand creation** in terms of mandates, targets, penalties • No regulations for supply of hydrogen peroxide in terms of incentives or subsidy
Technical	• **High TRL and technology maturity** as grey hydrogen will be directly replaced with green hydrogen without major infrastructure upgrades	• Purity of Green Hydrogen to be checked
Offtaker willingness	• No drivers present for hydrogen offtake for HOCL presently, however, support/mandates from government can drive adoption since hydrogen is used in direct form	• **Offtaker willingness is low at 1.4** on parameters including decarbonisation goals, hydrogen use case, adoption plans, tech confidence and offtake timelines

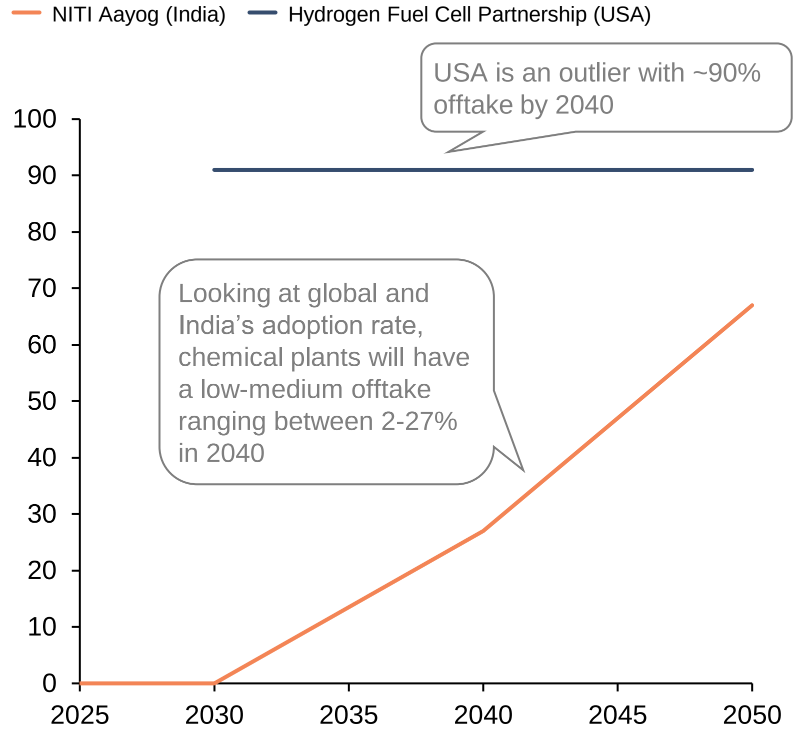
Source: Stakeholder Interviews; MEC+ analysis

Global adoption rates indicate low to medium demand by 2040

On applying global adoption rates of H_2 for chemical plants, a low to medium demand suggesting 0.02 kTPA demand in 2040

Adoption rate of hydrogen in chemical plants

% of total demand

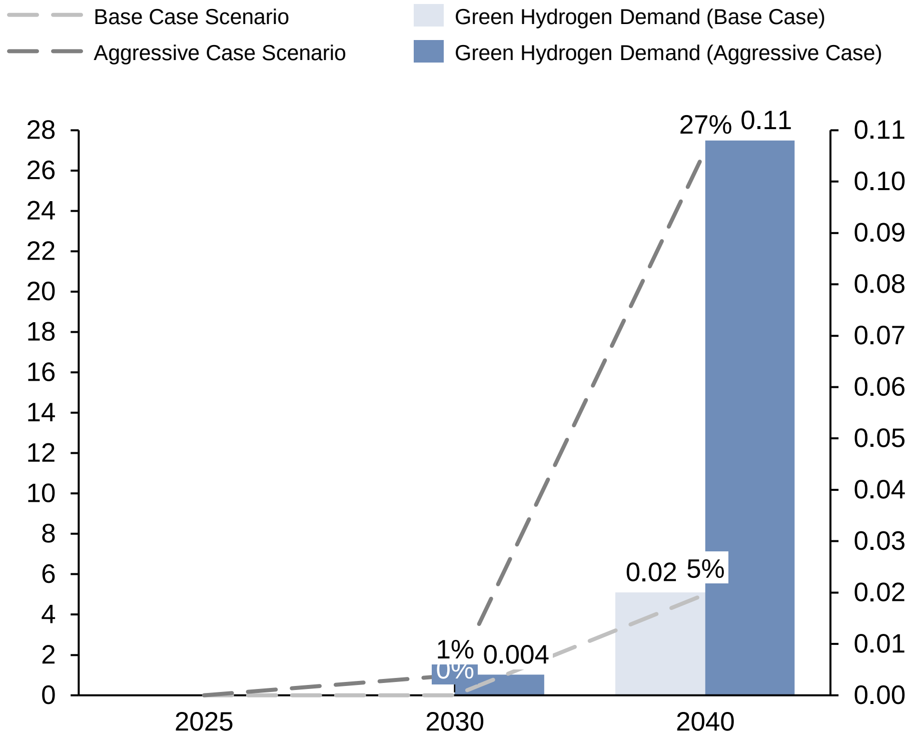


USA is an outlier with ~90% offtake by 2040

Looking at global and India’s adoption rate, chemical plants will have a low-medium offtake ranging between 2-27% in 2040

Expected adoption rates for chemical plants in the valley

% adoption



Note: Base and Aggressive cases are considered based on the high/low natural gas prices and price premiums for grey hydrogen, net zero targets of Kerala and valley specific parameters

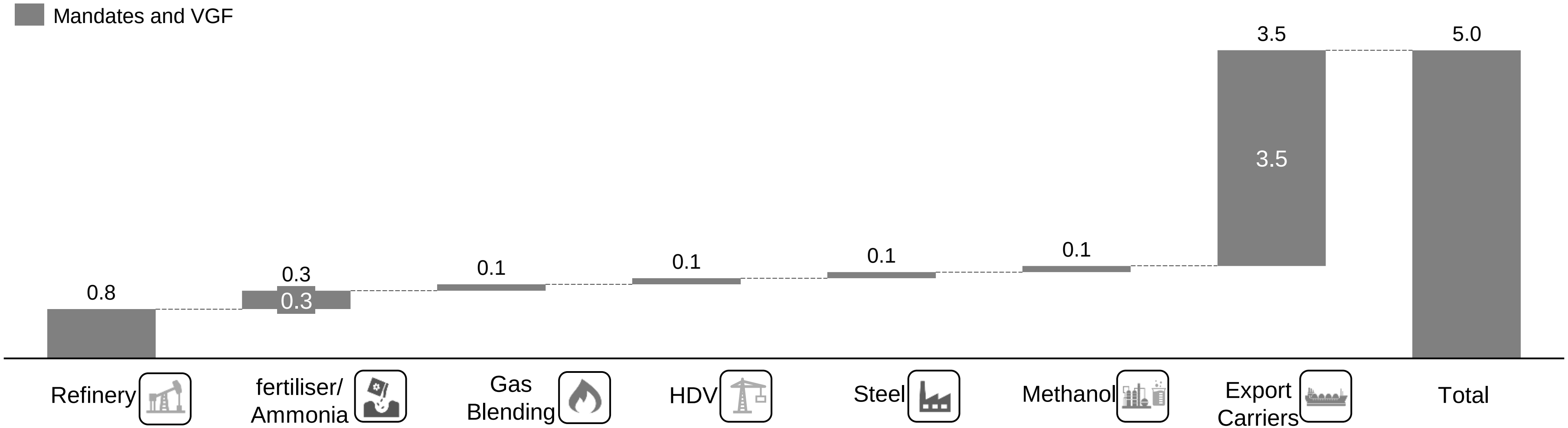
Source: NITI Aayog; HFCP; MEC+ analysis

GREEN AMMONIA EXPORTS

©Freepik

GoI plans to go 5 MTPA by 2030 – 70% from exports

NITI Aayog Vision 2030 for green hydrogen production including exports
MTPA



25 million tons ammonia exports to countries such as Japan, Korea, and the European Union

New plants with **>20 MTPA green steel** capacity primarily for exports towards EU and other markets

Methanol exports could increase in the long term as global demand from marine fuel increases

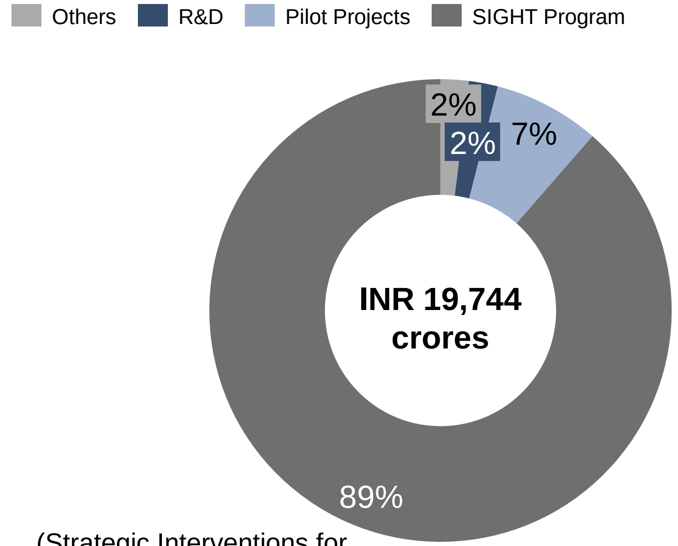
Green H2 in form of new carriers; if new carriers are not realized, Ammonia is likely to fulfil this portion of demand (41 GW)

Note: GoI: Government of India; 1 million tons of green hydrogen corresponds to around 11-13 GW of electrolyser capacity (NITI Aayog)
Source: NITI Aayog and RMI Report; News Articles; MEC+ analysis

Funds have been allocated for green hydrogen production in India

Green Hydrogen Mission| Budget Outlay

% of total outlay



(Strategic Interventions for Green Hydrogen Transition)

Export Focus of the Mission

Green Hydrogen Mission focuses on supporting development of:

  - **Port infrastructure** required for exporting green hydrogen Derivatives
  - **Pipelines to facilitate bulk transport** of green hydrogen
  - Ministry of Ports, Shipping and Waterways to play crucial role in **establishing export capabilities**
  - The Mission will facilitate development of **strategic international partnerships** to enable export of Green Hydrogen and derivatives
- The National Green Hydrogen Mission States that **growth in in export** market will have a **positive cascading effect on the domestic production** as well, this applies in the case of Kerala as well

- The green Hydrogen Mission has allocated INR 19,744 crores with INR 17,490 crores dedicated towards SIGHT program for hydrogen production and electrolyser manufacturing
- Kerala has also allocated INR 200 crore in budget to develop green hydrogen hubs

Source: National Green Hydrogen Mission; Govt. of Kerala; MEC+ analysis

Kerala fulfills the three baseline conditions that favor exports

Green Ammonia exports | Production plans, infrastructure development and exports

Green Ammonia Production Plans

- Kerala is developing a green hydrogen policy that would support the production of green hydrogen/ammonia in Kerala
- Companies have shown interest in developing green hydrogen/ammonia facilities in Kerala
- The options for green hydrogen/ammonia production in the state includes development of RE within the state as well as import of RE

✓

Infrastructure Development

- Kerala has one major port – The Cochin Port and an upcoming port – The Adani Vizhinjam International Seaport
- The Cochin port already has ammonia import operations and a facility of FACT for ammonia storage
- These ports can be connected through a coastal route
- These ports can be developed to facilitate ammonia exports from Kerala

✓

Export Plans

- The govt. of India is already in talks with multiple countries for export of green hydrogen/ammonia from India
- These include European nations like Germany, France, Italy, Netherlands and Asian nations like Japan, South Korea and Singapore
- Kerala with its access to sea-routes can leverage this opportunity to export ammonia to these countries

✓

- **As per MNRE, India would be initially exporting ~70% of the 5 million ton target set for 2030. Domestic demand would be limited in this timeframe**
- **Kerala can leverage this and focus on export-based production of green ammonia and green hydrogen until the demand in the valley picks up**

Note: MTPA- Million tons per Annum
Source: News Sources; MEC+ analysis

Kerala has two ports that can be transformed into export hubs

Cochin Port and Adani International Seaport can be transformed into export hubs for green ammonia

Cochin Port Authority
Kochi, Ernakulam

- Cochin Port is one of the major ports in India. The following gives Cochin Port a headway for developing green hydrogen/ammonia storage and export facilities:
  - As per the National Green Hydrogen Mission, all major ports to have green ammonia bunkers and refuelling facilities by 2035
  - Also, cochin port currently deals with the import of ammonia and hence has the infrastructure for Ammonia Handling
  - FACT has ammonia storage facility in Willingdon Island (Cochin Port Area)

Adani Vizhinjam International Seaport
Vizhinjam, Thiruvananthapuram

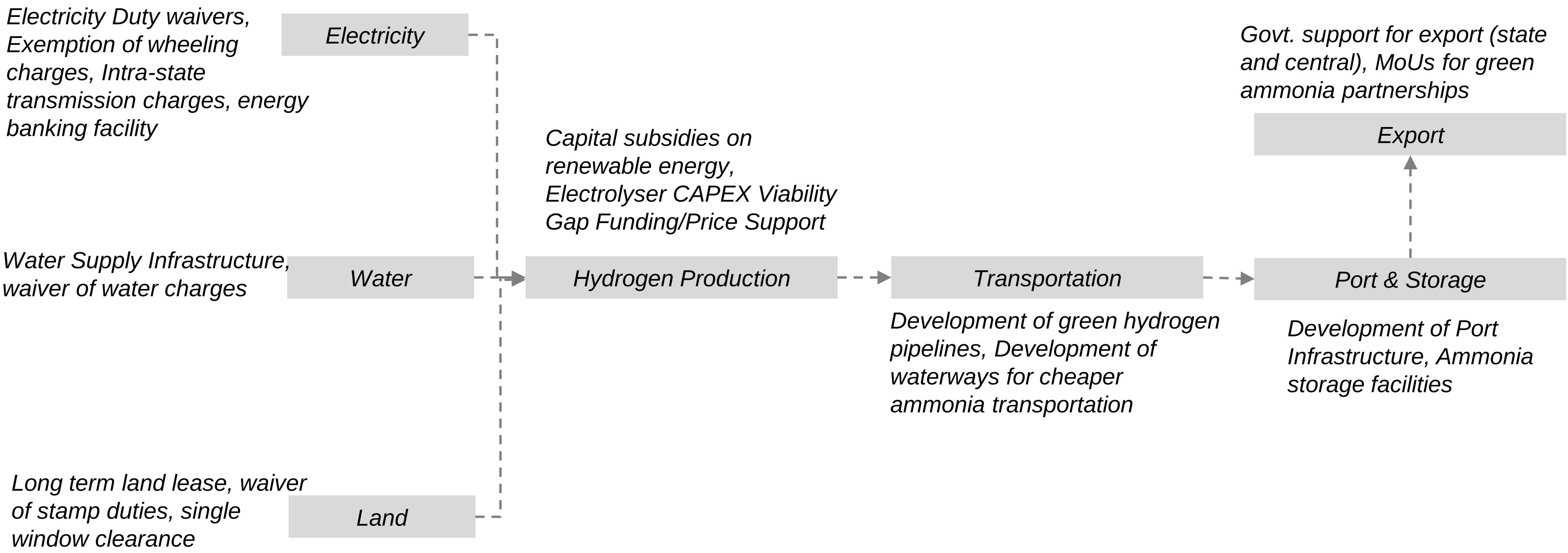
- Vizhinjam port can act as an export terminal for green hydrogen/ammonia from India:
  - Adani Ports has a vision to develop Vizhinjam port as a global bunkering hub that can supply green fuels like hydrogen and ammonia
  - Vizhinjam plays a central role in the green hydrogen hub in Trivandrum, also Kerala plans to develop West Coast Canal and Coastal highway into green corridors which can connect Vizhinjam to Cochin Port and other minor ports.
  - Vizhinjam could be an ideal location for new developers of green hydrogen entering the state for export

Source: Cochin Port Authority; Vizhinjam Port; News Sources; MEC+ analysis

Kerala needs a centralised H_2 supplier to kick-off green exports

who will initiate exports and can scale up in future to meet the demands of the valley

Export Scale Green Hydrogen/Ammonia Production
Incentives required and Development Pathways



Electricity Duty waivers, Exemption of wheeling charges, Intra-state transmission charges, energy banking facility

Electricity

Water Supply Infrastructure, waiver of water charges

Water

Long term land lease, waiver of stamp duties, single window clearance

Land

Capital subsidies on renewable energy, Electrolyser CAPEX Viability Gap Funding/Price Support

Hydrogen Production

Transportation

Development of green hydrogen pipelines, Development of waterways for cheaper ammonia transportation

Port & Storage

Development of Port Infrastructure, Ammonia storage facilities

Govt. support for export (state and central), MoUs for green ammonia partnerships

Export

Kerala would require a major centralised hydrogen supplier with sufficient scale to export in the initial phases and further meet the demand of the entire valley

Source: Govt. of Kerala; Green Ammonia Proposals; MEC+ analysis

9 states have announced incentives through policies

Rajasthan, Andhra Pradesh, Maharashtra announced their policies, and Punjab, Uttar Pradesh and Kerala in draft stages

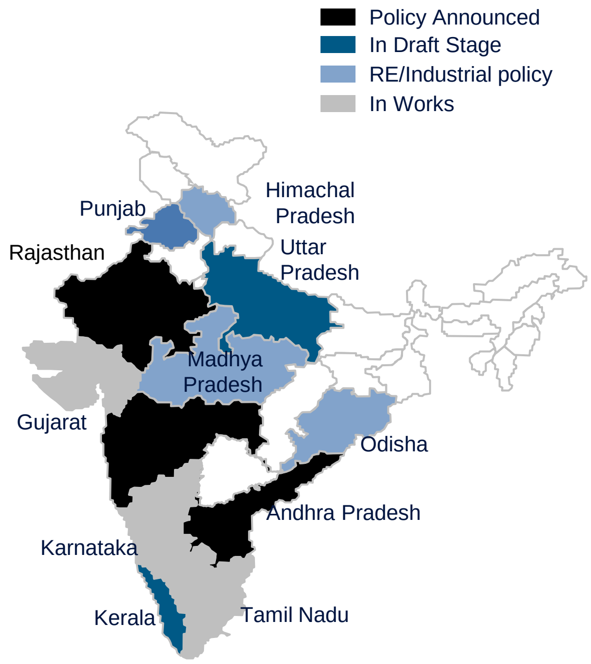
Level of incentives available across states with favourable policies

🟥 Not Available 🟩 Available 🟦 As per Industrial Policy

Level of Incentive ↑

Incentives Available	Part of State RE/Industrial Policy			Green Hydrogen Policy Draft			Policy Announced		
	HP	MP	OD	PB^	UP	KL	RJ	AP	MH*
Electrolyser Manufacturing Incentives	🟥	🟦	🟦	🟥	🟦	🟥	🟦	🟦	🟥
Hydrogen Asset Development	🟥	🟦	🟦	🟦	🟦	🟥	🟦	🟦	🟥
Technology Acquisition and R&D	🟩	🟥	🟥	🟩	🟩	🟥	🟩	🟥	🟥
Input Subsidies (exemptions- state transmission ,CSS, Wheeling)	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Investment Support (land subsidies, taxes, duty etc)	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩

States with Hydrogen Policy



Note: *Based on news articles; HP: Himachal Pradesh; MP: Madhya Pradesh; OD: Odisha; RJ: Rajasthan; UP: Uttar Pradesh; KL: Kerala; AP: Andhra Pradesh; MH: Maharashtra; ^PB: Punjab (Asset development subsidy for biomass-based hydrogen pathway)

Source: State Government Policies; News Articles; MEC+ analysis

Kerala has 3 export proposals currently

Kerala has received multiple Green Ammonia export facility proposals from private players

Export proposals in Kerala

	Proposal 1	Proposal 2	Proposal 3
Capacity NH_3 (kTPA)	1100	200	500
Capacity H_2 (kTPA)	220	40	100
Renewable energy capacity (MW)	6000	2700	3000
Electrolyser capacity* (MW)	2200	400	1000
Developer	ReNew	Confidential	Confidential

Kerala government has multiple proposals for setting up an export facility for Green Ammonia which can be leveraged for developing Kerala as an export hub. This will help in centralising the demand and supply and lead to economies of scale in the valley

*: Electrolyser capacity is estimated and not actual
Source: State Government; MEC+ analysis

Other states are also planning on developing GH_2/GNH_3 prod^n

focused on exports with multiple proposals from leading developers (I/II)

Green hydrogen project pipeline

Projects in the initial stages

Project name	Project status	Location	End use-case	Specification
ACME Group	Proposal Cleared	Karnataka	Ammonia	1.2 MTPA NH_3
ReNew Power	Proposal Cleared	Karnataka	Ammonia	1 MTPA NH_3
Avaada	Proposal Cleared	Karnataka	Ammonia	1 MTPA NH_3
JSW (Green H_2)	Proposal Cleared	Karnataka	Ammonia	*Not Available*
Avaada	Proposal Cleared	Odisha	Ammonia	INR 23,500 crores Investment
ACME	Proposal Cleared	Odisha	Ammonia	INR 58,000 cores Investment
ReNew Power	Proposal Cleared	Odisha	Ammonia	INR 20,000 crores Investment
Ocior Energy Pvt Ltd	Proposal Cleared	Odisha	Ammonia	INR 7200 crores Investment
ACME Group	MoU	Tamil Nadu	Ammonia	1.1 MTPA NH_3
ABC Cleantech	MoU	Karnataka	Ammonia	1 MTPA NH_3
Petronas	MoU	Karnataka	Ammonia	0.5 MTPA NH_3

Note: Non-exhaustive list of announced projects

Source: News Sources; Company Websites; MEC+ analysis

Other states are also planning on developing GH_2/GNH_3 production

focused on exports with multiple proposals from leading developers (II/II)

Green hydrogen project pipeline

Projects in the initial stages

Project name	Project status	Location	End use-case	Specification
Jakson	MoU	Rajasthan	Ammonia	0.365 MTPA NH_3
Avaada	MoU	Rajasthan	Ammonia	1 MTPA NH_3
Aditya Birla Renewables	MoU	Rajasthan	Not Available	Not Available
Ocior Energy Pvt Ltd	MoU	Andhra Pradesh	Ammonia	1 MTPA
Ocior Energy Pvt Ltd	MoU	Gujarat	Ammonia	1 MTPA NH_3
Umwelt Energy	MoU	Tamil Nadu	Methanol, Green Ammonia	100 KTPA CH_3OH
Amplus Solar	MOU	Andhra Pradesh	Green Hydrogen	7500 TPA H_2
Hygenco (Jindal)	Planning	Haryana	Steel	75 TPA H_2
O2 Power	Planning	Karnataka	Ammonia	*Not Available*
Govt. of Kerala – IH2A	Planning	Kerala	Mobility	21,900 TPA H_2
Avada group	Planning	Madhya Pradesh	Ammonia	*Not Available*

Note: Non-exhaustive list of announced projects

Source: News Sources; Company Websites; MEC+ analysis

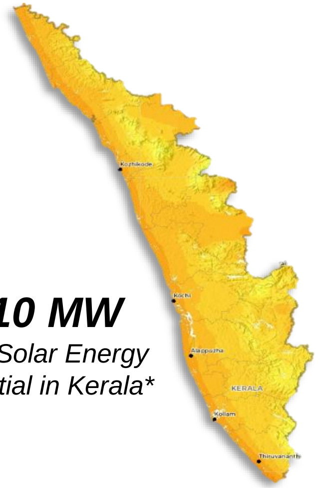
TOC

Kerala has 6,110 MW of grid-connected solar potential

resource quality is moderate to low as compared to other states in India

Solar Energy Potential in Kerala

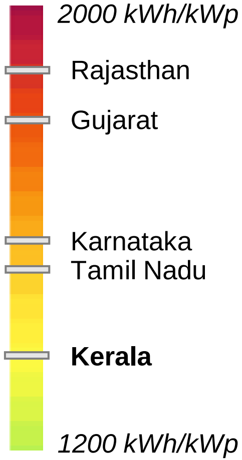
Photovoltaic Power Output (kWh/kWp)



6,110 MW

*Total Solar Energy Potential in Kerala**

Photovoltaic Power Output



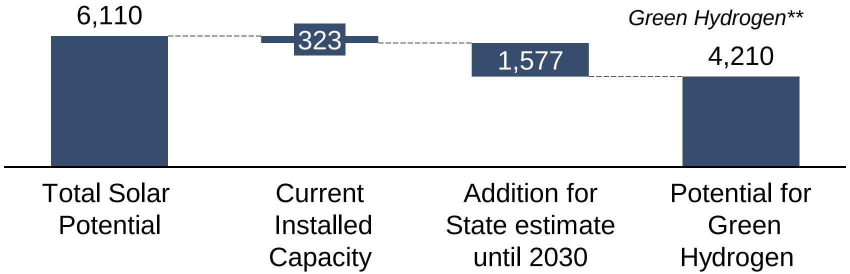
*Floating solar potential is estimated at **8.6 GW** in Kerala (High level estimation)*

Solar Energy Potential Available for Green Hydrogen Production

Potential Available in MW

4,210 MW

*Total Solar Energy Potential available for Green Hydrogen***



Capacity Available for Green Hydrogen	4,210	MW
Energy Produced	6638	MU
Potential Green Hydrogen Production	**119**	**kTPA**

- Kerala can produce 6638 MUs of energy with the un-utilised solar potential, translating to 119 kTPA of green hydrogen. This is equivalent to 17% of the total energy consumption of the state
- Given the state's target to be 100% RE dependent on its energy needs by 2040, the actual available solar potential for green hydrogen production could be even lower

Current Installed capacity refers to ground mounted installations | State Action plan estimates the cumulative solar projects to reach 3 GW (Including 1.1 GW of Rooftop PV) | Avg. CUF considered at 18%; State energy consumption at 23,983 units in 2022

Note: *Assuming 10% of waste land is viable for solar, actual availability of GH_2 energy requires further study. Current installed capacity pertains to ground-mounted installations. State action plan aims for cumulative solar projects to reach 3 GW (including 1.1 GW of Rooftop PV), with average CUF of 18%. State energy consumption was 23,983 units in 2022

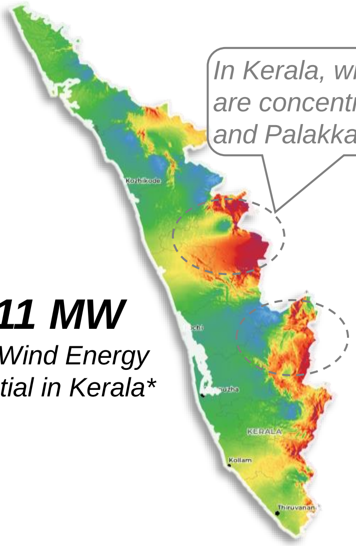
Source: Solar Atlas; Govt. of Kerala; MEC+ analysis

Kerala has 2,311 MW of wind potential

With high wind speed sites concentrated in two clusters in Palakkad and Idukki districts

Wind Energy Potential in Kerala

Wind Speeds at 150m



In Kerala, wind resources are concentrated in Idukki and Palakkad

2,311 MW

*Total Wind Energy Potential in Kerala**

Resource Quality:

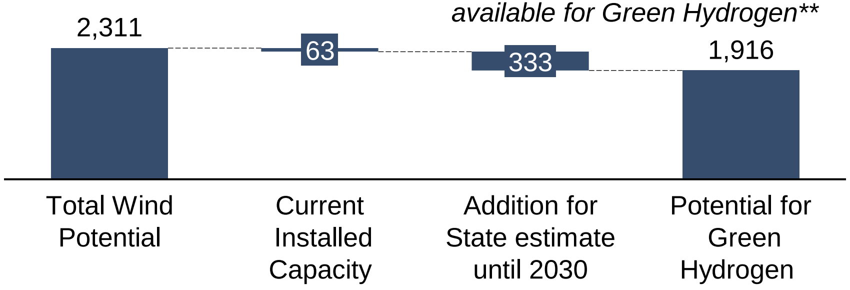
52% (1213 MW) of the wind potential in Kerala is at >35% CUF as per NIWE study, indicating good resource quality

Wind Energy Potential Available for Green Hydrogen Production

Potential Available in MW

1,916 MW

*Total wind Energy Potential available for Green Hydrogen***



Capacity Available for Green Hydrogen	1,916	MW
Energy Produced	5874	MU
Potential Green Hydrogen Production	**105**	**kTPA**

- Kerala can produce 5874 MUs of energy with the un-utilised wind potential, translating to 105 kTPA of green hydrogen. This is equivalent to 24% of the total energy consumption of the state
- Given the target to be 100% RE dependent for energy by 2040, the actual available wind potential for green hydrogen production could be even lower

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Note: * NIWE India Wind Potential at 120m; State Action Plan on climate change estimates the cumulative wind capacity addition to reach 395 MW by 2030; **Energy available for green hydrogen is only the total potential, actual availability estimation requires further studies; Average CUF considered at 35%

Source: NIWE; Global Wind Atlas; Kerala State Action Plan on Climate Change 2023-30; The Energy Report – Kerala; MEC+ analysis

Kerala has ~3 GW unexplored potential

Across large hydroelectric, small hydro and pumped hydro storage that is unexplored and can be studied for green hydrogen production

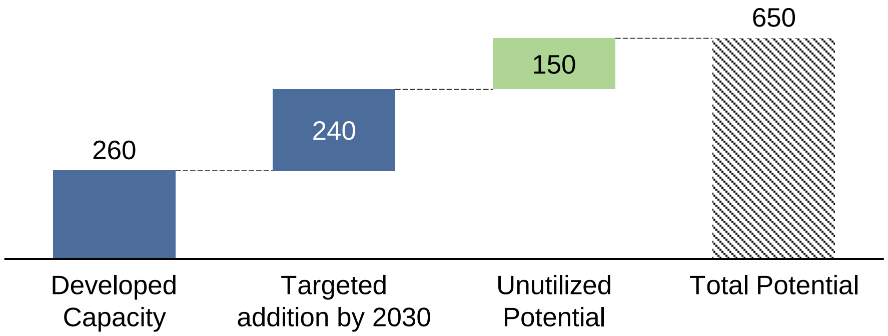
Hydroelectric Power Potential in Kerala
In MW

Pumped Hydro Storage Potential (Exploitable)

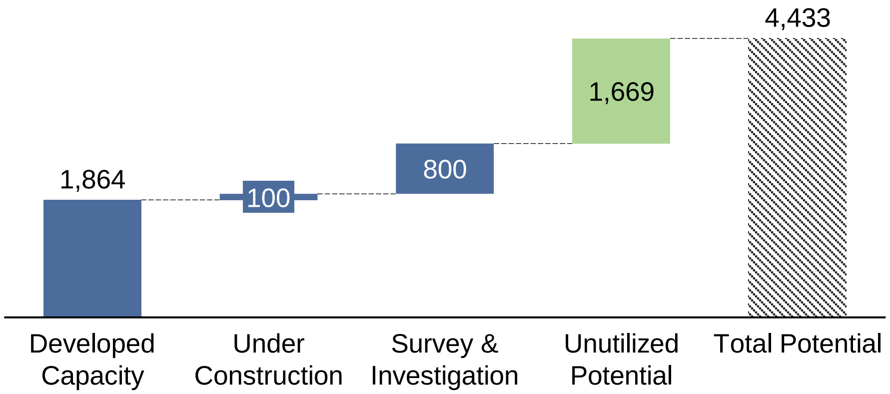
Project	Capacity (MW)
Idukki Pumped Storage Project	600
Pallivasal Pumped Storage Project	600
Total	**1200**

Both projects under study stage

Small Hydro Potential (MW)



Large Hydro Potential (MW)



- Kerala has an unutilised hydroelectric power generation potential of 1819 MW (1669 – Large Hydro and 150 – Small Hydro)
- There is another 1200 MW of pumped hydro potential that is currently in the study stage
- Totalling to ~3 GW of unexplored hydro potential in the state that can be availed for green hydrogen production

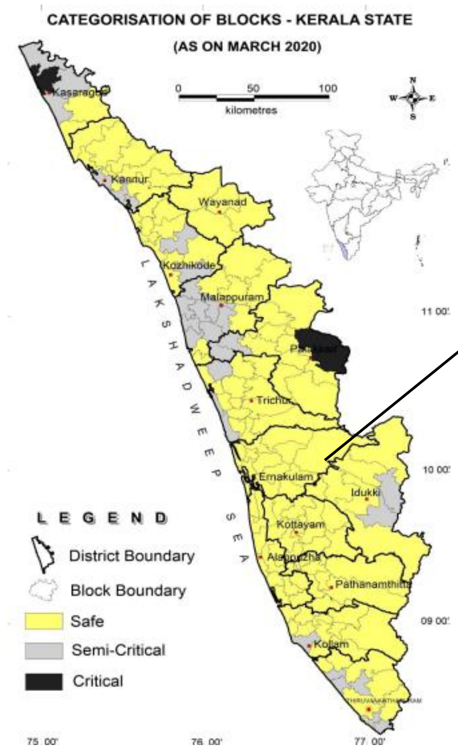
Note: 240 MW of small hydro is targeted addition and can also be utilised for green hydrogen production
Source: Ministry of Power; CEA; SHP Policy; MEC+ analysis

Water for electrolysis can be sourced from industrial pipelines

in initial phase and further alternatives like sea-water desalination can be considered; KWA supplies water in Kochi

Water Stress in Kerala

Groundwater Stress in different districts, 2020



Water Sources in Kochi

Natural Sources

Ground Water

Ground water stress level in Ernakulam is rated as safe (Level of groundwater extraction at 47.26%)

Coastline

Ernakulam has a coastline of 46 Km, which is 8% of Kerala's total cost line

Rivers

Periyar, the river with the largest discharge potential in Kerala flows through the district.

Rainwater

Ernakulam receives an annual average rainfall of 3099 mm with 132 average annual rainy days

Industrial Water Sources in Kochi

Water for Electrolysis

Kerala Water Authority	
Water Treatment Plants	5 (4 in Aluva, 1 in Maradu)
Current Capacity	325 MLD
New Proposal	190 MLD
Total Capacity	515 MLD
Expected Demand	478-600 MLD (By 2050)

- Water supply is Kochi is carried out by Kerala Water Authority from two major water treatment plants located in Aluva and Maradu
- Even though water stress levels are safe, there are regions in western Ernakulam that face water shortages
- Hence, the water for electrolysis can initially be sourced through KWA industrial water pipelines (or other water supply projects like KINFRA project)
- Later with increasing demand alternatives like water desalination plants can be looked upon
- Water conservation and rainwater harvesting should also be promoted

Note: KWA: Kerala Water Authority; MLD: Million Litres per Day
Source: Groundwater Resources in Kerala-2020; Kerenvis; KWA; ADB; MEC+ analysis

Kerala has seven 400 kV and one 320 kV transmission substations

6 out of these 8 HVDC substations are PGCIL substations

Transmission Infrastructure in Kerala
Substations in Kerala

- ● UKTL 400kV Substation, Kasaragod
- ● POWERGRID 400kV Substation, Malappuram
- ● POWERGRID 400kV Substation, Palakkad
- ● KSEB 400kV Substation, Trichur
- ● POWERGRID 400kV Substation, Trichur
- ● POWERGRID 320kV HVDC Substation, Trichur
- ● POWERGRID 400kV Substation, Kochi Ernakulam
- ● POWERGRID 400kV Substation, Trivandrum

Other Substations	
220 kV	33 substations
110 kV	177 substations
66 kV and Below	215 substations

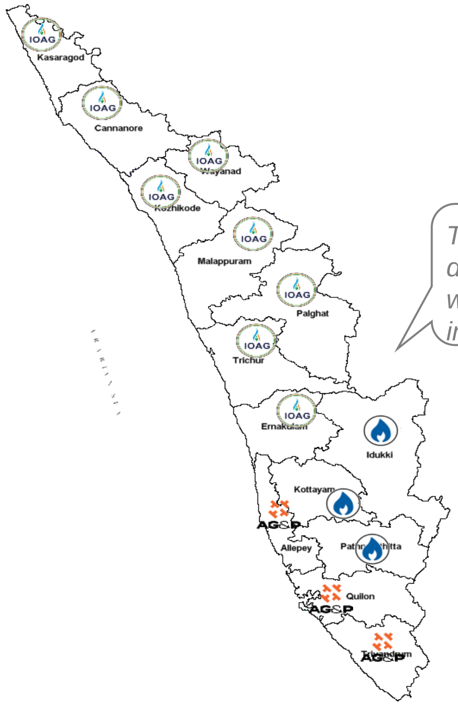
Note: UKTL: Udupi Kasargode Transmission Limited
Source: KSEB Transmission; MEC+ analysis

3 operators in Kerala are developing city gas distribution network

AG&P suggests need for studies to be undertaken for blending green hydrogen in city gas

City Gas pipelines in Kerala

Gas distribution operators



Indian Oil-Adani Gas Pvt Ltd

SHOLAGASCO

AG&P

There are three city gas distributors in Kerala with operations planned in all the districts

City gas distribution in Kerala

- City gas distribution networks are being developed in Kerala by 3 operators;
  - Indian Oil-Adani Gas in the northern and central districts
  - Shola Gasco in Idukki, Kottayam and Pathanamthitta
  - AG&P in Alappuzha, Kollam and Trivandrum

Pipeline Materials used for City Gas Distribution

- Steel pipelines for primary high pressure gas grid (underground)
- Medium Density Polyethylene (MDPE) pipelines are used for secondary medium pressure pipelines (Underground)
- H_2 blending pressure and temp. 5-6 bar and ambient temperature

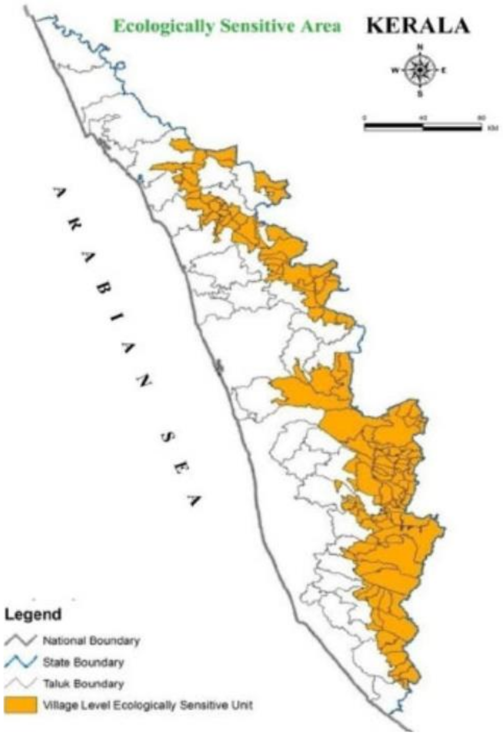
Studies required in Gas Blending – inputs from AG&P

- Need confirmatory studies to ascertain the potential impact of blending on carbon steel pipelines
- Need mechanisms to monitor and regulate the extent of GH_2 blends at varying natural gas flow rates

Source: AG&P; News Articles; MEC+ analysis

Land Availability

is limited in Kerala with limited industrial areas, population density in western coastal areas and ecologically sensitive areas in the east



Land Resources

- From east to west the land in Kerala are in three layers lowland, midland and highland
- Kerala has a fragile ecologically sensitive region on its east covered by the Western Ghats
- Total land area 38.86 lakh ha. Of which more than 80% is under agriculture and forest sectors

Industrial Land

- Kerala has been acquiring land for industrial development. The Directorate of Industries and commerce holds 10 industrial Development Areas, 25 Industrial plots and other estates totaling to 2500 acres
- But majority of these areas are already allocated to industries

Others

- Other players like Cochin Port, FACT, Refineries etc. have their own industrial complexes in the state
- Cochin Port Authority holds 2177 acres of land at various locations in Ernakulam district, the extent of land available for development needs to be studied

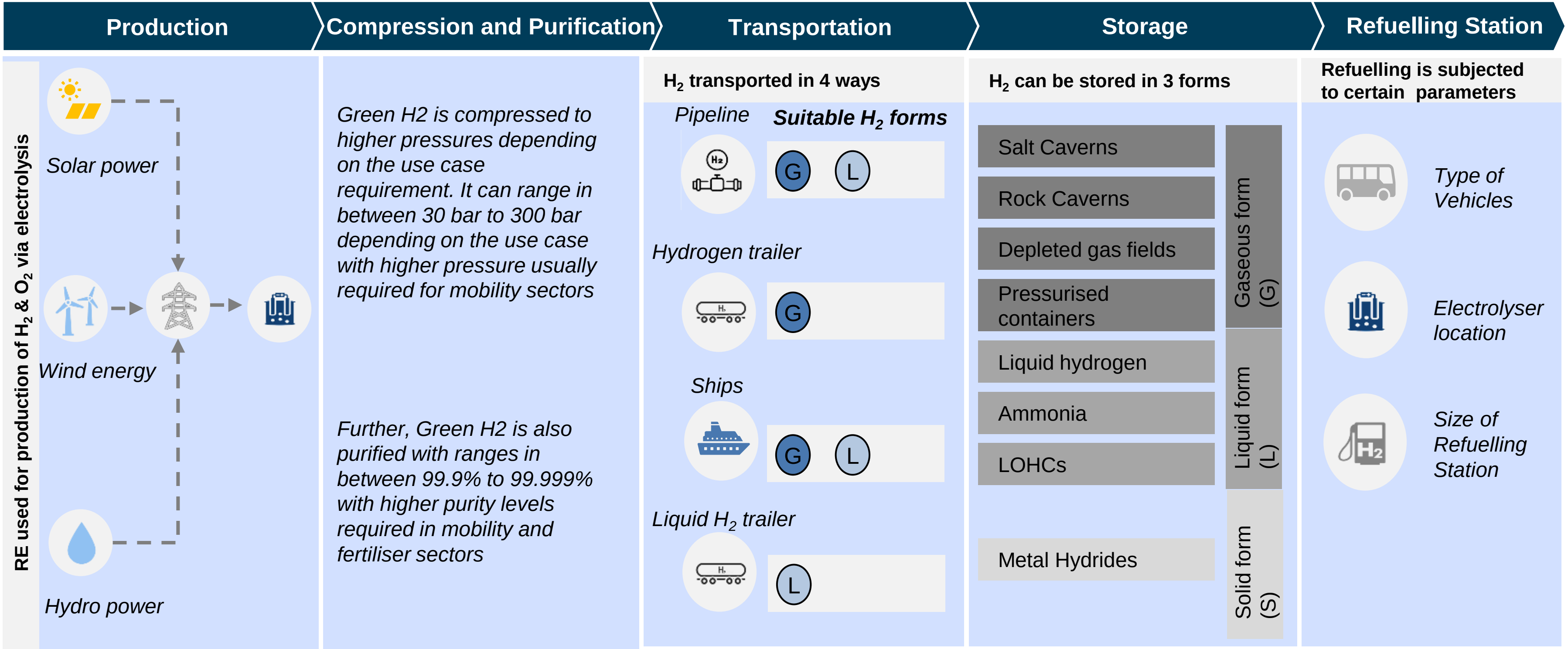
Source: ESA; Industrial Parks; Industrial Land Management; DIC; CPA; Kerenvis; MEC+ analysis

TOC

Various costs get added to LCOH

depending on the configurations and design choices throughout From the production to point of consumption

Landed cost parameters of H_2 and design choice at each stage



Production

RE used for production of H_2 & O_2 via electrolysis

Solar power

Wind energy

Hydro power

Compression and Purification

Green H2 is compressed to higher pressures depending on the use case requirement. It can range in between 30 bar to 300 bar depending on the use case with higher pressure usually required for mobility sectors

Further, Green H2 is also purified with ranges in between 99.9% to 99.999% with higher purity levels required in mobility and fertiliser sectors

Transportation

H_2 transported in 4 ways

	Suitable H_2 forms
Pipeline	G L
Hydrogen trailer	G
Ships	G L
Liquid H_2 trailer	L

Storage

H_2 can be stored in 3 forms

Salt Caverns Rock Caverns Depleted gas fields Pressurised containers	Gaseous form (G)
Liquid hydrogen Ammonia LOHCs	Liquid form (L)
Metal Hydrides	Solid form (S)

Refuelling Station

Refuelling is subjected to certain parameters

- *Type of Vehicles*
- *Electrolyser location*
- *Size of Refuelling Station*

Source: MEC+ analysis

Landed cost of hydrogen can range anywhere from 214-413 INR/Kg

depending on the use-case and the pathway taken in 2040

▢ H_2 Cost 🟦 NH_3 Cost ● Pathway taken ○ Pathway not taken

Sectors	Production	Compress.	Purification	Transport	Onsite Storage	Refuelling Station	Landed Cost of H_2/ NH_3 in 2040
1 **Refinery**	● **212.93**	○	○	● **3.04**	○	○	216.1 NR/Kg
2 **Chemicals**	● **212.93**	○	●	● **3.04**	○	○	218.1 INR/Kg
3 **Fertilisers**	● **48.2**	○	○	● **0.05**	○	○	48.21 INR/Kg
4 **Road Mobility**	● **212.96**	● **17.27**	● **2.08**	○	● **13.8**	● **167.51**	413.59 INR/Kg
5 **Water Mobility**	● **212.96**	● **17.27**	● **2.08**	○	● **13.8**	● **167.51**	413.59 INR/Kg

Note: Buffer Storage calculation are already a part of H_2 production costs; Decompression costs are not taken; Compress. : Compression

Source: IGEF-MEC+ Model ; MEC+ analysis

Five major factors drive the cost of producing green hydrogen

of which renewable capex and electrolyser capex form the 81% contribution to the cost

Factors contributing to green hydrogen production costs

🟩 Significant contribution 🟨 Medium contribution 🟥 Nominal contribution

Factors	Description	% Contribution
Renewable Energy (CAPEX)	Renewable energy is the source of the clean electricity needed to produce green hydrogen	🟩 *61.2%*
Electrolyser Plant (CAPEX)	Electrolyser is the device that is used to split the water molecules into H_2 and O_2	🟩 *19.4%*
Water Desalination (CAPEX)	Water desalination plant is used to provide a regular and sustainable source of water for electrolysis	🟥 *1%*
Hydrogen Storage	Hydrogen storage is required to deal with intermittency of RE resource and maximise production	🟨 *5.3%*
O&M Cost	Costs of regular operations and maintenance of RE, H_2 storage Electrolyser and Desalination plant	🟨 *13.6%*

Resultant LCOH for green hydrogen production comes out to be around INR 330-490/Kg

Note: 1000 hours of banking hourly settlement is considered for the LCOH numbers; Grid charges not considered due to current regulations

Source: IGEF-MEC+ Model

Cost reduction is expected in levelized cost of green H_2 production

because of decline in the per factor cost, says various international studies and reports

Cost trends for each factor contributing to levelized cost of green hydrogen production

Factors	Trends	Evidence
Renewable Energy (CAPEX)	↘	McKinsey & Company: Expects a **68% reduction** by 2030 from 2022 prices iea: Expects a **60% reduction** by 2030 from 2022 prices
Electrolyser Plant (CAPEX)	↘	McKinsey & Company: Expects a **60% reduction** by 2030 from 2022 prices iea: Expects a **62% reduction** by 2030 from 2022 prices
Water Desalination (CAPEX)	→	Water desalination costs are expected to remain constant in the near term due to maturity of technology
O&M Cost	↘	iea: O&M costs for RE are already considered low, however electrolyser O&M are expected to reduce significantly by 2030
H_2 Storage	↘	Bloomberg New Energy Finance: H_2 Storage costs are also expected reduced by ~ 10% from 2025 to 2050

- Renewable Energy cost is expected to be reduced by ~60-70% by 2030, which will can reduce the LCOH by almost 35-40%
- Electrolyser capex is also expected to reduce by an equivalent percentage however, it's impact would be ~15-16% reduction in LCOH
- More mature technologies like desalination and tertiary would not see a lot of change

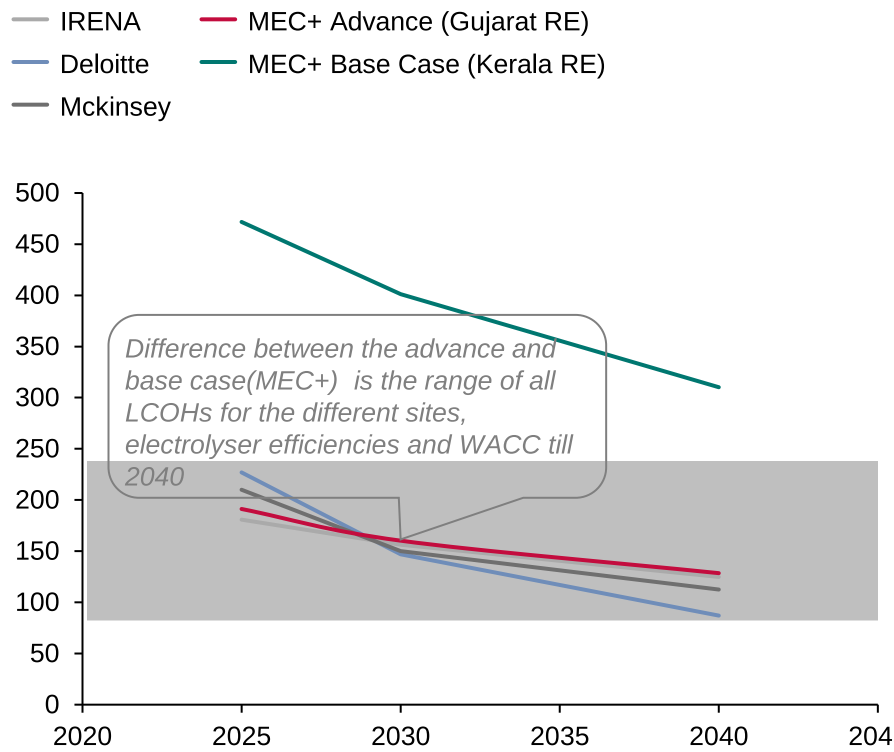
Note: Grid banking and monthly settlement is considered for the LCOH numbers

Source: McKinsey: Chilean Hydrogen Pathway; BNEF; IEA; MEC+ analysis

Levelized cost of H_2 is expected to fall steeply in the next decade

According to international reports; However wide range of costs can exist based on sites, capex, efficiency and WACC

Cost trends for each factor contributing to levelized cost of green hydrogen production
INR/Kg



Difference between the advance and base case(MEC+) is the range of all LCOHs for the different sites, electrolyser efficiencies and WACC till 2040

Assumptions

McKinsey & Company

Electrolyser Capex : 816 USD/kW in 2022 to 327 USD/kW in 2030
Renewable Electricity Cost : 2.3 USD/kWh in 2022 to 1.3 USD/kWh in 2030

IRENA
International Renewable Energy Agency

Electricity Cost : 20 USD/MWh constant across the years
Electrolyser Cost : 1000 USD/kw in 2020 change to 307/Kw in 2050
SEC: 51.2 kWh/kg (2020) to 43.8 kWh/kg (2050)

mec+

Difference between Advance vs Base Case
RE capex decline rate (y-o-y):
Base : 2%, Advance: 10%
Electrolyser efficiency:
Base: 56.6 kWh/kg (2025) to 44 kWh/Kg (2040)
WACC: Base: 9%, Advance 7%

Deloitte.

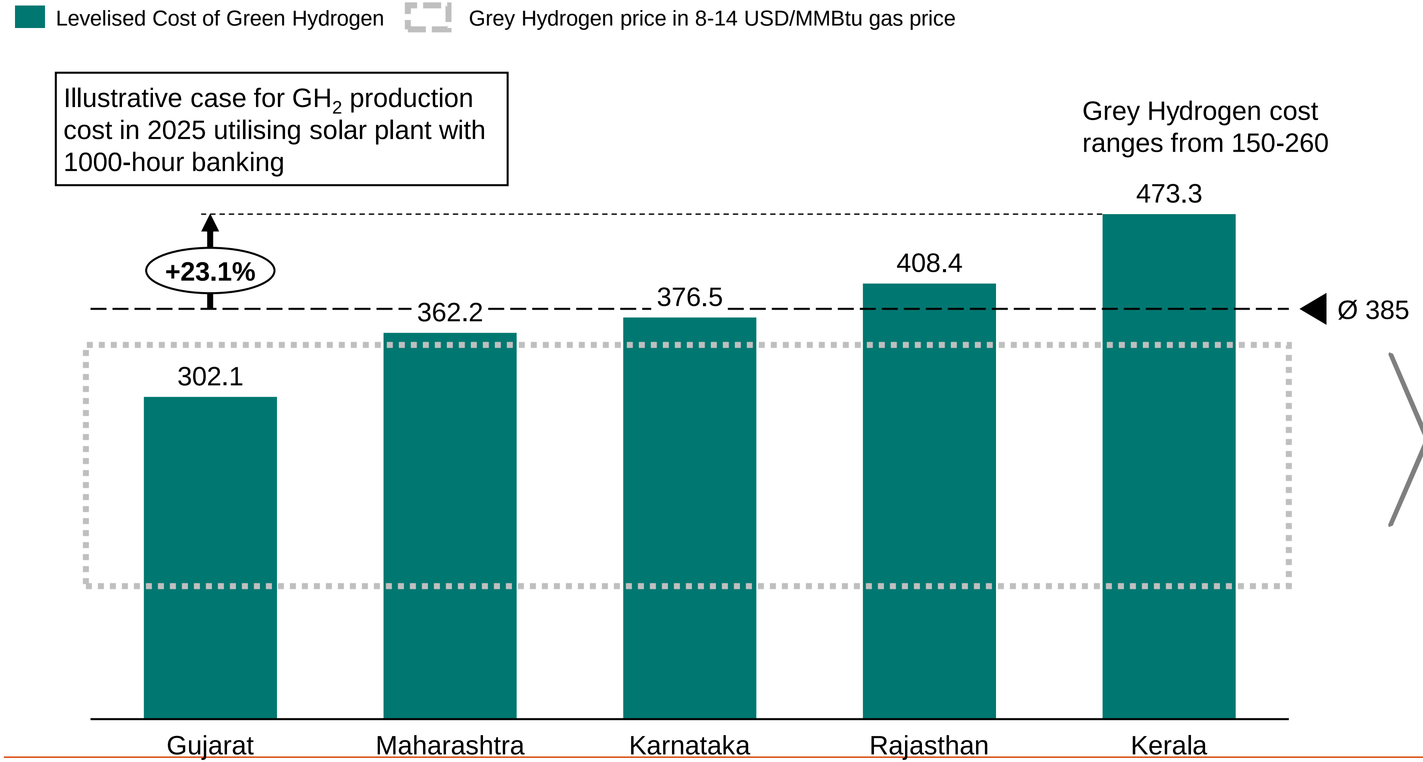
Electricity Cost : 15 USD/MWh (2030)
Electrolyser Capex: 447 USD/kW (2030) change to 295 USD/kW (2050)
Electrolyser efficiency: 69% (2030) to 75%(2050)
WACC: 7% (2020) to 4.2%(2050)

Note: For MEC+ model : Electrolyser capex is at 200000 INR/kW, Solar Capex: 3.6 INR/Cr, Wind capex: 8.43 INR/Cr
Source: IRENA; Deloitte; McKinsey; IGEF-MEC+ Model

Kerala’s low RE resources lead to a higher price premium

when compared with grey hydrogen despite India being cost competitive globally

Green Hydrogen production cost in different states of India in 2025 with 1000 hours banking
INR/kg



Illustrative case for GH_2 production cost in 2025 utilising solar plant with 1000-hour banking

Grey Hydrogen cost ranges from 150-260

Prices for Green Hydrogen production in Kerala is higher by 22.9% from the average cost production of states with better renewables resources leading to a clear need for the availability of subsidies to make the prices in Kerala competitive

Note: Gujarat RE hybrid + battery, Rajasthan solar + pumped hydro, Kerala: Solar + Pumped hydro storage, Karnataka: RE hybrid + battery
Source: IGEF-MEC+ Model; MEC+ analysis

Lower price premium with grey hydrogen can be maintained

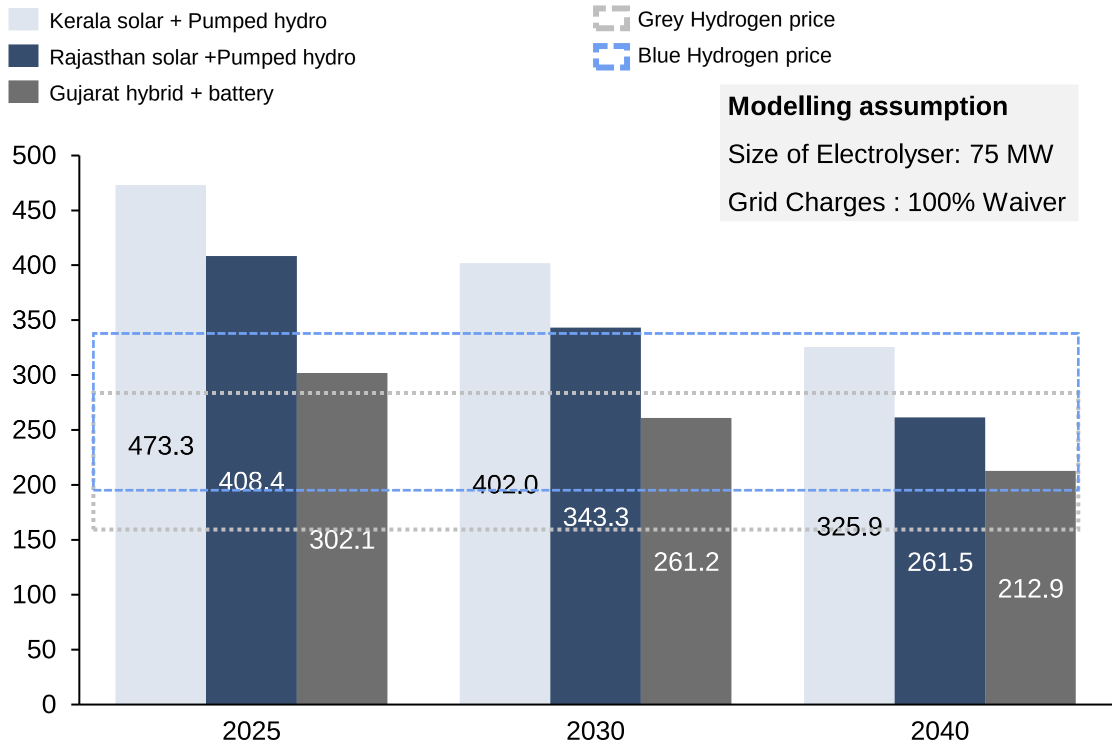
with renewable energy for Kochi valley sourced from outside of Kerala leveraging some of the best sites with ISTS charge waiver

Government regulations for ISTS charges

- The government of India has announced various waivers on renewable energy projects utilised for production of green hydrogen and green ammonia:
  - **ISTS Charges:**
    - ISTS charges waived off for plants commissioned after March, 2019 and **commissioned before December 31, 2030 for 25 years**
    - Post December 31, 2030 the **ISTS waiver will be phased out** with applicability of charges ranging from 25%-100% with 100% charges applicable from January 1, 2034
  - **Other charges:**
    - In line with the green energy open access rules, various states have also announced draft rules for waiver of additional surcharge and cross subsidy surcharge for projects utilised for GH_2 production

GH_2 production cost in different states of India with 1000-hour banking

INR/kg



Modelling assumption

Size of Electrolyser: 75 MW

Grid Charges : 100% Waiver

Note: ISTS losses and Intra-state transmission charges are waved off in the calculation, Natural gas price are considered at 10 USD/ MMBTU in 2025 and 12 USD/MMBTU in both 2030 and 2040

Source: IGEF-MEC+ Model; PIB: ISTS Charges

Compression costs are stable over time

given the maturity of compression technology; In Kochi valley, H_2 compression is vital for transport industries

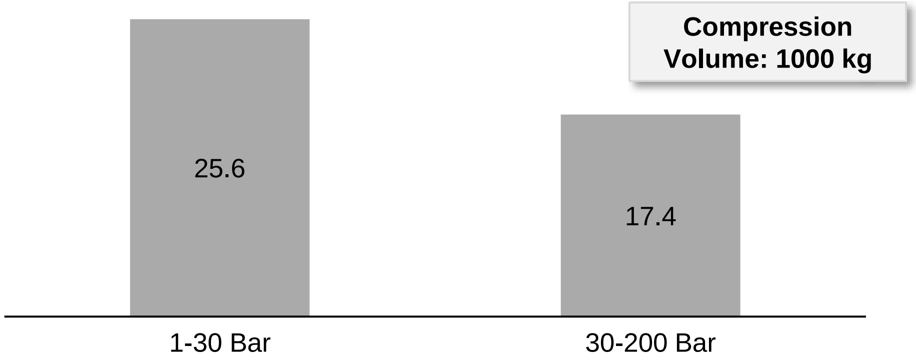
Hydrogen storage technology TRL and relevance for the valley

🟧 No purification 🟥 Need purification

Use-case		Pressure requirement at consumption point
1 **Refinery**	🟧	*30-195 Bar*
2 **Chemicals**	🟧	*30 Bar*
3 **Fertilisers**	🟧	*~30-40 Bar*
4 **Road Mobility**	🟥	*350 Bar*
5 **Water Mobility**	🟥	*350 Bar*
6 **Export**	🟧	*30 Bar*

Cost of H_2 compression

INR/Kg



Techno-Economics of Hydrogen compression: Transition accelerator Canada

- The report takes a bottom-up approach for calculating cost of hydrogen compression, hydrogen compression costs are dominated by energy/fuel costs rather capital costs
- Cost of H_2 compression are depended on 3 major factor
  - P_{input}/ P_{output}
  - Volume of H_2
  - Cost of electricity

Note: PAWE electrolyser release hydrogen at a pressure of 30 Bar form the stack; For refinery, the difference in pressure at point of consumption has to with the quality of the crude supplied; For Road transport and water transport; the compression of 200-350 Bar or 200-700 Bar is considered with Refuelling costs

Source: Transition accelerator; MEC+ analysis

Purification costs are projected to drop by ~65% by 2040

Which is in line with electrolyser CAPEX decline trend; For Kochi valley, H_2 purification is crucial for chemicals and transport industries

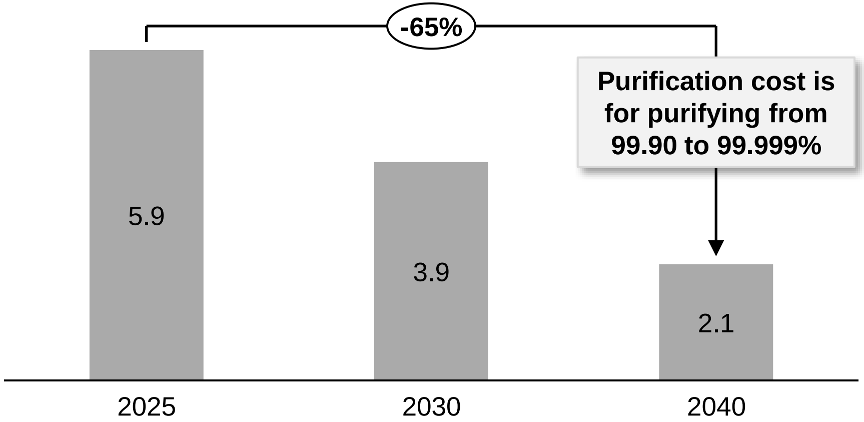
Hydrogen storage technology TRL and relevance for the valley

🟧 No purification 🟥 Need purification

	Use-case	Purity requirement
1	**Refinery**	🟧 *>99.90%*
2	**Chemicals**	🟧 *>99.90%*
3	**Fertilisers**	🟥 *99.999%*
4	**Road Mobility**	🟥 *99.999%*
5	**Water Mobility**	🟥 *99.99%*
6	**Export**	🟧 *>99.90%*

Cost of H_2 purification

INR/Kg



Purification cost is for purifying from 99.90 to 99.999%

NREL: Manufacturing Competitiveness Analysis for PEM and Alkaline Water Electrolysis systems

- Hydrogen purification is a part of larger system within the electrolyser called hydrogen processing, decrease of purification cost is taken as a function of overall decrease in electrolyser costs
- Purification is seen to be divided into 2 parts within hydrogen processing
  - Deoxo
  - Dryer

Note: PAWE electrolyser release hydrogen at a pressure of 99.9% form the stack; For Chemicals, the purification cost from 99.9% to 99.99% was not available and such we have taken the standard cost of purification for chemicals as well

Source: NREL; MEC+ analysis

Transport of H_2 can be done in five ways

depending on the demand and distance from point of production

Hydrogen transportation technologies

1 CGH₂ Trailer	2 Liquid H_2 Trailer	3 Distribution Pipeline	4 Transmission Pipeline	5 Ships
				
Conditions: 200 Bar, 30 °C Capacity: 200-300 kg	Conditions: 1 Bar, −253 °C Capacity: 3600 kg	Conditions: 20 Bar, 30°C Capacity: 10-100 tons/day	Condition: 40 Bar, 30 °C Capacity: >100 tons/day	Conditions: 1 Bar, -23 °C Capacity: >10 tons
• In India, hydrogen is currently transported at a maximum pressure of 200 Bar	• Single truckload can carry almost 10-12x the amount that can be carried in a 200 Bar trucks	• Size of pipeline : 20-inch diameters • Effective for distances up to hundreds of kilometers	• Size of pipelines: 32-inch diameter, might see an increase to 48-inch diameter as demand increases	▪ Shipping of ammonia as hydrogen would be effective only over large(>1000 km) distances and with large quantities

Note: Largest ammonia carrier ships today have a capacity of carrying ~56000 tons of NH_3, we expect this number to increase

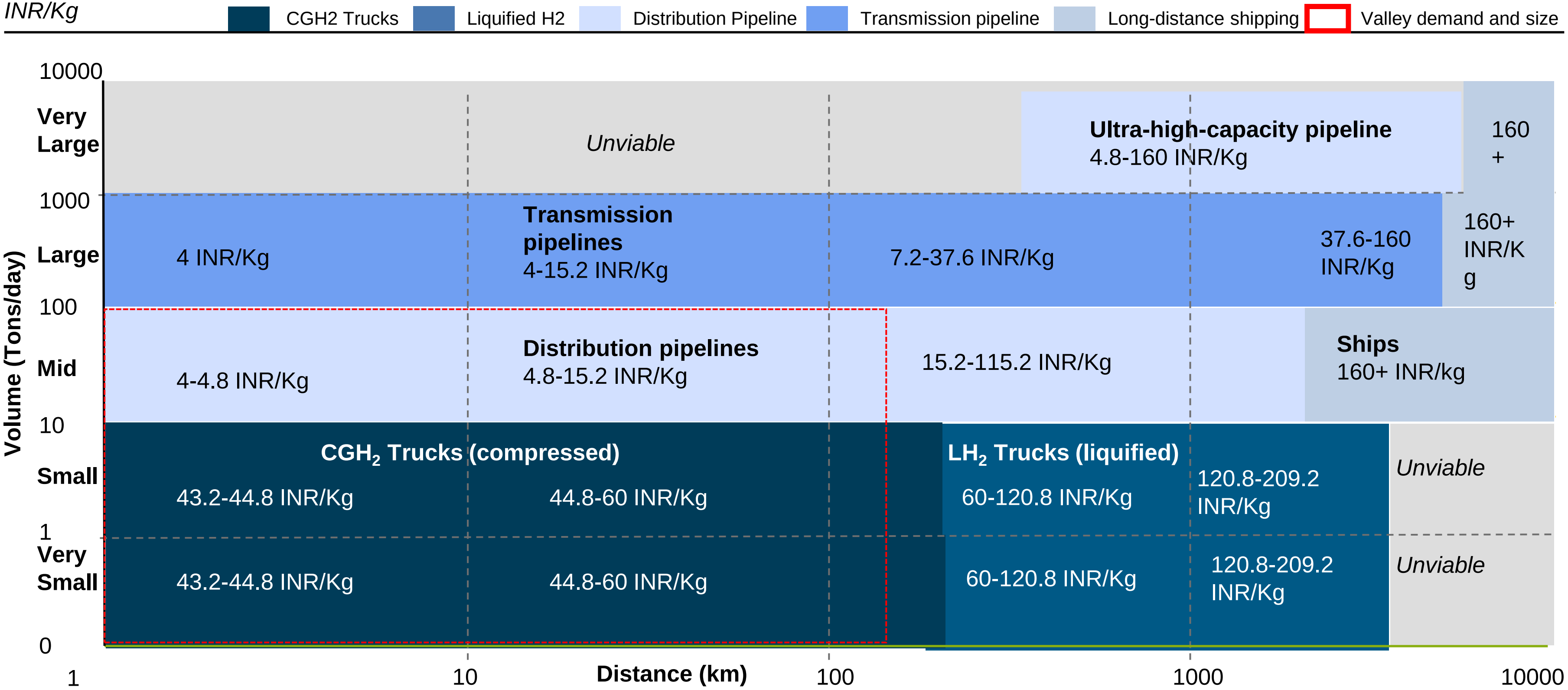
Source: European Hydrogen Backbone; Regulation for Max vessel pressure; MEC+ analysis

Cost is dependent upon the distance and volume of H_2

With GH_2 trucks and distribution pipelines being the cheapest modes considering the demand and distance of the valley

Lowest cost of H_2 transportation for different distances and volumes

INR/Kg



Note: Distribution pipelines are running at 40 Bar, Compressed trailers are running at 200 Bar

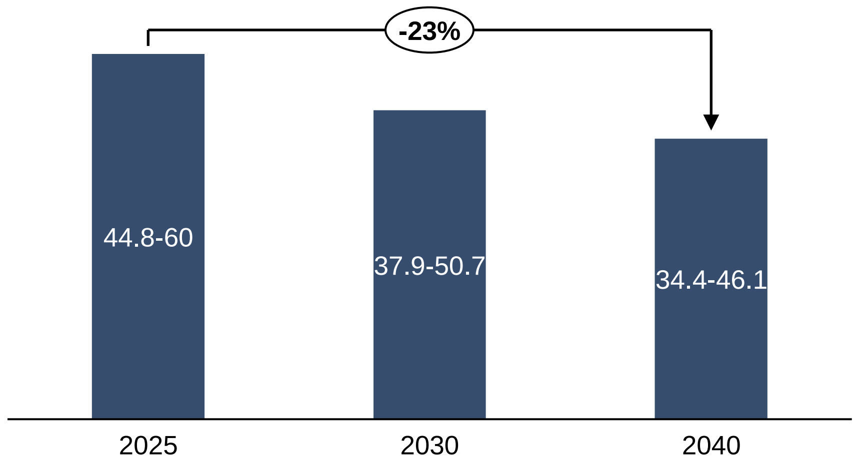
Source: Regulation for Max vessel pressure; Energy Transition Commission; BNEF; MEC+ analysis

H_2 trailers and H_2 pipelines are cheapest transportation modes

which can be utilised for the various use-cases within the valley. The cost of transportation decreases by 23% and 37% respectively for the two modes due to regulatory push and adoption at scale

Cost of transportation via Green H_2 trailers

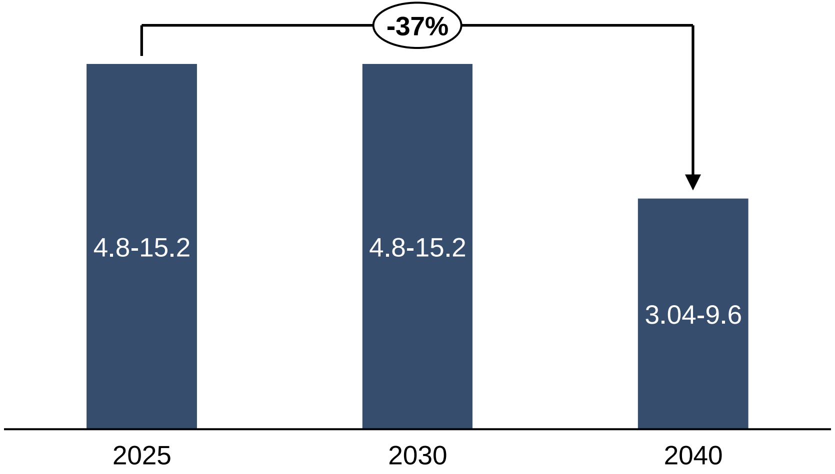
INR/Kg



- Ideal for distributed use-cases where demand of H_2 is not continuous
- Cost is depended on both distance and volume of H_2 that needs to be transported
- We expect that cost reduction would be in the form of regulations which would enable higher compression tank and larger volume of H_2 to be delivered by 2040

Cost of transportation via distribution Green H_2 pipeline

INR/Kg



- Ideal for transport of large volume of hydrogen where demand is continuous
- Transportation cost of H_2 in pipeline is significantly depended on the volume of H_2
- The cost of transport via pipeline is expected to be same until 2030. However, expect costs to decrease by 2040 due to large scale adoption

Note: Distribution pipelines are running at 40 Bar, Compressed trailers are running at 200 Bar

Source: Regulation for Max vessel pressure; Energy Transition Commission; BNEF; MEC+ analysis

Currently Hydrogen can be transported till a pressure of 200 Bar

as per regulation. Anticipated regulatory advancements may raise transport pressures to 500 bar as the hydrogen economy matures which would allow for greater quantities of H_2 to be transported

H_2 Trailers at different pressures

🟦 GH_2 trailers for transportation till 2040

🟩 Anticipated GH_2 trailers for transport post 2040

① CGH$_2$ Trailer

Conditions: 1-20 Bar, 30 °C
Capacity: Distributed

- Currently used for low/distributed demand of H_2 which include chloro-alkali plants and food processing units

② CGH$_2$ Trailer

Conditions: 200 Bar, 30 °C
Capacity: 200-300 kg

- Current mode of transportation of hydrogen in India. Use-cases include H_2 refuelling stations

③ CGH$_2$ Trailer

Conditions: 400-500 Bar, 30 °C
Capacity: 500 kg

- Currently, only running in Europe. Aim to increase the pressure up to 500 Bar and capacity to 1300 Kg by 2030

In India, the most optimal mode of transporting hydrogen for larger demands (300-400 kg per day) is through GH_2 trailers at 200 Bar pressure. This is because current regulations do not permit pressures beyond 200 Bar for hydrogen transport

In Europe, the European Union mandates hydrogen deliveries of around 1300 kg by 2030. With increased regulatory efforts and industry standards, it is anticipated that India will likely shift to transporting hydrogen in trailers at 400-500 Bar pressure, aligning with the current European standard.

Source: Hydrogen capacity of GH2 road trailers; Last Mile Delivery of Hydrogen: Linde; MEC+ analysis

Hydrogen storage can be classified in 3 broad categories

which are still in various stages of development

Hydrogen storage classification

🟩 TRL 9 🟧 TRL 7-9 🟨 TRL 6-7 🟥 TRL < 6

	Gaseous State	Liquid State	Solid State
Description	Storage of H_2 in compressed gaseous form for either long term or short-term storage	Use of Liquid H_2 or other derivatives as storage to maximize the volume of H_2 stored	Metals and metal alloy form a compound upon reaction with H_2 Absorbed H_2 can be released upon heating the metal hydride
Types of Storage	• Pressurised gas tanks • Salt Caverns • Rock caverns • Depleted gas fields	• Liquid Hydrogen • Ammonia • Liquid organic hydrogen carriers (LOHC)	Some of the more promising metal hydrides are • Lithium hydride • Lithium Aluminum hydride
Advantages	• No further processing of H_2 required with only cost of compression being added to overall cost	• Large volume of H_2 can store compared to gaseous H_2	• Room temperature and pressure storage of H_2
TRL	8-9	7-9	7-9

Note: TRL is considered for all types of hydrogen storage for each of the states, with gaseous state having the most varied range wait the most mature technologies i.e. H_2 cavern and pressurised gas tank being commercial

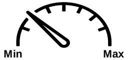
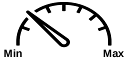
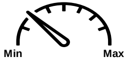
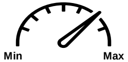
Source: Metal-Hydride Storage; DOE;; MEC+ analysis

Pressurised containers are the most effective storage technology

for the Kerala Green H_2 valley based on factors such as TRL, energy requirements and valley fit

Hydrogen storage technology TRL and relevance for the valley

🟩 TRL 9 🟧 TRL 7-9 🟨 TRL 6-7 🟥 TRL < 6

Description	Storage Type	TRL	Additional Energy requirements	Relevance for valley
Salt Caverns	Geological	9		↘
Rock caverns	Geological	2-3		↘
Depleted gas fields	Geological	2-3		↘
Pressurised Containers	Tanks	9		⬆
Liquid Hydrogen	Tanks	7-9		➡
Ammonia	Tanks	7-9		➡
LOHCs	Tanks	9		↘
Metal Hydride	Tanks	7-9		↘

Note: TRL: Technology Readiness Level, Additional energy requirements refers to additional compression, liquification, conversion and reconversion energy that is attached with each of the storage technologies

Source: Energy Transition Commission; DOE; MEC+ analysis

Cost of hydrogen storage decreases by ~10.4% from 2025 to 2040

whether at 200 Bar or 60 Bar has less to do with cost economics and more to do with size of storage

Hydrogen storage technology TRL and relevance for the valley

Compressed H_2 Tank

Hydrogen storage requirement in Kerala is based on to different use-cases at different technology

- Buffer Storage: 60 Bar
- refuelling Station Storage Cost: 200 Bar

1 CGH_2 tank @60 Bar

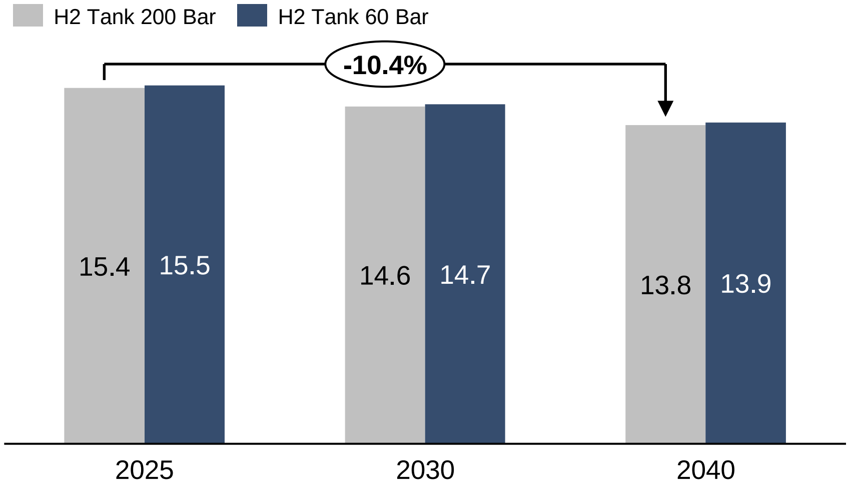
- Low pressure hydrogen storage ideally fertiliser and Chemicals industries where the input pressure of hydrogen is relatively low
- Used as a Buffer Storage for industrial application

2 CGH_2 Tank @200 Bar

- High pressure hydrogen storage ideally preserved for usage of hydrogen as a fuel
- Used as hydrogen refuelling station for daily storage

Cost of storage till 2040

INR/Kg



- Storage cost are so similar due to fact both the Tanks are made from similar materials (Type 1) and as such there is very little difference in their per kg of H_2 cost in their capex
- Only difference between the cost would come from an upstream calculation which would include the compression of H_2

Note: Storage costs are highly sensitivity to cycle rate the lower cost of hydrogen storage is considered for a daily cycle rate, and the higher cost is for hydrogen storage cycled weekly. For the 60 Bar buffer storage, our model already incorporates the cost within the production costs

Source: IGEF-MEC+ Model; Energy Transition Commission; DOE;; MEC+ analysis

A 350 Bar outlet pressure refuelling infrastructure is optimal

for the Kochi H_2 Valley, considering both road and water transportation

Refuelling Station

🟩 TRL 8-9 🟧 TRL 7-8 🟨 TRL 6-7 🟥 TRL < 6

	Pressure	Refuelling Amount	Single tank	TRL	Relevance for valley
Car	700 Bar	3.5 kg	3 minutes	7-8	↘
Truck	350 Bar	35-40 Kg	20-30 minutes	8-9	↑
Bus	350 Bar	35-40 Kg	10 minutes	8-9	↑
Boats	350 Bar	35-40 Kg	20-30 minutes	7-8	↑
Forklift	350 Bar	3.2 kg	2-3 minutes	8-9	→
Trains	350 Bar	170 Kg	30 minutes	7-8	→

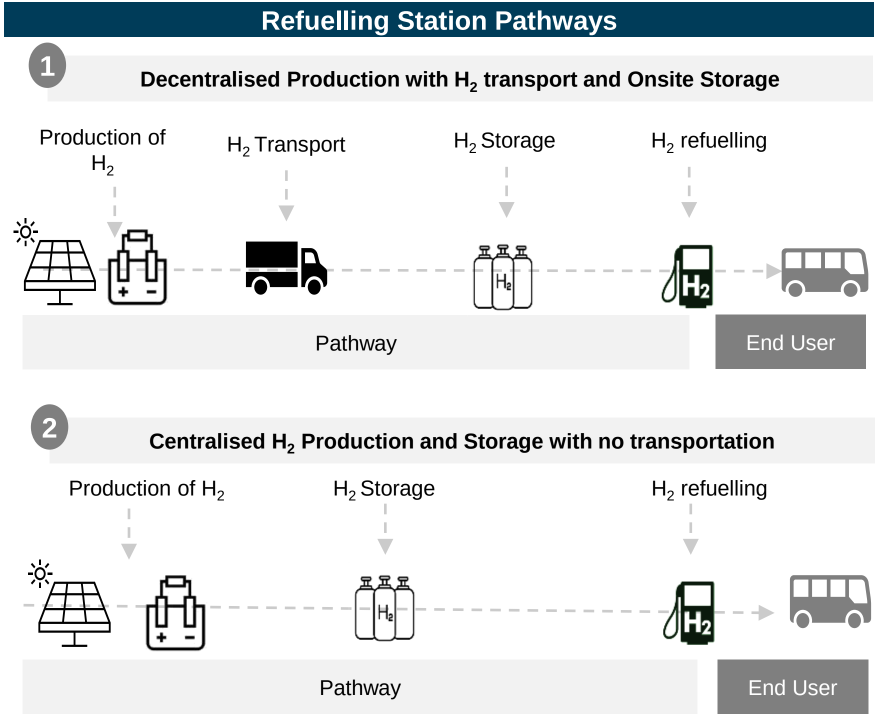
Note: Despite there being commercially available H_2 passenger cars, there are still low adoption and usage as Electrification is a better alternative as is the case with trains

Source: Introduction Stratégies for Hydrogen Infrastructure;Green hydrogen industrial cluster guidelines; DOE; MEC+ analysis

Centralised refuelling plant is cheaper than decentralised plant

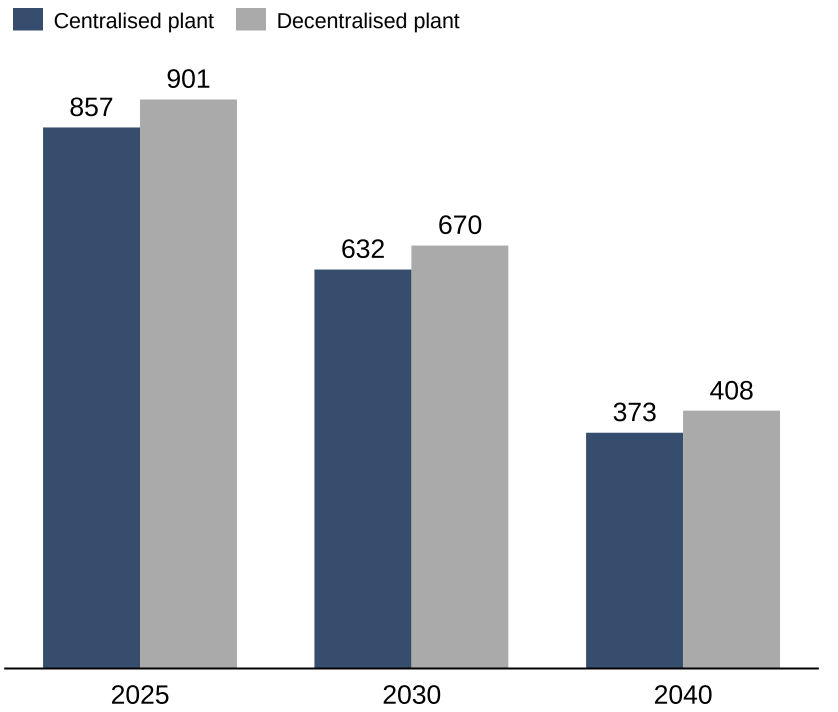
Refuelling stations have 2 design variations based on production location, consumption point and storage facility, centralised and decentralised

Refuelling Station pathways



Landed cost of refuelling for a centralised vs decentralised plant

INR/Kg



	Centralised plant	Decentralised plant
2025	857	901
2030	632	670
2040	373	408

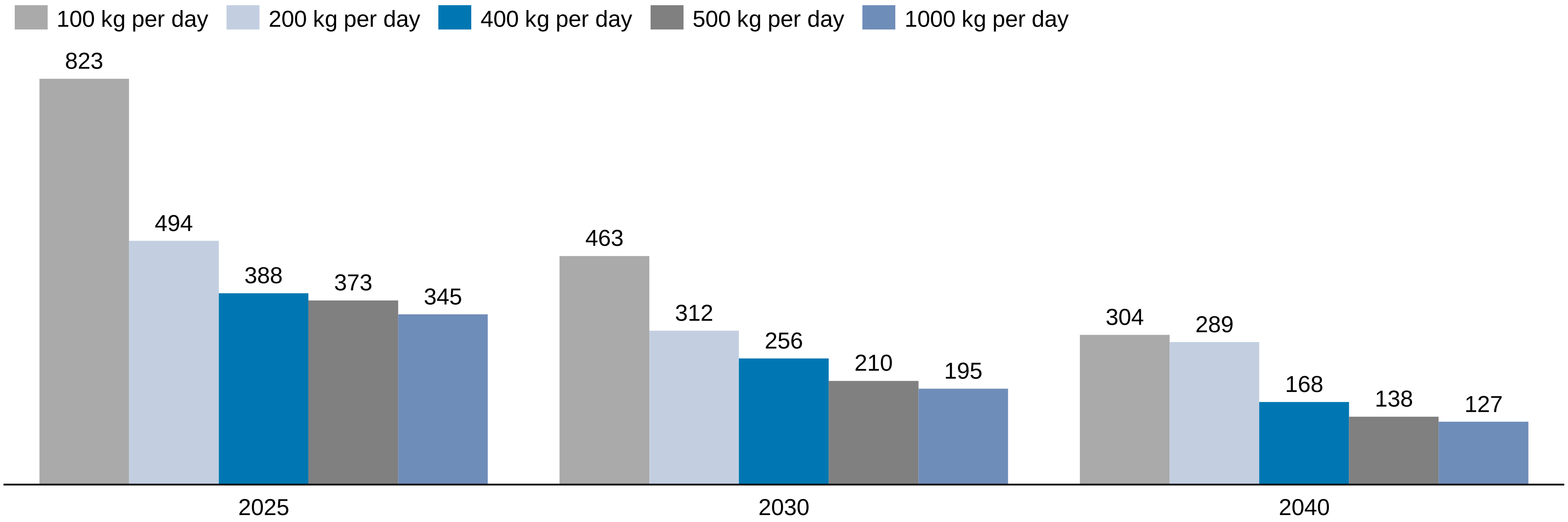
Note: refuelling stations pathways are subjected to consideration of various factor like production location, infrastructure and size of projects. For the centralised plant an electrolyser has been taken with in-situ storage of H_2, and for decentralized plant electrolyser and a transportation distance of 20km have been taken

Source: Hysolar; SMT AG; IGEF-MEC+ Model; MEC+ analysis

Refuelling costs are expected to drop by ~63% from 2025 to 2040

Refuelling costs are depended upon the size of the refuelling station, with there being a 58% cost difference between 100 to 1000 kg/day

Refuelling cost comparison at various capacities kg refuelling station
INR/Kg



- refuelling costs decrease as the size of the refuelling station increases, with the there being a 58% cost difference between 100 to 1000 kg per day station
- refuelling costs are expected to go down as the demand for hydrogen refuelling increases with a 63% decrease estimated over 2025 to 2040

Source: Primary; Introduction Stratégies for Hydrogen Infrastructure; ICCT; NREL; MEC+ analysis

TOC

In Hamburg, the investments for the GH_2 valley are planned

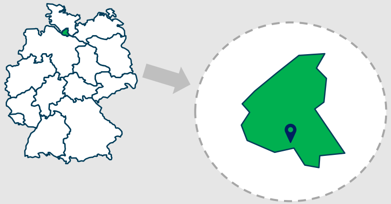
over shutdown of a coal fired plant for various clusters of heat, mobility, port and industries

Overview

General Overview of the Valley

- **Name**: Hamburg Green Hydrogen Hub (HGHH)
- **Valley purpose**: Decarbonisation of Hamburg's industry and port
- **Hydrogen Production Tech:** *Not available*
- **Production Capacity:** 11,500 tpa

Hamburg Green Hydrogen Hub (HGHH) is located on the site of the former power plant in Hamburg - Moorburg

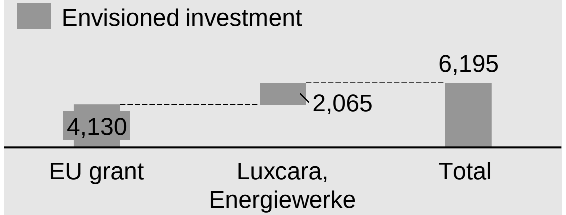


Valley genesis: RE focussed + supply infra driven

In 2020, Vattenfall secured the complete phase-out of a coal-fired power plant through an auction. By July 2021, the plant was closed and transformed into the HGHH.
The valley has various clusters including:

1. Heat
2. Mobility
3. Port
4. Industry

Investment Summary (INR Cr)



Note: The project's cost is INR 6195 Cr. Luxcara and Hamburger Energiewerke will cover ~one-third, while the EU's IPCEI program is anticipated to finance the rest. However, approval for HGHH's application is still pending

Timeline of valley development and investments

2020: Vattenfall submitted bid in auction for reduction of coal-fired electricity & awarded complete phase out

Jan-Apr 2021: Hamburg H_2 network formed with 9 companies & 9 projects of which HGHH is a part

Hamburger Energiewerke purchased the former Vattenfall Heizkraftwerk MoorburgGmbH

May 2021: HGHH included in German Federal Ministry of Economics' projects under consideration for funding under the EU IPCEI program

2023: Hamburger Energiewerke purchased the former Vattenfall Heizkraftwerk Moorburg GmbH

Luxcara to take over shares from Shell and Mitsubishi subject to approval of the German Federal Cartel Office

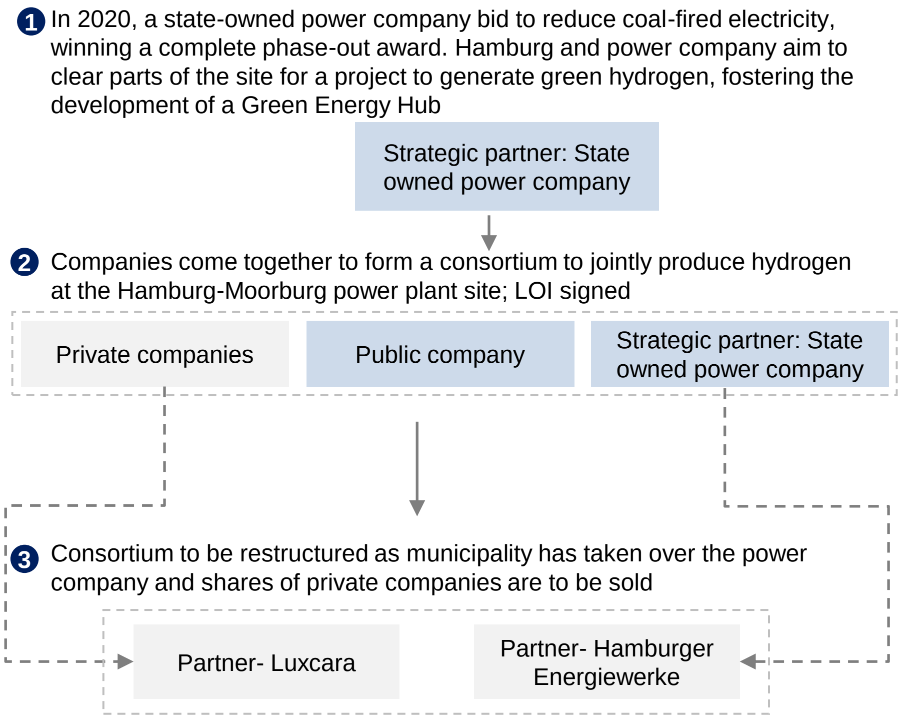
2026: Expected production start

Note: 1 EUR = INR 88.5
Source: HGHH; News Article; Webinar; MEC+ analysis

The governance structure for the valley stems from a collaboration

between public private players to create a consortium

Governance framework of the valley



❶ In 2020, a state-owned power company bid to reduce coal-fired electricity, winning a complete phase-out award. Hamburg and power company aim to clear parts of the site for a project to generate green hydrogen, fostering the development of a Green Energy Hub

Strategic partner: State owned power company

❷ Companies come together to form a consortium to jointly produce hydrogen at the Hamburg-Moorburg power plant site; LOI signed

Private companies

Public company

Strategic partner: State owned power company

❸ Consortium to be restructured as municipality has taken over the power company and shares of private companies are to be sold

Partner- Luxcara

Partner- Hamburger Energiewerke

Governing body and its functions

⬜ Public-Private bodies 🟦 Public bodies

VATTENFALL	Submitted bid in auction for reduction of coal-fired electricity & was awarded complete phase out; Played the role of a **strategic partner** with private and public companies of the consortium
MITSUBISHI HEAVY INDUSTRIES Private companies	Shell will **build a holistic supply chain** & is primarily responsible for **overall project development along with stakeholder and customer relationships**; Mitsubishi will act as a **technical consultant** around system integration
Wärme Hamburg Public company	Interest shown in water-based cargo movement (by beneficiaries) and operators are willing for pilots if adequate support is given by the government
Luxcara	Luxcara is set to acquire shares in Shell and Mitsubishi pending approval from the German Cartel Office. They'll **oversee renewable power sales, procurement**, and play a vital role in securing funding through the EU IPCEI
Hamburger Energiewerke	Hamburger Energie and Warme Hamburg merged to form Hamburger Energiewerke; Purchased Vattenfall wholly and is now a lead partner in the consortium; playing a key role in **acquiring funding under EU IPCEI**

Note: LOI- Letter of Intent

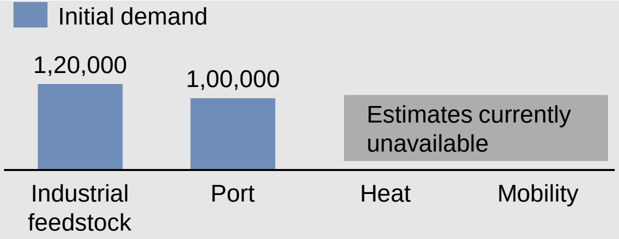
Source: HGHH;; MEC+ analysis

Development is expected to create a Potential Demand & Supply

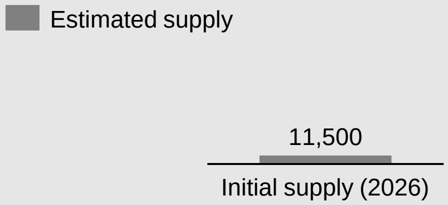
This development is expected to create a potential demand and supply of 2,22,000 and 11,500 TPA respectively with demand offtake guaranteed by mobility, heat, industries and import

Overview

Demand volumes estimated (tons per annum)



Supply volumes estimated (tons per annum)



Benefits

Jobs and GVA

Presently no evidence of the number of jobs created/GVA is available.

CO_2 emission reduction

Around 92,000 tpa of CO_2 is estimated to be reduced

Demand volumes estimated (tons per annum)

- **Import:** Import from production facilities globally, conversion of ammonia to GH_2 via Air Products' facilities in Hamburg before distribution to local buyers and Northern Germany
- **Heat:** 13 MW of usable heat enough to supply up to 6,000 households
- **Mobility:** European logistics hubs including trucks, shunters, ships, terminal equipments
- **Industry:** to be done in 4 stages starting with green steel & aluminum, port & sea import, hydrogen backbone connection and finally green refineries & copper
- **Future sector:** Chemicals

Supply sources for renewable energy

- Onshore wind
- Offshore wind
- Solar

Supply sources for renewable energy

- Connected to the national 380,000-volt transmission grid and the 110,000-volt grid of Hamburg
- Overseas vessels can dock on-site, using the port as an import terminal
- Existing 45 km gas network suitable for H_2 by 2025 and expanded to 60 km by 2030

Source: Future Hamburg (Industrial feedstock); Future Hamburg (Port); Infra supply; Webinar; MEC+ analysis

The valley will see a participation from various stakeholders

spread across government and private entities for investments, governance and project development

Types of stakeholders involved in creation of Hamburg Green Hydrogen Hub

	Investment Stakeholders	Knowledge Institutions, R&D	State Entities	Private Companies
Role	Investment for the valley is a mixture of **public and private co-funding**. Further, the valley has applied for **funding under EU IPCEI**	The **Cluster Agency connects numerous experts** with R&D background including companies, universities and research or funding institutions to promote innovative projects	**The municipal company is an offtaker in the hub** with a goal to dispense heat using existing waste heat from industry, wastewater, recycling by 2030 and in the future from green hydrogen	**Initiate valley development** by bringing in their expertise and required investments
Participating entities	Luxcara Hamburger Energiewerke *Luxcara and Hamburger Energiewerke will cover ~one-third of total cost; EU IPCEI program is anticipated to finance the rest. However, approval is still pending*	Hydrogen Hamburg Renewable Energy Hamburg *The Hamburg Green Hydrogen Hub is listed in the projects of the Cluster Agency*	Hamburger Energiewerke *Hamburger Energiewerke is a municipal company that supplies around 500,000 residential units in Hamburg with local district heating*	Luxcara MITSUBISHI HEAVY INDUSTRIES *Luxcara is taking over the shares from Shell and Mitsubishi. subject to the approval of the German Federal Cartel Office*

Source: Hydrogen Hamburg; News article; HGHH; MEC+ analysis

TOC

In Netherlands, the investments for the GH_2 valley are planned

in the form of clusters comprising of individual projects where project partners form SPVs to undertake the project

Overview

General Overview of the Valley

- **Name**: Hydrogen Energy Applications in Valley Environments for Northern Netherlands (HEAVENN)
- **Valley purpose**: Large scale demonstration project supported by public and private bodies
- **Hydrogen Production Tech:** PEM + Alkaline electrolyser
- **Production Capacity:** 2,810 tons/year using offshore wind plant at 56% CUF

The valley is located in the Gronigen and Drenthe province of Northern Netherlands across 6 regions

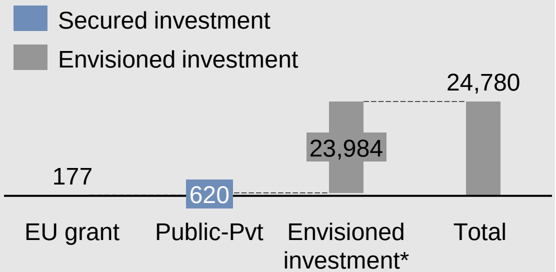
Valley genesis: RE focussed

The valley formed as an **association of public and private stakeholders** aims to **utilize green hydrogen throughout the value chain and create scalable business models** for the regional energy system

The valley is divided into the following **5 clusters:**

1. Chemical park Delfzijl
2. Storage and built environment
3. Green mobility
4. Emmen industry
5. Studies & replication

Investment Summary (INR Cr)



Note: The funding is not inclusive of RE costs as specific set up of projects for RE generation are not seen in the valley yet

Timeline of valley development and investments

2019

Applied for FCH-JU funding programme for valley development

Received a grant of INR 177 Cr and public-private co funding of INR 620 Cr

2020

New Energy Coalition began valley development and execution

2022

Five electrolysers with a total of 35.7 MW to be installed

220 MW electrolysers in FID stage

Waddenfonds and the Province of Groningen allocated INR ~17 Cr for the development of Chemical park Delfzijl, EU grant INR ~11 Cr

2025

Estimated Project completion

Note: Exact split of investments for all projects in currently unavailable

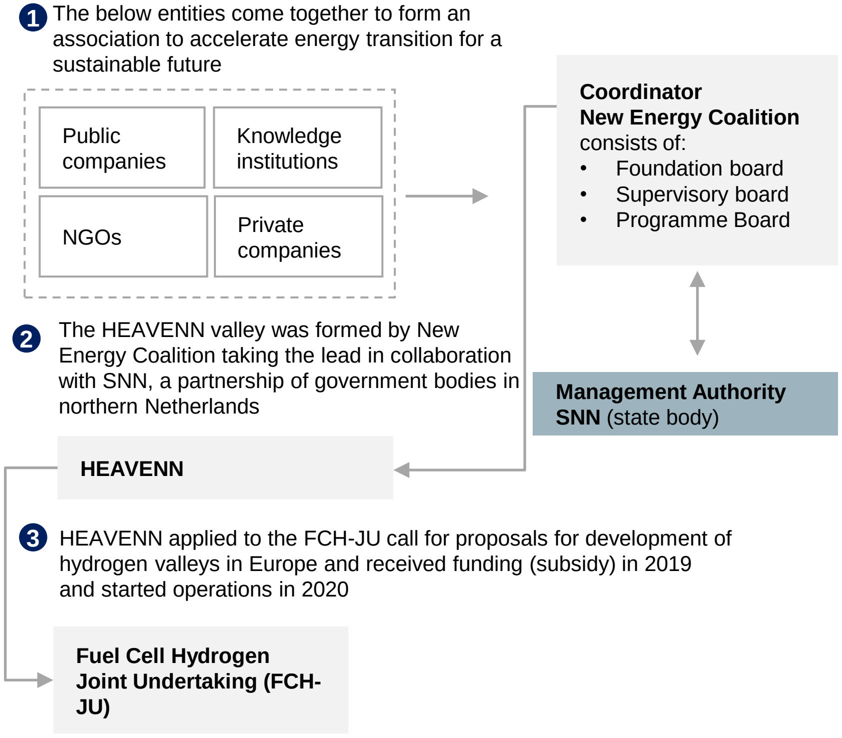
Note: 1 EUR = INR 88.5; RE: renewable energy; * Envisioned investment is based on current estimations provided by Mission Innovation Platform and actual figures may differ

Source: HEAVENN; NEC; Investment Plan; Mission Innovation Report; HEAVENN News; News Article; MEC+ analysis

The governance structure for the valley stems from a collaboration

between an association of public-private bodies and the Northern Netherlands Alliance (SNN)

Governance framework of the valley



❶ The below entities come together to form an association to accelerate energy transition for a sustainable future

- Public companies
- Knowledge institutions
- NGOs
- Private companies

Coordinator
New Energy Coalition consists of:
- Foundation board
- Supervisory board
- Programme Board

Management Authority
SNN (state body)

❷ The HEAVENN valley was formed by New Energy Coalition taking the lead in collaboration with SNN, a partnership of government bodies in northern Netherlands

HEAVENN

❸ HEAVENN applied to the FCH-JU call for proposals for development of hydrogen valleys in Europe and received funding (subsidy) in 2019 and started operations in 2020

Fuel Cell Hydrogen Joint Undertaking (FCH-JU)

Governing body and its functions

⬜ Public-Private bodies 🟦 Public bodies

New Energy Coalition	**Coalition of 150 public - private partners** that helps connects the knowledge, experience, innovation and willpower of companies, government bodies, NGOs and knowledge institutions
Foundation Board	Foundation board is **the highest strategic advisory organ within New Energy Coalition consisting of 3 public, 1 private and 2 knowledge institutions**. The Foundation Board is consulted on new (annual) plans
Supervisory Board	A **five-member board** appointed by the foundation board comprising of members from government, knowledge institutions and companies that **provides advisory on projects**
Programme Board	Programme Board members are at the frontline of the development of new knowledge and innovations. **They are involved in the development of new projects, from initiation to implementation**
SNN	A **partnership of three northern provinces and four major cities in the Northern Netherlands** for coordinating spatial planning and economic strategy that lobbied for HEAVENN valley
HEAVENN	The HEAVENN Valley **comprises of 31 public and private parties** across 6 European countries that have set up projects in 4 clusters across Netherlands
FUEL CELLS AND HYDROGEN JOINT UNDERTAKING	The Fuel Cell Hydrogen Joint Undertaking (FCH-JU), now Clean Hydrogen Partnership is a unique **public-private partnership supporting research and innovation (R&I) activities in hydrogen technologies in Europe**.

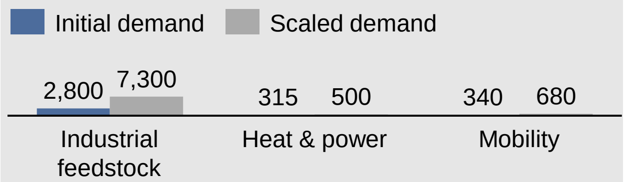
Source: New Energy Coalition; SNN; HEAVENN; News articles; MEC+ analysis

Development will create a Demand & Supply

of 3,455 and 2,810 TPA respectively with demand offtake guaranteed by municipalities in the initial phase

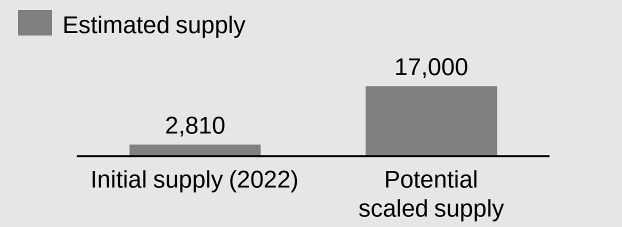
Overview

Demand volumes estimated (tons per annum)



Note: Currently, there is no evidence of subsidy provided on offtake

Supply volumes estimated (tons per annum)



Benefits

According to Province of Groningen, Northern Netherlands envisions to attract over **25,000 hydrogen related jobs by 2030.**

Recurring jobs: 22,500

Non-recurring jobs: 2,500

These jobs span across the entire value chain of a hydrogen valley including manufacturing and supply chain

As **HEAVENN is the pioneer valley in Northern Netherlands and also Europe**, the valley will create socio-economic benefits for the region and help realise this goal of 25,000 jobs

CO_2 emission reduction

The Delfzijl park which is the largest on-going project in HEAVENN is estimated to reduce 27,000 tons CO_2e/year

Demand volumes estimated (tons per annum)

Domestic utilisation focused on the following:

On-going projects

- **Chemical industry -** Delfzijl park, Emmen industry
- **Heating** - heating system for homes (old and new)

Future projects

- **Aviation (Groningen airport) -** multi-fuel filling station serving groundside, airside; hydrogen drones and ground handling equipment on airside
- **Mobility** - 4 trucks and 8 light duty vans to be purchased by Municipality of Groningen; 8 trucks & 100 cars available on lease by Green Planet
- **Power back-up** - Bytenest datacenter

Supply sources for renewable energy

- Onshore wind
- Offshore wind
- Solar

Supply sources for renewable energy

- **Existing offshore wind capacity** developed in the North Sea
- Access to **dense gas infrastructure**, with **high-quality parallel gas pipelines, salt caverns for hydrogen storage, and ports** in Delfzijl and Eemshaven

Note: The demand volumes are based on estimates provided by the architect of the valley

Source: DJEWELS; HEAVENN; GH_2 Netherlands; Aviation; News articles; Groningen; MEC+ analysis

The valley will see a participation from various stakeholders

spread across government and private entities for investments, governance and project development

Types of stakeholders involved in creation of HEAVENN

	Investment Stakeholders	Knowledge Institutions, R&D	State Entities	Private Companies
Role	Investment for the valley was given in the form of **subsidy** by the European union and also includes **public-private co-funding** into specific projects	Conduct **exploratory studies, techno-economic analysis, business-model and impact analysis, replication and scale-up studies** etc. **University of Groningen is the academic lead for the valley**	Government authorities & state-owned companies help **make plans, provide advisory, take part in project implementation, agg. demand, provide incentives & policies** for valley development etc	**Initiate valley development and set-up projects** by bringing in their expertise and required investments. Companies set up projects individually or along with project partners forming SPVs
Participating entities	FCH FUEL CELLS AND HYDROGEN JOINT UNDERTAKING € waddenfonds provincie Drenthe Public-private co-funding *Note: Stakeholder details and exact split for public-private co-funding is currently unavailable*	university of groningen EMEC HYDROGEN ERIG European Research Institute for Gas and Energy Innovation Ha Foundation for the development of new hydrogen technologies in Aragon	ebn Hydrogen Ireland gasunie crossing borders in energy Qbuzz GRONINGEN SEAPORTS EWE Government authorities Gemeente Emmen Gemeente Groningen Gemeente Hoogeveen SNN Samenwerkingsverband Noord-Nederland	Green Planet today for tomorrow HyEnergy TransStore NOBIAN TotalEnergies HYDROGEN VALLEY bytesnet Energy Taxi OV Touringcar ENGIE H2Tec BV Hinicio NAM GETEC NPRC

Source: HEAVENN partners; MEC+ analysis

TOC

In Basque, investments for the GH_2 valley are secured for 5 projects

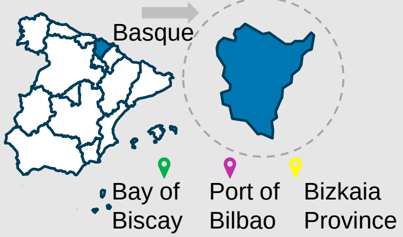
of 332.5MW of electrolysers as well as renewable energy and other infrastructure

Overview

General Overview of the Valley

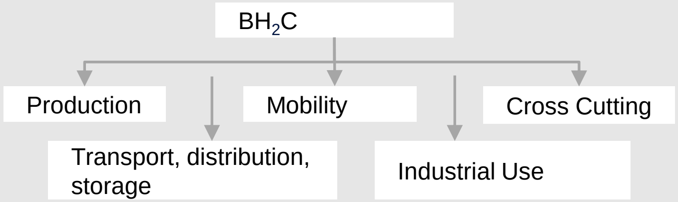
- **Name**: Basque Hydrogen Corridor (BH_2C)
- **Valley Purpose**: To undertake large scale demonstration projects backed by public-private collaborations and scale up to 90% of H_2 demand
- **Hydrogen Production Tech:** Alkaline + AEM + PEM, thermochemical cycles
- **Production Capacity:** 1,250 tpa in 2024 going to 13,250 tpa in 2025 & 33,250 tpa in 2030

The valley is located in the Basque Autonomous Community of Spain



Valley genesis: RE focussed

The valley genesis is based on funding individual projects in five activities across the H_2 value chain under an association formed by member organizations of BH_2C


BH_2C

Production

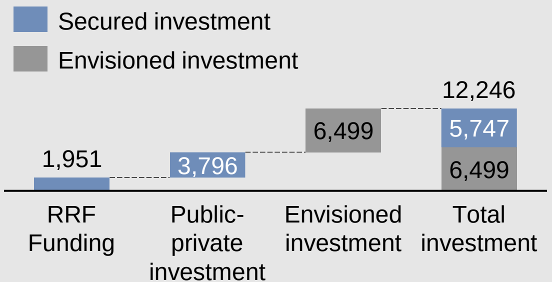
Mobility

Cross Cutting

Transport, distribution, storage

Industrial Use

Investment Summary (INR Cr)



Investments for Basque have been made for electrolyser capacity of 332.5MW as well as RE and other infrastructure development

Timeline of valley development and investments

Hydrogen Strategy released by the Basque government & BH_2C association launched

10 MW electrolyser by Petronor & Saudi Aramco for INR **531 Cr** in Bilbao Port for synfuel production

100 MW electrolyser by Petronor to decarbonise Bilbao refinery (**IPCEI** project)

H_2 bus fleet deployment planned by govt. but no funding yet

Basque allotted INR **1951.4 Cr** of RRF* funds to BH_2C under Euskadi Next Program

2.5 MW electrolyser installed for INR **79 Cr** by Petronor at its Bilbao refinery

Electrolyser factory planned by Sener for INR **88.5 Cr** (**IPCEI** project)

20 MW (in 2025) & **200 MW** (in 2030) of electrolyser by H_2yFive for a total of INR **3097.5 Cr**

Note: Recovery and Resilience Facility (RRF) forms a core part of Next Generation EU Economic Recovery Fund 2021-2026; 1 EUR = 88.5 INR

Source: Basque H_2 Strategy; BH_2C; Bilbao Port; EUSKADI; News Article; Repsol Investor Update 2023; Press Release; HyFive; MEC+ analysis

Governance structure for the valley is in the form of an association

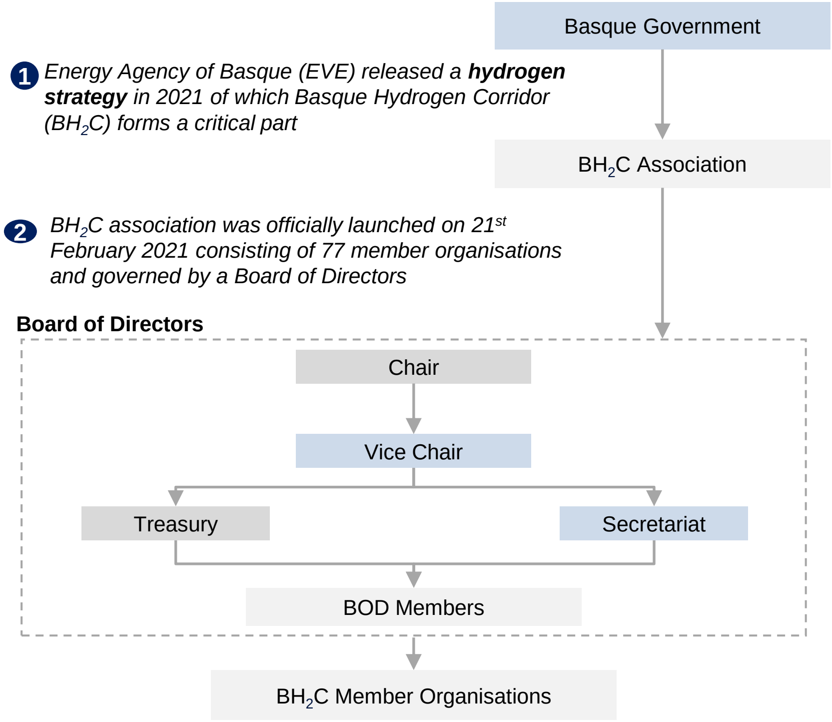
governed by a board of directors comprising public and private enterprises

■ Private bodies

□ Public-Private bodies

🟦 Public bodies

Governance framework of the valley



Basque Government

BH$_2$C Association

Board of Directors

Chair

Vice Chair

Treasury

Secretariat

BOD Members

BH$_2$C Member Organisations

① *Energy Agency of Basque (EVE) released a* ***hydrogen strategy*** *in 2021 of which Basque Hydrogen Corridor (BH$_2$C) forms a critical part*

② *BH$_2$C association was officially launched on 21st February 2021 consisting of 77 member organisations and governed by a Board of Directors*

Governing body and its functions

Eusko Jaurlaritza Gobierno Vasco	The Basque Hydrogen Strategy 2021 was a **roadmap** set out by the Government **to promote hydrogen production, distribution & offtake** in Basque Autonomous Community
Chair Petronor	BH$_2$C Board is chaired by **Petronor** oil and gas company, Repsol Group's subsidiary in Basque, that **oversees the development of the H$_2$ valley.**
Vice-Chair Energiaren Euskal Erakundea Ente Vasco de la Energía	**Energy Agency of Basque (EVE)** is a government-owned entity with a focus on energy efficiency, diversifying energy sources, and promoting renewables. It actively **monitors the Basque H$_2$ strategy and Basque H$_2$ Corridor.**
sarralle A Universe of Engineering	**Saralle**, a private company headquartered at Basque, is an industrial engineering leader for companies in environment, energy, and steel sectors. **It serves as a treasurer for the BH$_2$C association.**
Secretariat enargi	**BH$_2$C Secretariat ENARGI,** Energías renovables de Álava is a provincial entity managed by The Department of Economic Development & Innovation of Alava, Spain.
BOD Members	8 members, comprising of public and private companies, form a part of the board of directors representing a total of 77 member organisations
BH$_2$C Basque Hydrogen Corridor	Member organizations comprises 12 government institutions, 13 knowledge centers & business associations, and 52 companies that set up projects across the H$_2$ value chain

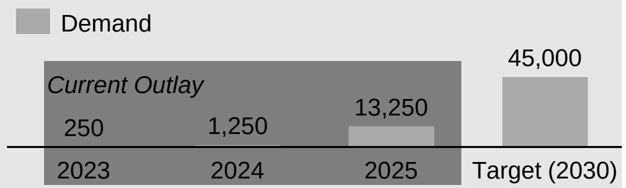
Source: Basque Hydrogen Strategy 2021; BH$_2$C Website; MEC+ analysis

Development will create a Demand & Supply

of 3,455 and 2,810 TPA respectively with demand offtake guaranteed by municipalities in the initial phase

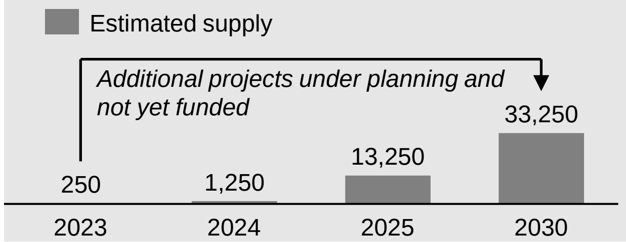
Overview

Demand volumes estimated (tons per annum)



Basque government desires to meet 90% of the current H_2 demand (50,000 tpa) with GH_2 by 2030

Supply volumes estimated (tons per annum)



Benefits

Jobs created

The project is expected to create around 7,753 jobs by 2026 throughout the value chain:

- **Direct Jobs:** 2,101
- **Indirect Jobs:** 3,918
- **Knock-on effect:** 1,734

Gross value addition

The project is expected to add INR 20,740 Crores to the economy

- **Direct effect:** 12,250 Crores
- **Indirect effect:** 7,208 Crores
- **Knock-on effect:** 1,292 Crores

CO2 emissions reduction

The Basque Hydrogen Corridor is expected to make a significant contribution to the environment, with a reduction of 1,281,673 tons/year of CO2 emissions

Demand volumes estimated (tons per annum)

The demand is predominantly **domestic driven** Primary offtake sectors are:

Demand from funded projects (Substitution based)

- **Petrochemical:** H_2 for synfuel production (10 MW project), as feedstock at Petronor refinery (100 MW project), and 2.5 MW to service Petronor refinery along with Abanto Tech Park's H_2 refuelling stations
- **H_2y Five use-case:** H_2 used as replacement fuel for natural gas to decarbonise the Amorebieta Power Plant run by White Summit & Castleton (CCI)

Demand from future projects (Conversion based)

- **Mobility use-case:** Deployment of H_2 bus fleet by Provincial Council of Araba, Gipuzkoa and Bizkaia

Supply sources for renewable energy

- Wind
- Solar

Supply sources for renewable energy

Three electrolyser plants will be setup by Petronor, 2.5MW in 2022, 10MW in 2024 and 100MW in 2025

220MW of electrolysers to be installed by H_2y Five under BenortH_2 initiative in three phases (5MW & 15MW in 2025, and 200MW in 2030)

Note: For supply volumes, the conversion rate considered is 100 tons of green hydrogen per MW of electrolyser capacity

Source: Basque Hydrogen Strategy 2021; BH_2C website; BH_2C projects; MEC+ analysis

The valley will see a participation from various stakeholders

spread across government and private entities for investments, governance and project development

Types of stakeholders involved in creation of Basque Hydrogen Corridor

	Investment Stakeholders	Knowledge Institutions, R&D	State Entities	Private Companies
Role	Partial Investment for the valley came from the **European Union under RRF funding and IPCEI funding.** Rest includes **public-private co-funding** into specific projects.	Conduct **exploratory studies, techno-economic analysis, business-model and impact analysis, replication and scale-up studies** etc.	Basque government authorities and state-owned companies help **make plans, take part in project implementation, aggregate demand, provide incentives and policies** for valley development etc.	**Initiate valley development and set-up projects** by bringing in their expertise and required investments. Companies set up projects individually or along with project partners in an SPV.
Participating entities	European Commission Basque Government € Public-private co-funding *Note: Stakeholder details and exact split for public-private co-funding is currently unavailable*	Centro Nacional de Hidrógeno Parke Basque Country Technology Parks somorrostro ceit ikerlan cidetec University of the Basque Country CIC energiGUNE tecnalia Tekniker Ha MUBIL	Bilbao Port Bizkaia garbiker enargi LURRALDEBUS GHK Gipuzkoako Hondakinen Kudeaketa Energiaren Euskal Erakundea Ente Vasco de la Energía Council of Bizkaia Council of Gipuzkoa	Petronor REPSOL ajusa enagas nortegas sarralle A Universe of Engineering sener Irizar ArcelorMittal "AERO-FERR" Gestión Integral de Transporte

Note: This is non exhaustive

Source: BH$_2$C website; BH$_2$C projects; MEC+ analysis

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In Oman, the development of green H2 valley is anchored

across project specific investments where the govt. of Oman does resource allocation, and the rest is done via debt-equity financing

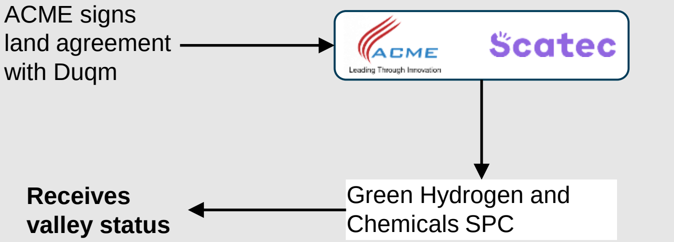
Overview

General Overview of the Valley

- **Name**: Green Hydrogen and chemicals Oman
- **Valley purpose**: Single project for Green Ammonia production and offtake
- **Hydrogen Production Tech:** Alkaline electrolyser
- **Production Capacity:** Initially 100,000 tons/year green ammonia gradually increasing with increase in electrolyser capacity

Green hydrogen and chemicals Oman is planned in the SEZ of Duqm with a 92km^2 land allotted for the project

Valley genesis: RE focussed

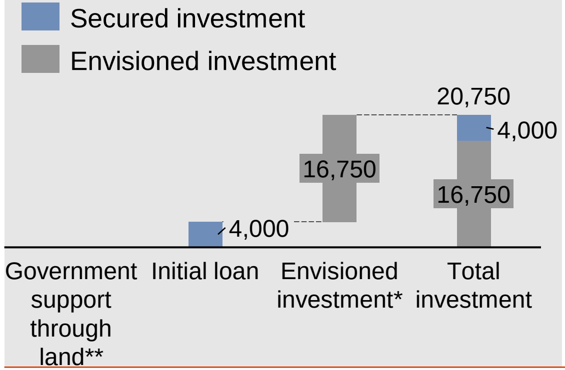

ACME signs land agreement with Duqm

ACME Scatec

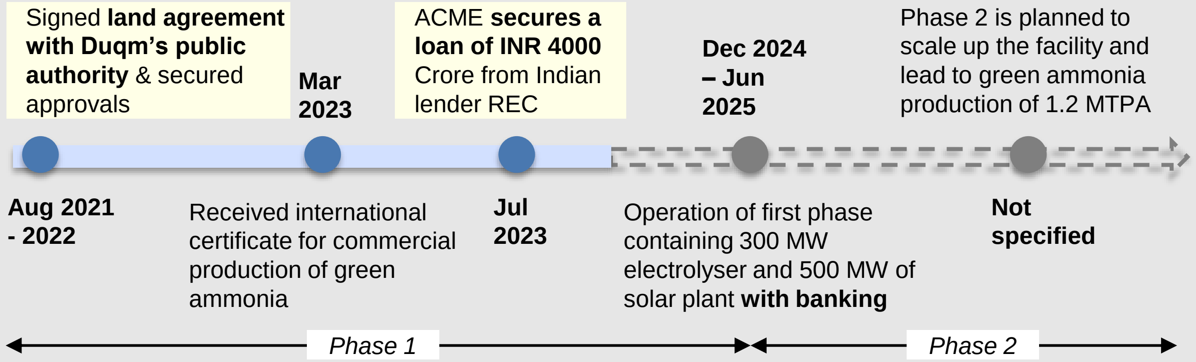
Green Hydrogen and Chemicals SPC

Receives valley status

Investment Summary (INR Cr)



Timeline of valley development and investments


Aug 2021 - 2022: Signed **land agreement with Duqm's public authority** & secured approvals

Mar 2023: Received international certificate for commercial production of green ammonia

Jul 2023: ACME **secures a loan of INR 4000** Crore from Indian lender REC

Dec 2024 – Jun 2025: Operation of first phase containing 300 MW electrolyser and 500 MW of solar plant **with banking**

Not specified: Phase 2 is planned to scale up the facility and lead to green ammonia production of 1.2 MTPA

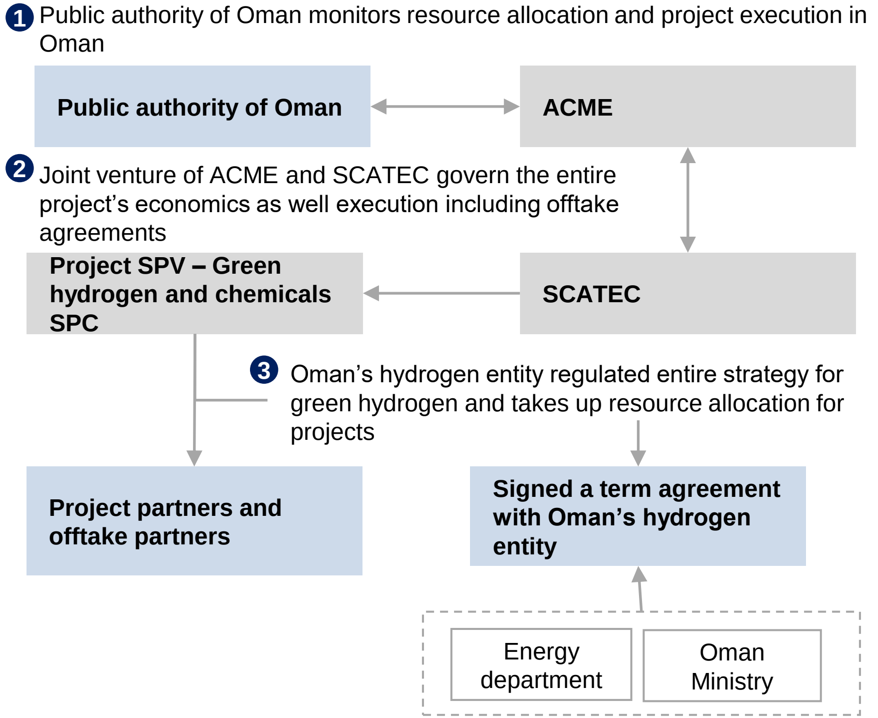
Note: *Envisioned investment is based on current estimations provided by press releases and may differ; ** Exact figures not known

Source: Investment; Loan; Interview transcript; SCATEC; ACME; MEC+ analysis

The governance structure for the valley stems from the initiative

taken by the private companies to setup a project in Oman under the support of the government

Governance framework of the valley



① Public authority of Oman monitors resource allocation and project execution in Oman

Public authority of Oman ↔ **ACME**

② Joint venture of ACME and SCATEC govern the entire project's economics as well execution including offtake agreements

Project SPV – Green hydrogen and chemicals SPC ← **SCATEC**

③ Oman's hydrogen entity regulated entire strategy for green hydrogen and takes up resource allocation for projects

Project partners and offtake partners

Signed a term agreement with Oman's hydrogen entity

Energy department

Oman Ministry

Governing body and its functions

⬜ Public-Private bodies 🟦 Public bodies

Public Authority Tatweer	**Tatweer –** a wholly owned subsidiary of Oman's Public Authority for Special Economic Zone (OPAZ) identified and signed an agreement for the land parcel to be allocated to ACME
Oman's Hydrogen Entity hydrom	Central and independent entity owned by Oman government responsible for coordinating and overseeing the entire implementation of the project, conducting auctions for land allocation for GH_2 projects, and managing common infrastructure
Ministry of Energy and Minerals Energy Development Oman	**Ministry of Energy and Minerals and Energy Development Oman** own Hydrom and are responsible for regulatory and policy making initiatives for green hydrogen in Oman
ACME Scatec	**Private companies ACME and SCATEC** setup a joint venture to develop the project end to end for green ammonia production as well as offtake wherein ACME takes the initiatives to collaborate with the government of Oman via land agreements
*Project and offtake partners KBR, TÜV Rheinland, NUSAIL Surveys, Yara Clean Ammonia	Several players collaborate with the project company to supply electrolysers, conduct feasibility and consultancy studies. Project also signed a term agreement with the company **YARA Clean Ammonia** as an offtaker

Note: Not an exhaustive list of project partners

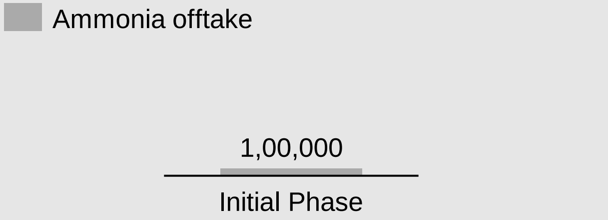
Source: Ammonia Energy Association; Hydrom; YARA; articles; MEC+ analysis

A demand and supply creation of 100,000 TPA

scaled up to supply of 1.2 MTPA of green ammonia is expected

Overview

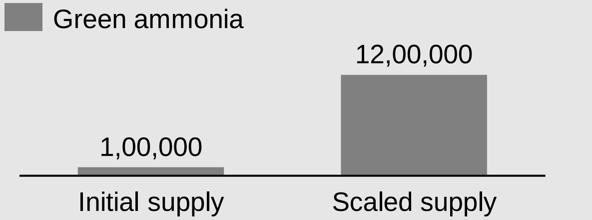
Demand volumes estimated (tons per annum)



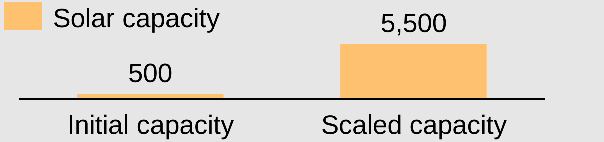
Demand volumes estimated (tons per annum)

- The valley focus is **majorly on derivative production** as **major demand** for the Oman green hydrogen valley comes from **green ammonia**
- **ACME has signed a term sheet agreement with a fertiliser giant Yara for the complete offtake of the produced GNH_3 in phase 1**
- As of now, there is **no evidence for government support as subsidies/offtake** for the demand creation in Oman

Supply volumes estimated (tons per annum)



Supply sources for renewable energy



Banking also available to store the excess power

Supply sources for renewable energy

- ACME and Yara to develop a self infrastructure for supply wherein the land is provided by the Oman government at some concessional rates

Benefits

The Ministry of Energy and Minerals in its green hydrogen strategy aims to create 70,000 jobs as a part of green hydrogen development in Oman

This is envisioned at an electrolyser capacity of 10 GW

Since Oman follows a project-based approach of governance structure, the benefits created directly flow from the government vision in the hydrogen strategy

Basis this, ***the ACME project is expected to create 2100 jobs in Oman in the initial phase which when scaled up can create 24,500 jobs***

Source: Yara Agreement; ACME supply; Hydrogen report; MEC+ analysis

The valley will see a participation from various stakeholders

spread across government and private entities for investments, governance and project development

Types of stakeholders involved in creation of Green Hydrogen and Chemicals Oman Valley

	Investment Stakeholders	Knowledge Institutions, R&D	State Entities	Private Companies
Role	Investment for the valley was provided in the form of concessional prices by the government of Oman for land and the rest was done by ACME via debt-equity financing	Conduct feasibility studies, land selection studies, provide certifications business model analysis and scale up studies for Green hydrogen/derivatives production	In Oman, government authorities of the port of Duqm as well as energy department and ministry of minerals take up the policy making, resource allocation, monitoring of the project and strategic initiatives	Valley development is majorly done by project registration via private companies who are also value chain players along with other supply chain players, consultants, certification players
Participating entities	وزارة الطاقة والمعادن Ministry of Energy and Minerals شركة تنمية طاقة عُمان ENERGY DEVELOPMENT OMAN تطوير الدقم Tatweer Duqm Government of Oman आरईसी REC असीमित ऊर्जा, अनन्त संभावनाएं Endless energy. Infinite possibilities. Debt financing for ACME via Indian company	وزارة الطاقة والمعادن Ministry of Energy and Minerals شركة تنمية طاقة عُمان ENERGY DEVELOPMENT OMAN تطوير الدقم Tatweer Duqm Government of Oman ACME Leading Through Innovation Scatec Project lead applicants	وزارة الطاقة والمعادن Ministry of Energy and Minerals شركة تنمية طاقة عُمان ENERGY DEVELOPMENT OMAN تطوير الدقم Tatweer Duqm Government of Oman, especially port authorities of Duqm region	ACME Leading Through Innovation Scatec Project development TÜVRheinland® Genau. Richtig. Certification for GNH_3 KBR SenseHawk Worley energy | chemicals | resources BLACK & VEATCH Project partners Synergy Consulting Financial advisor YARA Yara Clean Ammonia

Note: This is non exhaustive

Source: News article; Ammonia energy association; MEC+ analysis

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Flemish Ports Hydrogen Valley is anchored

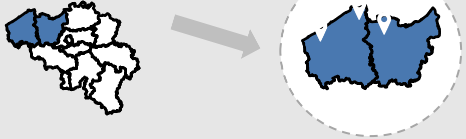
around the port aggregation and gas pipeline infrastructure in Belgium, with an emphasis on import of GH_2 and its derivates into Europe

Overview

General Overview of the Valley

- **Name**: Flemish Ports Hydrogen Valley
- **Valley purpose**: Large scale port and infrastructure development project for green hydrogen upscale
- **Hydrogen production tech:** Alkaline + PEM + CCUS + Import (international)
- **Production Capacity:** 6,500 tpa (2024), 26,250 tpa (2025), 27,250 tpa (2026) and final target of 31,200 tpa

The valley is located close to Northern Belgium, in the Flemish region



North Sea Port | Port Oostende | Port of Antwerp Bruges

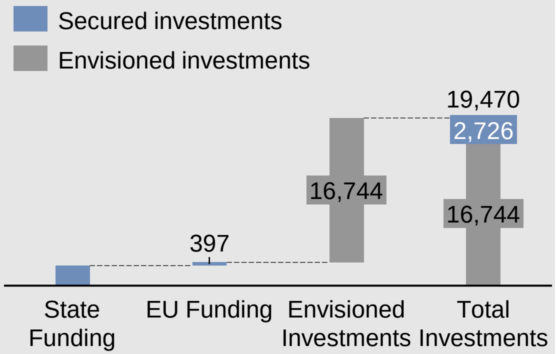
Flemish Ports Hydrogen Valley

Valley genesis: RE focussed

Since 2018, the 3 ports have seen various hydrogen projects. These **ports are complementary in their activities, where they combine steel and chemical industries with energy hubs** and offshore renewable energy production. Their strategic positions serve as vital gateways to European H_2 infrastructure networks. As such, they have been given the title of "H_2 Valley"

Port of Antwerp-Bruges	North Sea Port	Port of Oostende

Investment Summary (INR Cr)



Timeline of valley development and investments

2019 – **Valley Formation**

INR 8.85 Cr for the feasibility study for Power to Methanol project from Flemish Government

2020 – Port of Oostende, DEME and PMV to build a 70 MW Electrolyser plant

Plug Power 100 MW Electrolyser in Port of Antwerp; North-C-Hydrogen will have a 67 MW plant in the Port of Ghent

2022 – The Hyoffwind 25 MW plant funded with INR 203.5 Cr from the EU and INR 70.8 Cr from local govt

Terranova NV to set up 2.5 MW electrolyser INR 38 Cr funding from Flemish Government

2023 – Plug Power 10 MW electrolyser (offshore) with INR 193 Cr funding from EU; Belgium Govt approved INR 2212 Cr for creating a H_2 pipeline

2030 – **Project completion time**

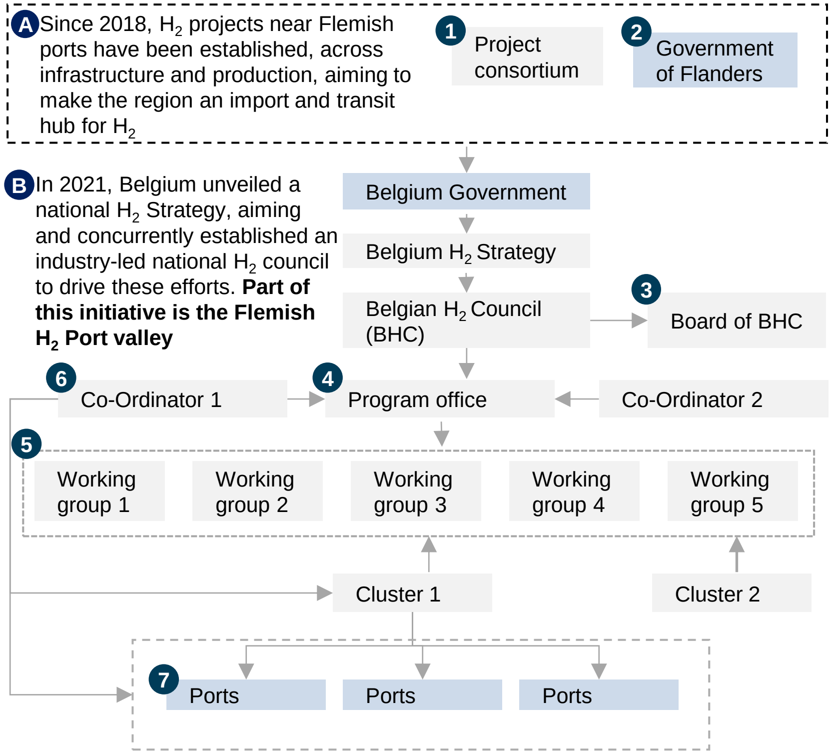
Note: Total investment is taken from Mission Innovation platform EU, break up of investment is not available currently

Source: Port of Antwerp-Bruges; Clean Hydrogen Partnership; WaterstofNet; MEC+ analysis

In Belgium, the genesis and governance of the valley stems

from a singular goal of the government to become the transit and import hub of H_2 in Europe

Governance framework of the valley



A Since 2018, H_2 projects near Flemish ports have been established, across infrastructure and production, aiming to make the region an import and transit hub for H_2

B In 2021, Belgium unveiled a national H_2 Strategy, aiming and concurrently established an industry-led national H_2 council to drive these efforts. **Part of this initiative is the Flemish H_2 Port valley**

Governing body and its functions

⬜ Public-Private bodies 🟦 Public bodies

1 Port of Antwerp Bruges; North Sea Port; WaterstofNet	Across the different projects there are multiple project consortiums that have taken part in the Flemish region however, a point of commonality with them is that either the 3 ports or WaterstofNet were involved in the projects
2 Government of Flanders	Government of Flanders via its innovation and entrepreneurship ministry has already funded multiple feasibility studies on GH_2 project in the Flanders, and was an active member in the creation of the National H_2 strategy
3 Port of Antwerp Bruges; fluxys; engie; virya; sirris; John Cockerill; ArcelorMittal	The board of the BHC is formed by eight companies, covering the hydrogen value chain, will represent BHC in high-level dialogues with the policy makers at the different Belgian federal levels. Port of Antwerp-Brugges is the COB*
4 Program Office	Program Offices are the coordinators of the Hydrogen industrial clusters of Wallonia and Flanders region, they take on the role of secretariat, organization and co-ordination of BHC
5 Working Groups	Working Groups are formed of the members of both the industry clusters of Wallonia and Flanders, will take on tasks including advising policy makers on important hydrogen issues such as development of infrastructure and certification
6 WaterstofNet	WaterstofNet Coordinates the Belgian H_2 council, the Waterstof Industrie Cluster and the Flemish Ports H_2 Valley project
7 Port of Antwerp Bruges; North Sea Port; Port Oostende	Focal point of H_2 projects across Flanders, they interact with projects either as a landlord or directly as an investor into the projects

Note: Chairman of the Board

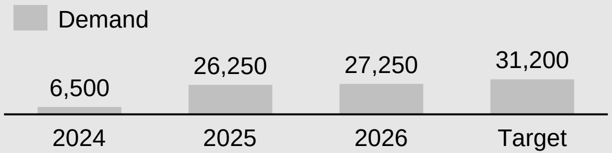
Source: Belgian Hydrogen Council; Port of Antwerp-Bruges; Waterstof Industrie Cluster; MEC+ analysis

Development will create an Aggregation of Green H_2 & Derivatives

supply near the points of consumption in the Flemish ports

Overview

Demand volumes estimated (tons per annum)



The focus is creating a supply of GH_2 near demand areas. Hence current outlay of supply matches demand

No evidence for demand volumes seen currently

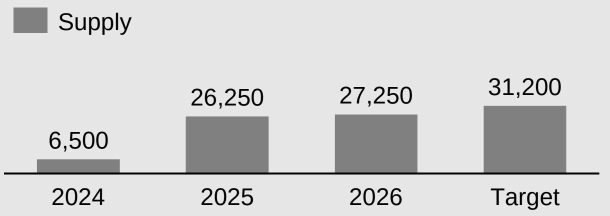
Demand volumes estimated (tons per annum)

In Flemish H_2 ports valley, the government aims to bring Green H_2 closer to the point of consumption i.e., ports. Ports further act as landowners and sometimes investors for the projects, most of the project development is handled by both Government and private players

Demand offtake for planned projects

- Refinery : Plug Power 100 MW at Port of Antwerp
- Multiple Use case :HyoffWind, DEME and PMV at Port of Oostende
- Mobility :Terranova NV, Plug Power 10 MW-Offshore
- Methanol :Power to Methanol & North-C-Methanol

Supply volumes estimated (tons per annum)



Supply sources for renewable energy

- Onshore wind
- Offshore wind
- Solar

Supply sources for renewable energy

- Existing potential for renewable energy across all 3 ports including **Solar, Onshore Wind and Offshore Wind**
- Access to Europe's **largest gas pipeline**
- **H_2 derivates bunkering** facility in the ports

Benefits

In Flemish ports green hydrogen valley, we expect creation of 3000-4000 jobs on installation of 200 MW of electrolyser

The valley will also significantly contribute towards reducing carbon-dioxide emissions as ports are a concentrated zones of high carbon-di-oxide emissions

Currently, no evidence for benefit creation has been seen for Flemish ports

Note: Supply volume is based on size of H_2 production plants that have been planned in and around the three ports, Demand and Supply

Source: Clean Hydrogen Partnership; North Sea Port; Port of Antwerp-Bruges; Port of Oostende; MEC+ analysis

The valley will see a participation from various stakeholders

spread across government and private entities for investments, governance and project development

Types of stakeholders involved in creation of Green Hydrogen and Chemicals Oman Valley

	Investment Stakeholders	Knowledge Institutions, R&D	State Entities	Private Companies
Role	Investment for the valley was directed majorly via EU and the Flemish Government	Multiple feasibility studies and socio-economic studies conducted via government of Belgium and Flanders	Government authorities and state-owned companies help **make plans, provide advisory, take part in project implementation, aggregate demand, provide incentives and policies**	**Private set-up and operate projects** by bringing in their expertise and required investments. Companies set up projects individually or along with project partners in a SPV
Participating entities	Port of Antwerp Bruges North Sea Port Government of Flanders Port Oostende European Commission € Public-private co-funding *Note: Stakeholder details and exact split for public-private co-funding is currently unavailable*	WaterstofNet Belgian Hydrogen Council TU Delft Solent University Southampton Université Polytechnique Hauts-de-France vives hogeschool Lloyd's Register	fluxys Port Oostende Port of Antwerp Bruges North Sea Port	Parkwind EOLY HybridMarine virya energy DEME Air Liquide plug CMB.TECH EXMAR ENGIE YES Marine Power

Note: Non-exhaustive list

Source: WaterstofNet Industrie Cluster; Port of Antwerp-Bruges; MEC+ analysis

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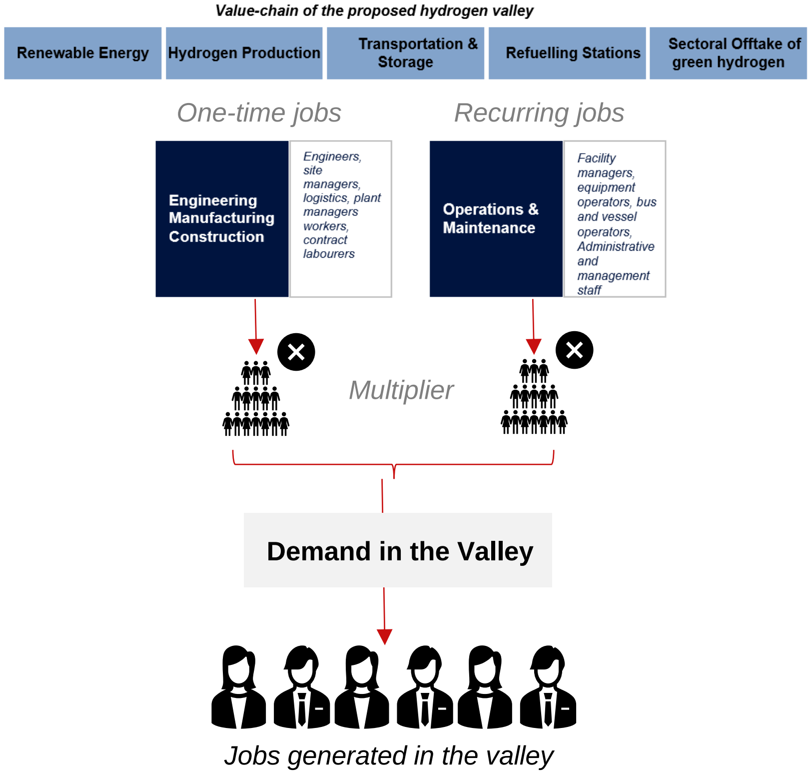
Appendix

Methodology for jobs creation in the valley



Value-chain of the proposed hydrogen valley

Renewable Energy | **Hydrogen Production** | **Transportation & Storage** | **Refuelling Stations** | **Sectoral Offtake of green hydrogen**

One-time jobs

Engineering Manufacturing Construction

Engineers, site managers, logistics, plant managers workers, contract labourers

Recurring jobs

Operations & Maintenance

Facility managers, equipment operators, bus and vessel operators, Administrative and management staff

Multiplier

Demand in the Valley

Jobs generated in the valley

The job creation potential of the valley is calculated as the sum of all jobs opportunities that the valley creates across the different value chain activities

The jobs generated in the valley are divided into one-time (construction/manufacturing/sector deep-dives) and recurring jobs (operations/maintenance/governance)

A unit multiplier is calculated for the different value chain activities based on a combination of existing literature, primary inputs from the industry, proxy industry metrices and logical assumptions

The unit multiplier was multiplied with the demand arising in the valley for the specific value chain activity to arrive at the number of jobs created

The jobs created are the number of people employed to carry-out the specified activity for a defined period and not the number of job years (FTEs) required to carry-out the activity. One-time jobs are expected to be for the duration of the construction/manufacturing activity spanning between 6 months to 2 years and O&M jobs are expected to be for the lifetime of the developed asset

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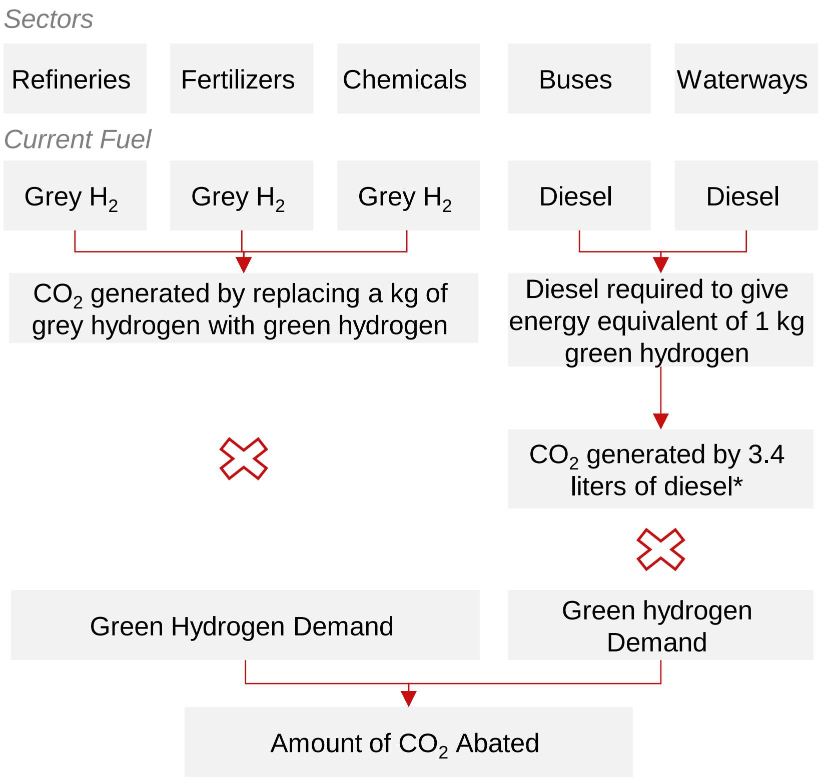
Note: The job creation calculations are intended as a starting point based on high level calculations

Source: MEC+ analysis

Appendix

Methodology for CO_2 abatement in the valley



Sectors

Refineries | Fertilizers | Chemicals | Buses | Waterways

Current Fuel

Grey H_2 | Grey H_2 | Grey H_2 | Diesel | Diesel

CO_2 generated by replacing a kg of grey hydrogen with green hydrogen

×

Green Hydrogen Demand

Diesel required to give energy equivalent of 1 kg green hydrogen

CO_2 generated by 3.4 liters of diesel*

×

Green hydrogen Demand

Amount of CO_2 Abated

CO_2 abatement is calculated as the amount of CO_2 emissions that can be prevented by using a kg of green hydrogen (replacing the current fuel)

The two dominant fuels/feedstock that are being replaced by green hydrogen in the valley are grey Hydrogen and Diesel

For this, the amount of CO_2 abated in the valley by using a kg of green hydrogen instead of the current fuel is calculated

This is multiplied by the amount of green hydrogen used in the valley by different sectors to get the amount of CO_2 abated on a sector level

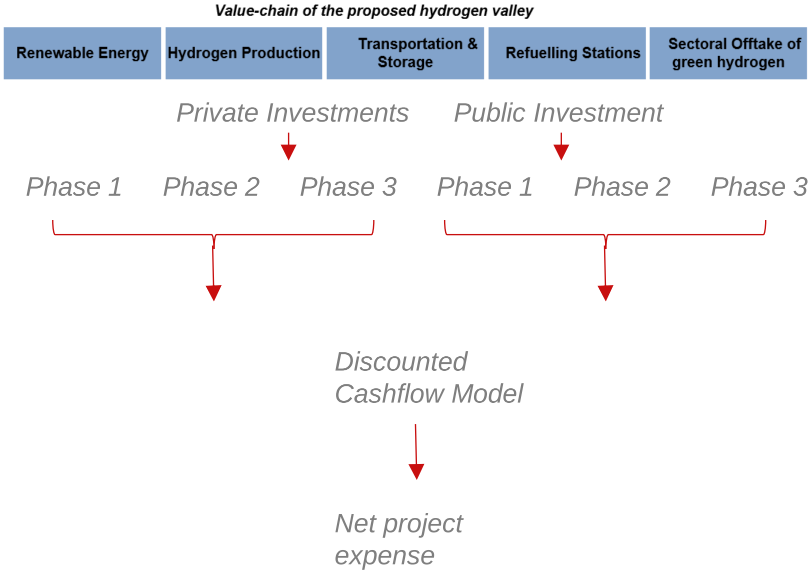
The total CO_2 abated by all sectors together give the CO_2 abatement potential of the valley. The calculation only considered the direct emission reduction on replacing grey hydrogen or diesel with green hydrogen in the valley. It does not consider the CO_2 emissions at the construction stage of the valley or other scopes of CO_2 emissions

Note: *3.4 litres of diesel equals energy from 1 kg of hydrogen

Source: MEC+ analysis

Appendix

Methodology for value in the valley



Value-chain of the proposed hydrogen valley

Renewable Energy	Hydrogen Production	Transportation & Storage	Refuelling Stations	Sectoral Offtake of green hydrogen

Private Investments

Public Investment

Phase 1

Phase 2

Phase 3

Phase 1

Phase 2

Phase 3

Discounted Cashflow Model

Net project expense

Value addition of the valley

Value in the valley is accounted for with the understanding that there is a net quantum of money that is being put into the valley, the value of that total investment after accounting for deprecation of infrastructure and operational costs over the lifetime of the valley is considered the value added

For the purpose, a discounted cash flow model is created, which is further divided into 2 distinct set of investments

1) Public (Government) Investment
2) Private Investment

The model considers input on interest rate on debt, split of debt-equity on the projects and the target IRR to find the rate of deprecation/ WACC (Weighted average cost of capital)

The model considers both the initial investment (Capex) and annual operating expenses (Opex). It discounts the total cash outflow and subtracts the cash inflow from selling the asset after the project's lifespan to total cash outflow to come to NPV of the project

Source: MEC+ analysis

Appendix

Mapping of Industries in Kerala (I/VII)

S. No.	Company	Sector	Public/Private	Location	Website
1	Al Marine Products India Private Limited	Food Processing Units	Private	Alappuzha	NA
2	Protech Organo Foods Pvt Ltd	Food Processing Units	Private	Alappuzha	https://protechorgano.com/
3	Autokast Ltd	Metals	Public	Alappuzha	https://www.autokast.com/
4	Kerala State Drugs and Pharmaceuticals Ltd	Chemical Plant	Public	Alappuzha	https://ksdp.co.in/
5	Milma, Kerala Co-operative Milk Marketing Federation (KCMMF)	Food Processing Units	Public	Alappuzha	https://milma.com/
6	Excel Glasses Ltd.	Chemical Plant	Private	Alappuzha	http://www.excelglasses.com/
7	HIC-ABF Special Foods Pvt Ltd	Food Processing Units	Private	Alappuzha	https://hic-abf.com/
8	Moon Fishing India (P) Ltd., Aroor	Food Processing Units	Private	Alappuzha	NA
9	Cochin International Airport Limited (CIAL)	Aviation	Public-Private (PPP)	Ernakulam	https://www.cial.aero/
10	Hindustan Organic Chemicals Limited (HOCL)	Chemical Plant	Public	Ernakulam	https://www.hoclindia.com/
11	Phillips carbon black limited	Chemical Plant	Private	Ernakulam	https://www.pcblltd.com/
12	Sud Chemie India Pvt Ltd (formerly United Catalysts and Chemicals India Ltd)	Chemical Plant	Private	Ernakulam	https://www.sud-chemie-india.com/
13	The Travancore Cochin Chemicals Limited	Chemical Plant	Public	Ernakulam	https://www.tcckerala.com/
14	Hindalco Alupuram Works	Metals	Private	Ernakulam	https://www.hindalco.com/operations/aluminium-downstream/alupuram
15	Nitta Gelatin, formerly Kerala Chemicals & Proteins Ltd	Chemical Plant	Public-Private (PPP)	Ernakulam	https://www.gelatin.in/
16	Binani Zinc Ltd	Metals	Private	Ernakulam	https://www.binaniindustries.com/
17	Synthite	Food Processing Units	Private	Ernakulam	http://www.synthite.com/synthite.html
18	Plant Lipids	Food Processing Units	Private	Ernakulam	https://www.plantlipids.com/
19	A V Thomas And Co Ltd	Food Processing Units	Private	Ernakulam	http://www.avtgroup.in/
20	Periyar Chemicals Ltd	Chemical Plant	Private	Ernakulam	NA

Note: Non-exhaustive
Source: Company Websites; MEC+ analysis

Appendix

Mapping of Industries in Kerala (II/VII)

S. No.	Company	Sector	Public/Private	Location	Website
21	THE FERTILISERS AND CHEMICALS TRAVANCORE LTD	fertiliser Plant	Public	Ernakulam	https://www.fact.co.in/
22	Bioingredia Natural Private Limited	Food Processing Units	Private	Ernakulam	http://www.bioingredia.com/
23	Cacobean Chocolate Factory Pvt Ltd	Food Processing Units	Private	Ernakulam	https://www.cacobean.com/
24	Vazhakulam Nadukkara Agro Processing Factory	Food Processing Units	Public	Ernakulam	http://jivekerala.com/about/
25	COCHIN SHIPYARD	Shipping	Public	Ernakulam	https://cochinshipyard.in/
26	Bharat Petroleum Corporation Limited	Refinery	Public	Ernakulam	https://www.bharatpetroleum.in/
27	Kerala State Road Transport Corporation (KSRTC)	Road Mobility	Public	Ernakulam	https://www.keralartc.com/main.html
28	Urban Mass Transit Company Limited	Road Mobility	Public	Ernakulam	https://www.umtc.co.in/
29	Mangala Marine Exim India Private Limited	Food Processing Units	Private	Ernakulam	https://mangalagroup.in/
30	Accelerated Freeze Drying Company (AFDC	Food Processing Units	Private	Ernakulam	https://amalgamfoods.com/afdc/
31	Cochin Cements	Chemical Plant	Private	Ernakulam	https://www.cclcement.com/
32	Akay Natural Ingredients Private Limited	Food Processing Units	Private	Ernakulam	https://www.akay-group.com/
33	Kerala State Industries Enterprises Ltd., (Cochin International Container Freight Station)	Aviation	Public	Ernakulam	https://www.ksie.net/units/pro/5/Cochin-International-Container-Freight-Station.html
34	PETRONET CCK LIMITED.- BPCL- Transport	Road Mobility	Public	Ernakulam	https://www.bharatpetroleum.in/pdf/ourfinancial/petronetnew.pdf
35	Cochin Port Authority/ Port Trust	Shipping	Public	Ernakulam	https://www.cochinport.gov.in/cpt
36	Kochi Water Metro	Water Mobility	Public	Ernakulam	https://watermetro.co.in/
37	HINDUSTAN UNILEVER LTD	Chemical Plant	Private	Ernakulam	https://www.hul.co.in/
38	COCHIN MINERALS & RUTILE LTD	Metals	Private	Ernakulam	https://www.cmrlindia.com/
39	25NORDEN FASSADE PRIVATE LIMITED	Metals	Private	Ernakulam	NA
40	AB MAURI INDIA Pvt Ltd, Cochin Spices	Food Processing Units	Private	Ernakulam	https://cochinspices.com/

Note: Non-exhaustive
Source: Company Websites; MEC+ analysis

Appendix

Mapping of Industries in Kerala (III/VII)

S. No.	Company	Sector	Public/Private	Location	Website
41	ABAD EXIM PVT.LTD	Food Processing Units	Private	Ernakulam	https://abadfisheries.com/
42	AL Badr Seafoods private Limited	Food Processing Units	Private	Ernakulam	NA
43	Amazing Rubber Products Pvt Ltd	Chemical Plant	Private	Ernakulam	NA
44	Asma Rubber Products Pvt Ltd	Chemical Plant	Private	Ernakulam	http://asmaglove.com/
45	Carborundum Universal Ltd	Chemical Plant	Private	Ernakulam	https://www.cumi-murugappa.com/
46	CII GUARDIAN INTERNATIONAL LTD.	Metals	Private	Ernakulam	https://www.ciiguardian.net/
47	Crusader Chemical Co. Inc	Chemical Plant	Private	Ernakulam	https://www.crusaderchemical.com/
48	DELICIOUS CASHEW COMPANY	Food Processing Units	Private	Ernakulam	https://dccdelicious.com/
49	ELECTRONIC CONTROLS & DISCHARGE SYSTEMS PVT.LTD.(UNIT 2)	Metals	Private	Ernakulam	http://www.ecdsin.com/
50	ELECTRONIC CONTROLS AND DISCHARGE SYSTEMS PVT. LTD.	Metals	Private	Ernakulam	http://www.ecdsin.com/
51	ELECTRONIC CONTROLS AND DISCHARGE SYSTEMS PVT. LTD. (UNIT 3)	Metals	Private	Ernakulam	http://www.ecdsin.com/
52	GREENBAND FOODS (INDIA) PVT LTD	Food Processing Units	Private	Ernakulam	NA
53	HT FOODS PRIVATE LIMITED	Food Processing Units	Private	Ernakulam	https://www.htfoods.com/
54	Innovate Polimer Company	Metals	Private	Ernakulam	http://www.innovatepolimer.kochidigitalmarketing.com/
55	J J Perfumes International	Chemical Plant	Private	Ernakulam	NA
56	KAY SALIZAR	Chemical Plant	Private	Ernakulam	https://www.kaysalizar.com/
57	L.J.INTERNATIONAL LIMITED	Chemical Plant	Private	Ernakulam	NA
58	MOBIL AB GLUE WORLD	Chemical Plant	Private	Ernakulam	NA
59	NIKASU FROZEN FOOD PVT. LTD.	Food Processing Units	Private	Ernakulam	https://nikasu.com/
60	NIKASU PACK (P) LTD.	Food Processing Units	Private	Ernakulam	NA

Note: Non-exhaustive
Source: Company Websites; MEC+ analysis

Appendix

Mapping of Industries in Kerala (IV/VII)

S. No.	Company	Sector	Public/Private	Location	Website
61	PRIMUS GLOVES PVT LIMITED	Chemical Plant	Private	Ernakulam	https://www.primusgloves.com/
62	ROYALMALABAR FOODS PVT LIMITED	Food Processing Units	Private	Ernakulam	http://nestroyaldelicacy.com/
63	SAFECARE RUBBER PRODUCTS PRIVATE LIMITED	Chemical Plant	Private	Ernakulam	NA
64	Safeshield India Rubber Products Pvt Ltd	Chemical Plant	Private	Ernakulam	https://www.safeshieldindia.com/
65	STABLE MAGNET WIRE PVT LTD	Metals	Private	Ernakulam	http://www.stablemagnet.com/
66	TAG Chemicals India Private Limited	Chemical Plant	Private	Ernakulam	https://www.tagchemicals.com/
67	TCL CERAMICS LIMITED	Chemical Plant	Private	Ernakulam	http://www.tclceramics.com/
68	Trex Tyres India Private Ltd.	Chemical Plant	Private	Ernakulam	NA
69	Unilever India Exports Ltd.	Chemical Plant	Private	Ernakulam	NA
70	INDIAN OIL CORPORATION LIMITED	Chemical Plant	Public	Ernakulam	https://iocl.com/
71	PETRONET ENERGY LIMITED	Chemical Plant	Public	Ernakulam	https://petronetlng.in/
72	INDIA GATEWAY TERMINAL PRIVATE LIMITED	Shipping	Public-Private (PPP)	Ernakulam	NA
73	Aspinwall and Company Limited (Stakeholder in Cochin Ports)	Shipping	Private	Ernakulam	https://www.aspinwall.in/
74	Poovath Paree & Sons	Shipping	Private	Ernakulam	NA
75	Kinship Services Pvt Ltd.	Shipping	Private	Ernakulam	http://www.kinshipping.com/
76	Kerala Shipping and Inland Navigation Corporation	Shipping	Public	Ernakulam	https://ksinc.in/
77	Meat Products of India Ltd (MPI)	Food Processing Units	Public	Ernakulam	https://www.meatproductsofindia.com/
78	Apollo Tyres	Chemical Plant	Private	Ernakulam	https://corporate.apollotyres.com/
79	HIL (INDIA) LIMITED (FORMERLY KNOWN AS HINDUSTAN INSECTICIDES LIMITED.)	Chemical Plant	Public	Ernakulam	https://www.hil.gov.in/Hindi/homepage.aspx
80	Cochin Petromins	Chemical Plant	Private	Ernakulam	https://cppl.co.in/

Note: Non-exhaustive

Source: Company Websites; MEC+ analysis

Appendix

Mapping of Industries in Kerala (V/VII)

S. No.	Company	Sector	Public/Private	Location	Website
81	Indsil Group	Metals	Private	Idukki	https://www.indsil.com/
82	KERALA CLAYS AND CERAMIC PRODUCTS LIMITED (KCCPL)	Chemical Plant	Public	Kannur	https://kccpl.in/
83	Keltron Component Complex Ltd	Metals	Public	Kannur	http://www.keltroncomp.org/index.php
84	Rubco Compound Mixing Plant	Chemical Plant	Public	Kannur	https://www.rubcogroup.com/our-companies/rubco-rubber-compund-mixing-plant/
85	KERALA MINERALS & METALS LIMITED	Metals	Public	Kollam	https://www.kmml.com/
86	Kerala State Cashew Development Corporation Limited (KSCDC)	Food Processing Units	Public	Kollam	https://cashewcorporation.com/
87	Indian Rare Earths, Chavara Mines	Metals	Public	Kollam	https://www.irel.co.in/chavara-mineral-division#:~:text=The%20Chavara%20mines%20contain%20as,variety%20having%2060%25%20TiO2%20Ilmenite.
88	Kerala Ceramics Ltd., Kundara	Chemical Plant	Public	Kollam	http://www.keralaceramics.com/company.htm
89	Kerala Premo Pipe Factory Limited	Chemical Plant	Private	Kollam	NA
90	The Kerala Agro Industries Corporation Limited	Food Processing Units	Public	Kollam	https://www.keralaagro.com/
91	Vijayalaxmi Cashew Company (VLC)	Food Processing Units	Private	Kollam	https://vlccashews.com/
92	Kerala Paper Products Limited (KPPL)	Chemical Plant	Public	Kottayam	http://www.keralapaper.in/
93	Travancore Cements Ltd	Chemical Plant	Public	Kottayam	https://www.travcement.com/
94	Canara Paper Mills Pvt Ltd	Chemical Plant	Private	Kottayam	http://www.canarapaper.com/
95	MRF Ltd. PB-2, Vadavathoor	Chemical Plant	Private	Kottayam	https://www.mrftyres.com/
96	SAIL-SCL Kerala Limited (SSKL)	Metals	Public	Kozhikode	https://www.steelcomplexkerala.com/
97	Peekay Steel	Metals	Private	Kozhikode	https://peekaysteels.com/
98	CRONUS STEEL DETAILING PRIVATE LIMITED	Metals	Private	Kozhikode	https://www.cronussteel.com/
99	Cocogreen Essentials Pvt Ltd	Food Processing Units	Private	Malappuram	NA
100	MALABARNATURAL FOODS PRIVATE LIMITED	Food Processing Units	Private	Malappuram	https://malabartreats.com/

Note: Non-exhaustive
Source: Company Websites; MEC+ analysis

Appendix

Mapping of Industries in Kerala (VI/VII)

S. No.	Company	Sector	Public/Private	Location	Website
101	MEBRAN SPICES PRIVATE LIMITED	Food Processing Units	Private	Malappuram	NA
102	SHAZZ CURRY PASTE PVT LTD	Food Processing Units	Private	Malappuram	NA
103	Ubergreen Organic Pvt Ltd	Food Processing Units	Private	Malappuram	NA
104	Unipulp Agro Industries	Food Processing Units	Private	Malappuram	NA
105	Western Ghat Agricultural Products Processing Pvt Ltd	Food Processing Units	Private	Malappuram	NA
106	KAAF LOGISTICS PRIVATE LIMITED	Road Mobility	Private	Malappuram	https://www.kaaflogistics.com/
107	Anthocyanin Naturals India Pvt Ltd	Food Processing Units	Private	Palakkad	https://www.anthocyanin.in/
108	Flavco Natural Products Private Limited	Food Processing Units	Private	Palakkad	https://www.flavconaturals.com/
109	Grain N Grace Food Ingredient Manufacturing Pvt. Ltd	Food Processing Units	Private	Palakkad	https://grainngrace.co/
110	Leaven Essentials Private Limited	Food Processing Units	Private	Palakkad	https://leavenessentials.com/
111	Maak Natural Extractors Pvt. Ltd	Food Processing Units	Private	Palakkad	https://www.maaknaturals.com/
112	Surabhi Steels (P) Ltd.	Metals	Private	Palakkad	NA
113	SMM Steel Re-Rolling Mills	Metals	Private	Palakkad	NA
114	Paragon Steels (P) Ltd	Metals	Private	Palakkad	http://www.paragonsteels.in/
115	Malabar Cements Ltd	Chemical Plant	Public	Palakkad	https://www.malabarcements.co.in/en/
116	Utility Alloys (P) Ltd	Metals	Private	Palakkad	NA
117	Agni Steels	Metals	Private	Palakkad	https://www.agnisteels.com/
118	Prince Alloys Private Limited	Metals	Private	Palakkad	NA
119	Prime Industries Ltd	Food Processing Units	Private	Palakkad	https://www.primeindustrieslimited.com/
120	Sueera Alloys (P) Ltd.	Metals	Private	Palakkad	https://www.sueeraaglobal.com/

Note: Non-exhaustive
Source: Company Websites; MEC+ analysis

Appendix

Mapping of Industries in Kerala (VII/VII)

S. No.	Company	Sector	Public/Private	Location	Website
121	Southern Ispat Ltd.	Metals	Private	Palakkad	NA
122	SVA Steel Re-rolling Mills Ltd.	Metals	Private	Palakkad	NA
123	A.P.Steel Re-Rolling Mill Ltd.	Metals	Private	Palakkad	NA
124	TRAVANCORE TITANIUM PRODUCTS LIMITED	Metals	Public	Thiruvananthapuram	https://travancoretitanium.com/
125	Kerala Automobiles Limited (KAL)	Road Mobility	Public	Thiruvananthapuram	https://kal.org.in/
126	English Indian Clays Ltd	Chemical Plant	Public	Thiruvananthapuram	https://eicl.in/
127	Nilamels & Kaimals Foods Private Limited	Food Processing Units	Private	Thiruvananthapuram	https://www.nilamel.com/
128	Kerala State Industries Enterprises Ltd., (Air Cargo Complex)	Aviation	Public	Thiruvananthapuram	http://www.ksie.net/
129	Kerala State Salicylates & Chemicals ltd.,	Chemical Plant	Public	Thiruvananthapuram	NA
130	Pure Petrochem India Private Ltd	Chemical Plant	Private	Thiruvananthapuram	https://www.purepetrochem.com/
131	Southern Refineries Ltd.	Chemical Plant	Private	Thiruvananthapuram	NA
132	Thiruvananthapuram Airport (Owned by Airport Authority of India, Run by Adani Group)	Aviation	Public-Private (PPP)	Thiruvananthapuram	https://www.trivandrumairport.com/
133	KSE Limited	Chemical Plant	Private	Thrissur	https://www.kselimited.com/
134	KERALA FEEDS LIMITED	Chemical Plant	Public	Thrissur	https://www.keralafeeds.com/
135	Steel & Industrial Forgings Limited(SIFL)	Metals	Public	Thrissur	https://www.siflindia.com/
136	Perfetto Naturals Pvt. Ltd.	Food Processing Units	Private	Wayanad	https://www.perfettonaturals.com/
137	Kottayam Port and Container Terminal	Port	PPP	Kottayam	https://www.kottayamport.com/
138	Kerala State Water Transport Department	Water Mobility	Public	Alappuzha	https://www.swtd.kerala.gov.in/pages-en-IN/index.php
139	Houseboat Owners Association	Water Mobility	Private	Alappuzha	https://www.keralahouseboatowners.com/

Note: Non-exhaustive
Source: Company Websites; MEC+ analysis

Appendix

Envisioned and Potential (Representative) Offtakers for the Kochi Green Hydrogen Valley

Company	Sector	Public/Private	Location	Offtake
Bharat Petroleum Corporation Limited	Refinery	Public	Ernakulam	Envisioned Offtake – Refinery
The Fertilizers and Chemicals Travancore Limited	fertiliser Plant	Public	Ernakulam	Envisioned Offtake – fertiliser
Hindustan Organic Chemicals Limited (HOCL)	Chemical Plant	Public	Ernakulam	Envisioned Offtake – Chemicals
Kerala State Road Transport Corporation (KSRTC)	Road Mobility	Public	Ernakulam	Envisioned Offtake – Road Transport
Kochi Water Metro	Water Mobility	Public	Ernakulam	Envisioned Offtake – Water Transport
Kerala Shipping and Inland Navigation Corporation	Shipping	Public	Ernakulam	Envisioned Offtake – Water based Cargo
Kottayam Port and Container Terminal	Port	PPP	Kottayam	Potential Representative – Ports (Own Cargo Movement)
Kerala State Water Transport Department	Water Mobility	Public	Alappuzha	Potential Representative - Water Transport
Kerala Minerals and Metals Limited	Metals	Public	Kollam	Potential Representative – Industrial use and goods transport
Houseboat Owners Association	Water Mobility	Private	Alappuzha	Potential Representative - Houseboats
Vizhinjam International Seaport Limited	Port	PPP	Thiruvananthapuram	Potential Representative - Bunkering
Cochin Shipyard Limited	Shipping	Public	Ernakulam	Potential Representative - Heavy Equipment
Cochin Port Authority/ Port Trust	Shipping	Public	Ernakulam	Potential Representative - Port Equipment
Cochin International Airport Limited (CIAL)	Aviation	Public-Private (PPP)	Ernakulam	Potential Representative - Port Equipment
Thiruvananthapuram Airport	Aviation	Public-Private (PPP)	Thiruvananthapuram	Potential Representative - Port Equipment
SAIL-SCL Kerala Limited (SSKL)	Metals	Public	Kozhikode	Potential Representative - Metals
Paragon Steels (P) Ltd	Metals	Private	Palakkad	Potential Representative - Metals
AG&P	Gas Distribution	Private	Thiruvananthapuram	Potential Representative - Gas Blending

Note: Non-exhaustive; potential off takers are representatives of a sector with offtake potential

Source: Company Websites; MEC+ analysis

Appendix

Data Sheets| Infrastructure Costs

S. No.	Component	Year	Cost	Units	Sources
1	Electrolyser Cost	2025	200000	INR/kW	Discussion with developers & investors
2	Electrolyser Cost	2030	80955	INR/kW	Discussion with developers & investors
3	Electrolyser Cost	2040	25240	INR/kW	Discussion with developers & investors
4	Solar Capex Cost	2025	36100000	INR/MW	Discussion with developers and investors
5	Solar Capex Cost	2030	32648193	INR/MW	Discussion with developers and investors
6	Solar Capex Cost	2040	26703183	INR/MW	Discussion with developers and investors
7	Wind Capex Cost	2025	84328000	INR/MW	Discussion with developers and investors
8	Wind Capex Cost	2030	74481849	INR/MW	Discussion with developers and investors
9	Wind Capex Cost	2040	63774750	INR/MW	Discussion with developers and investors
10	H_2 refuelling Station Cost	2025	96000000	INR	CE Delft, NREL
11	Battery Capex	2025	94300000	INR/MW	Discussion with developer and investors
12	Pumped Hydro Storage Capex	2025	41300000	INR/MW	Discussion with developer and investors
13	H_2 refuelling Station Cost	2030	53100000	INR	CE Delft, NREL
14	H_2 refuelling Station Cost	2040	46963407	INR	CE Delft, NREL
15	H_2 Storage Cost	2025	41329	INR/Kg H_2	RMI, CEEW
16	Transmission Infrastructure Cost	2025	560000000	INR	DHBVN
17	Transmission Infrastructure Cost	2040	2390000000	INR	DHBVN, CEA, PSERC

Note: *HB: Haber-Bosch
Source: MEC+ analysis

Appendix

Data Sheets| Infrastructure Costs II/II

S. No.	Component	Year	Cost	Units	Sources
18	Ammonia Synthesis Unit Cost	2025	44000	INR/ton NH_3	Fashi et al-2021
19	Ammonia ASU Unit Cost	2025	4400	INR/ton NH_3	IRENA. Fashi et al-2021
20	Ammonia Storage Unit Cost	2025	54824	INR/ton NH_3	Fashi et al-2021
21	H_2 FCEV Bus Cost	2025	20000000	INR	Ashok Leyland number assumed at 0 profit margin
22	H_2 FCEV Bus Cost	2030	17142857	INR	Ashok Leyland number assumed at 0 profit margin
23	H_2 FCEV Bus Cost	2040	14285714	INR	Ashok Leyland number assumed at 0 profit margin
24	H_2 ICE Bus Cost	2025	8000000	INR	Primary, Government of Kerala
25	H_2 ICE Bus Cost	2030	6857142	INR	Primary, Government of Kerala
26	H_2 ICE Bus Cost	2040	5714285	INR	Primary, Government of Kerala
27	HFCEV Boat Cost	2025	200000000	INR	Primary
28	HFCEV Boat Cost	2030	180000000	INR	Primary
29	HFCEV Boat Cost	2040	162000000	INR	Primary
30	Water Cost	2025	60	INR/KL	Kerala Government
31	H_2 Pipeline Cost	2025	163282500	INR/Km	European Hydrogen Backbone
32	NH_3 Pipeline Cost	2025	68560000	INR/Km	University of Twente, IEA
33	Land Cost	2025	3900000	INR/Acre	VOC Port, Government of Tamil Nadu

Note: *HB: Haber-Bosch
Source: MEC+ analysis

Appendix

Data Sheets| Land requirement

S. No.	Component	Phase	Land Requirement	Units	Costs	Units
1	Electrolyser Plant	Phase-2	1.2	Acre	0.482	INR/Crore
2	Electrolyser Plant	Phase-3	21	Acre	8.19	INR/Crore
3	Renewable Ammonia Plant	Phase-3	148	Acre	57.72	INR/Crore
4	H_2 refuelling Station	Phase-1	0.3	Acre	0.117	INR/Crore
5	H_2 refuelling Station	Phase-2	0.3	Acre	0.117	INR/Crore
6	H_2 Storage	Phase-2	0.05	Acre	0.019	INR/Crore
7	H_2 Storage	Phase-3	0.82	Acre	0.32	INR/Crore
8	H_2 Pipeline	Phase-2	1.7	Acre	0.668	INR/Crore
9	NH_3 Pipeline	Phase-3	1.9	Acre	0.759	INR/Crore

Note: If a certain phase is not mentioned for the component, it is assumed for that phase no new land is required, all the land required at each phase are additional

Source: MEC+ analysis

Appendix

Technology Readiness Level (TRL) Definitions

TRL Level	Level Name	Definition
TRL 1	Basic Research	Initial scientific research is conducted. Principles are qualitatively postulated and observed. Focus is on new discovery rather than applications. Examples include studies on basic material properties
TRL 2	Applied Research	Initial practical applications are identified. Potential of material or process to solve a problem, satisfy a need, or find application is confirmed
TRL 3	Critical Function or Proof of Concept Established	Applied research advances and early-stage development begins. Includes studies and initial laboratory measurements to validate analytical predictions of separate elements of the technology. Examples include research on materials, components, or processes that are not yet integrated
TRL 4	Lab Testing/Validation of Alpha Prototype Component/Process	Design, development and lab testing of components/processes. Results provide evidence that performance targets may be attainable based on projected or modeled systems.
TRL 5	Laboratory Testing of Integrated/Semi-Integrated System	System Component and/or process validation is achieved in a relevant environment (beta prototype component level)
TRL 6	Prototype System Verified	System/process prototype demonstration in an operational environment (beta prototype system level)
TRL 7	Integrated Pilot System Demonstrated:	System/process prototype demonstration in an operational environment (integrated pilot system level)
TRL 8	System Incorporated in Commercial Design	Actual system/process completed and qualified through test and demonstration (pre-commercial demonstration)
TRL 9	System Proven and Ready for Full Commercial Deployment	Actual system proven through successful operations in operating environment, and ready for full commercial deployment

Source: TRL; MEC+ analysis

Appendix

Primary Interview Summaries (I/XIII)

FACT | Stakeholder Interview Responses

Decarbonisation goals	• Decarbonisation activities at FACT revolve around RE adoption. Currently RE adoption at FACT is progressing at a slow pace - we have installed 10kW rooftop solar. FACT has its own reservoir and plans on setting up 6 MW of floating solar.	
Hydrogen use case	• FACT has a direct use case for hydrogen, hydrogen is also used in the chemicals division. We need to understand the technology changes in the ammonia plant and interact with technology providers who can integrate green hydrogen into current plant in a step-by-step manner	
Green H_2 adoption plans	• Currently we have not defined any plans for green hydrogen adoption. In current scenario, at best can try to stop importing ammonia as per the plans of the government	
Green H_2 tech confidence	• We need to receive and evaluate proposals containing the technical details and the price of green NH_3 to evaluate the option of green ammonia. Smaller capacity plants could be very expensive. Need to interact with technology providers.	
First offtake timelines	• We see the move to green NH_3 in three stages, first stage would be to develop RE power (6 MW floating solar plans and could go up to 8 or 9 MW RE power). Second, to produce green hydrogen and third step would be green ammonia. Currently there are no timelines set.	
Other Comments	• We have expertise in the operations of ammonia plant but have no technical expertise in running an electrolyser plant. We need to understand whether green hydrogen can be input into current plant in a step-by-step manner, what are the technology changes required for using green hydrogen and the price levels of green NH_3	

Source: Primary Interviews; MEC+ analysis

Appendix

Primary Interview Summaries (II/XIII)

BPCL | Stakeholder Interview Responses*

Decarbonisation goals	BPCL has a net-zero emissions target by 2040
Hydrogen use case	BPCL has a direct hydrogen use-case. H_2 is currently produced at a facility located at the Kochi refinery and is operated by Air Products. H_2 is also available as process by-product
Green H_2 adoption plans	BPCL is currently undertaking green hydrogen production pilot at the BPCL Bina refinery and further plans would depend on the success of the pilot
Green H_2 tech confidence	*Not discussed*
First offtake timelines	*Not discussed*
Other Comments	*Not discussed*

Note: *Interactions with BPCL representatives limited to conversations during the stakeholder meetings held in Kochi

Source: Primary Interviews; MEC+ analysis

Appendix

Primary Interview Summaries (III/XIII)

HOCL | Stakeholder Interview Responses

Decarbonisation goals	• We currently do not have any specific goals for decarbonisation or any mandates from the government for decarbonisation or use of green hydrogen	
Hydrogen use case	• HOCL has a direct use case for hydrogen. We currently source our hydrogen from BPCL through pipelines and use it to produce hydrogen peroxide	
Green H_2 adoption plans	• We do not have any plans to switch to green hydrogen. Our use case compared to others (refineries and fertilizers) are very small and we also have a stable contract with BPCL currently to meet our hydrogen demand	
Green H_2 tech confidence	• Substitution of grey hydrogen with green hydrogen would not pose a challenge but the availability of green hydrogen at a competitive price would hinder the confidence to uptake green hydrogen as HOCL faces competitive pressure from other H_2 peroxide manufacturers	
First offtake timelines	• We don't have plans to offtake green hydrogen, but we will follow any mandates put forward by the government. Our consumption of hydrogen is very small compared to other hydrogen consumers in the state	
Other Comments	• HOCL would like to remain a consumer of hydrogen and would not want to invest in green hydrogen production given the consumption is limited. However, HOCL had an electrolyser set up in late 1990s which is currently not in use	

Source: Primary Interviews; MEC+ analysis

Appendix

Primary Interview Summaries (IV/XIII)

KSRTC | Stakeholder Interview Responses

Decarbonisation goals	- KSRTC has deployed EV buses as a part of fleet decarbonisation. We do not have any targets set specific for green hydrogen powered buses	
Hydrogen use case	- Currently hydrogen is not used as a fuel in any road transport operations. The use of green hydrogen in mobility would require investments in assets and infrastructure	
Green H_2 adoption plans	- We don't have defined plans for adoption of green hydrogen, discussions and ideations have happened in the past regarding the possibility of using green hydrogen powered buses	
Green H_2 tech confidence	- Technology confidence would depend on addressing the challenges of refuelling infrastructure availability, progress in terms of pilots of different green hydrogen based technologies	
First offtake timelines	- KSRTC is willing to run pilots to test the financial and technical aspects of green hydrogen-based technologies given support from the government in terms of infrastructure and CAPEX. Currently there are no defined timelines	
Other Comments	- Around 3000 buses are available with KSRTC for replacement. Kochi-Trivandrum area is where we have the most coverage with ~1000 buses. The northern regions are largely led by private operators	

Source: Primary Interviews; MEC+ analysis

Appendix

Primary Interview Summaries (V/XIII)

Stakeholder Interview Responses

Kochi Rail Metro Limited	• Kochi Metro operates feeder services connecting the metro with the other parts of the city. Currently 6 feeder buses and 75 e-Auto rickshaws operational in the city. • There were plans for green hydrogen buses, obtaining buses on wet lease but the financials were not favorable at that time. Budget available was lower than the VGF calculated for the project • KMRL has plans to set-up solar plants to decarbonise its operations. The metro has peak demands in the morning and evening peak hours • The distances in which the feeder services run are favorable for EV bus operations and hydrogen would not make sense. Kochi Metro is willing to evaluate opportunities in new and emerging fuels and with government support can look at running pilots
Kerala Transport Company	• Kerala Transport Company has their own fleet of trucks that carry-out logistics operations in different cities in Kerala. There are two types of operations – line haul operations that run inter-city and delivery trucks that run the last mile • The trucks operate an average of 200 kms and the average mileage of a 10 ton truck would be 5-6 Kms per litre • KTC is willing to initiate conversations to understand the opportunities that are available in switching to green hydrogen • Important factors to consider would be the economic viability of using green hydrogen, the operational parameters like the refuelling time and the availability or reliable supply of green hydrogen to meet the demand

Source: Primary Interviews; MEC+ analysis

Appendix

Primary Interview Summaries (VI/XIII)

KSINC | Stakeholder Interview Responses

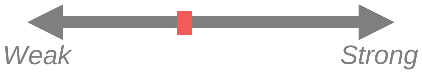
Decarbonisation goals	- KSINC operates multiple vessel types. Currently there are no defined decarbonisation goals or plans for use of green hydrogen	
Hydrogen use case	- There are no use cases for hydrogen currently in the operations of KSINC vessels	
Green H_2 adoption plans	- KSINC is the designated cargo operator for KMML in Kollam and with adequate support and studies on the financial and technical viability, KSINC can explore H_2 in barge operations	
Green H_2 tech confidence	- KSINC has not explored green hydrogen-based alternatives	
First offtake timelines	- KSINC had plans to operate (diesel) barges from Kochi to KMML in Kollam. This is currently on hold as the route is still under development. Pilots can be done after proving viability of such operations	
Other Comments	- KSINC had initially looked at converting the barges into LNG but the plan did not go through. Meeting the demand of KMML would require 2 barges (Acid and Furnace Oil)	

Source: Primary Interviews; MEC+ analysis

Appendix

Primary Interview Summaries (VII/XIII)

KWML | Stakeholder Interview Responses

Decarbonisation goals	• Kochi Water Metro currently operates hybrid EV boats that run on electricity with a back-up diesel generator.	
Hydrogen use case	• Currently there is no use case for hydrogen in the water metro operations. Hydrogen powered fuel cell EV boats or hydrogen Internal combustion boats can be tested.	
Green H_2 adoption plans	• We had proposals for running green hydrogen powered fast ferries on the coastal route connecting the different metros (IMO wanted to promote 5 pilot projects in India and KWMLs project was one among them)	
Green H_2 tech confidence	• Hydrogen purity required for fuel cells is very high, even for test runs with grey hydrogen the purity levels would require investments in systems. Availability of green hydrogen would also be a concern if not produced internally	
First offtake timelines	• The proposals have not taken off so far. So no timelines set as of now	
Other Comments	• Cost of hydrogen and uninterrupted supply of green hydrogen would be the major concerns for green hydrogen offtake	

Source: Primary Interviews; MEC+ analysis

Appendix

Primary Interview Summaries (VIII/XIII)

Stakeholder Interview Briefs

Kottayam Port

- Kottayam Port currently owns a 240-ton barge and have considered converting it into a hydrogen powered barge. But the cost economics was not favourable
- Currently operations of the port are halted due to some customs procedures and the port will start operations in the first half of 2024. Movement of goods from Kochi to Kottayam takes 7 hours and consumes 28 litres of fuel per hour
- We expect a 300-400 container demand on Kochi-Kottayam route, and we are willing to explore pilot operations with green hydrogen barges
- Govt. should incentivise water-based cargo movement as this can reduce congestion on roads, pollution and in turn emissions

KMML, Kollam

- KMML is currently dependent on road for movement of raw materials and fuels. Required 90 Kilo litre of Furnace Oil and 135 TPD of hydrochloric acid
- KMML intends to move the transportation to waterways. KMML is developing a jetty currently and would be ready by March 2024
- We are willing to explore the possibilities of green hydrogen based barges on the Kochi to KMML route based on the financial viability of such proposals and the government support available. Economic viability and availability of green hydrogen would be the major concerns
- We have earmarked 10-15% of our productions for exports and this could also be transported through the waterways in the future

Source: Primary Interviews; MEC+ analysis

Appendix

Primary Interview Summaries (IX/XIII)

Stakeholder Interview Responses

Kerala State Water Transport Department	• Operations are limited to certain clusters and only passenger operations • We have explored both CNG and solar boats in the past • Long distance passenger transport may not be feasible due to the constraints in terms of speed • Willing to explore H_2 based boats if adequate support in terms of CAPEX and infrastructure is provided
Kerala Maritime Board	• At present the smaller ports in Kerala are not operational as shipping is not viable. The availability of return cargo is a challenge in this regard. There are 1600 inland vessels in Kerala and all together there could be 3000+ vessels • Our ambition is to shift 20% of the road traffic to waterways (coastal shipping) by 2030. Need government intervention to mitigate the problem of return cargo • We can consider provision of land for refuelling stations – based on the proposal. Govt. can mandate government companies to use waterways to move cargo to boost the sector
Inland Waterways Authority of India	• There are three main routes that are operational currently in Kochi, Cochin Port to Ambalamghal, Cochin port to Udyogamandal and Udyogamandal to Ambalamughal • Kochi to Kollam route is still under development, the Trikunnapuzha lock is under construction and will realistically be operational by March 2025 and by this time all the other minor work on the Kochi Kollam route will also be completed by then • The route from Kottapuram to Kozhikode would be done at a later stage as the demand on this route is limited
Kerala Steamer Agents Association	• Challenges for inland waterways could be in the form of lack of clearances (low bridges), narrow stretches etc. Kochi Kottayam can have good cargo movement. Kollam ports needs alignment to handle bigger vessels • On the coastal route, it is hard to find operators with viable proposals. KMB had tried to incentivize operators, but it did not go through. Need development of port infrastructure and government incentives for cargo movement through waterways • Cargo movement through waterways can have challenges in the form of time delays and last mile deliveries, dispatchable trailers like in Netherlands can be tested in Kerala

Source: Primary Interviews; MEC+ analysis

Appendix

Primary Interview Summaries (X/XIII)

CSL | Stakeholder Interview Responses

Hydrogen Business Case	• Cochin Shipyard builds vessels for both defense and commercial sectors. CSL is building a hydrogen powered vessel for IWAI (Varanasi) and for a Norwegian logistics company
Technology Readiness	• The vessel built for IWAI to be deployed in Varanasi is almost ready and will be tested in Kochi in the beginning of 2024 and then deployed at Varanasi
Confidence in hydrogen	• We have done research in developing hydrogen powered vessels. H_2 has potential in specific use cases where battery faces practical difficulties. CSL can build H_2 vessels for cargo requirements as well
Challenges Faced	• Availability of green hydrogen at a reasonable cost and uninterrupted supply will be the major challenges. Refuelling and transportation infrastructure will also need to be developed
Support Required	• Central government should promote use of hydrogen vessels in waterways with VGFs and grants, this can be complemented by state government incentives
Other Comments	• The vessels developed for Varanasi are 50 pax hydrogen Fuel Cell EV vessels planned for 8 hours of operation. Hydrogen Fuel cell vessels can be developed with higher fuel cell capacity to enhance range and load carrying capacities

Source: Primary Interviews; MEC+ analysis

Appendix

Primary Interview Summaries (XI/XIII)

Air Products | Stakeholder Interview Responses

Hydrogen Business Case	• We invest, install, operate and supply hydrogen molecules in India and globally. We have business interests in green hydrogen. We have two hydrogen dispensing stations (in mobility) under Air Products India. Green Ammonia is the most feasible for transportation and we have global green ammonia supply projects as well
Technology Readiness	• Green Hydrogen can be produced. 1 ton/hour of green hydrogen would require ~60MW of RE, a 350-dispensing station. H_2 cylinder filling stations are currently not present
Confidence in hydrogen	• Spare hydrogen is present at BPCL facility, but Air Products is in a tolling agreement with BPCL and they have expansion plans as well.
Challenges Faced	• We are interested in supplying green hydrogen, but it would be commercially challenging. Offtake and business model is missing. We (in mobility) do not see business case for 5-10 buses. The hydrogen produced currently is not H_2 grade, would need purification (if plans are there to use grey hydrogen in testing stages)
Support Required	• Air Products are up for discussions with the stakeholders. Need clarity on the mode – whether it's a tender or a consortium, are the resources given by the government
Other Comments	• Long terms (5 to 10 years) offtake contracts can help kick-start the hydrogen production. If this is made possible Air Products can also initiate conversations with RE developers

Source: Primary Interviews; MEC+ analysis

Appendix

Primary Interview Summaries (XII/XIII)

Stakeholder Interview Responses

KPIT Technologies	• KPIT Technologies develop hydrogen fuel cells. KPIT is also into generation of hydrogen from biomass. We have two technologies currently biomass digestion from paddy straw fermentation and woodchips/bamboo gasification • KPIT is partnering with Cochin Shipyard to develop hydrogen fuel cell electric vessels that comes with 40kg of hydrogen capacity (5 cylinders of 8 kg each). We believe fuel cells can be a good alternative for vessels where battery faces practical difficulties (based on the current technology levels) • Current tanks are at 350 bar pressure and with the approval of new tanks with 700 bar pressure more hydrogen can be carried giving better ranges. This way we can also have longer range vessels operating in the Kerala waterways
n3e	• n3e is a SOPAN group company and intends to work in the global green hydrogen and derivatives ecosystem. With a focus in blending systems and refuelling infrastructure • We have indigenously developed products like hydrogen refuelling stations, hydrogen storage solutions and hydrogen blending, we were also the EPC partners for a hydrogen refuelling station that was set up in Gujarat by Reliance • Cost of refuelling stations will decrease by 30% in 2030 and by up to 50% in 2040. The refuelling stations would see better cost economics with increased utilisation rates. The costs of a 1 TPD plant at 20% utilisation would be double of that of a plant with 100% utilisation
Greenstat	• Greenstat is interested in demonstrating a zero-emission waterborne transport in Vembanad lake by modification of existing diesel powered houseboats to green hydrogen fuel cell powered • We are in conversation with houseboat operators for tie-ups to demonstrate the technology. There is a potential for ~100 boats which will be powered by hydrogen from a local electrolyser (~0.5 MW) • The houseboats can run on a 60 to 80 kW fuel cell. This could be a form of sustainable tourism as well but will require subsidies from the government
AG&P	• AG&P acknowledges the need for confirmatory studies before blending green H2 in API 5L grade steel pipelines. There is also a need for establishing mechanisms to monitor and regulate the extent of GH2 blends at varying Natural gas flow rates

Source: Primary Interviews; MEC+ analysis

Appendix

Primary Interview Summaries (XIII/XIII)

Stakeholder Interview Responses

Vizhinjam International Seaport Ltd	• VISL is proactively involved in decarbonisation projects, we are planning a floating wave energy plant with IIT-M and American firms (in lab testing stages) and rooftop solar projects. Defunct waterbodies at ports can be used for floating solar • We have had discussions with international ports regarding the possibility of green ammonia production. Land is a constraint in the port and we are planning to acquire land within 2 km radius of the port • We are willing to explore opportunities for green ammonia bunkering in VISL to meet the demand that is expected to arise in the future as vessels will make the switch to green fuel alternatives
Adani Vizhinjam Port	• Adani Ports and SEZ is developing the deep-sea water port at Vizhinjam. Adani had announced interest in green fuel bunkering but cannot comment on this now. Details on whether we would produce green ammonia/derivatives or procure it is also not decided as of now • The port has floating crafts and ITVs that currently run on diesel. Floating crafts consume 200 to 250 thousand liters per month and ITVs consume 50 to 60,000 liters per month cumulatively • For Green Fuel bunkering, land availability is a concern as liquid bunkering would require large land requirement
Trivandrum Airport	• Trivandrum Airport has 3000 to 4000 liters of diesel consumption across all applications (DG, Dewatering pumps, Airport vehicles). In total we have a demand of 10000 to 12000 litres per month of diesel across all airport inventories (all scopes) • Currently have 16 Diesel Generators – 1010 kVA x 4 nos, 500 kVA x 6 nos and 125 kVA x 6 nos • Willing to explore alternatives for Diesel operated vehicles and DGs, technology availability is a concern. Need to understand the prospect of a hydrogen-based generator, the capex for a 1000 kVA hydrogen-based generator and its operational challenges

Source: Primary Interviews; MEC+ analysis

Selection of Global Valleys

To be based on qualification criteria and diversity parameters

Global Valleys | Selection Framework

Size of the Valley

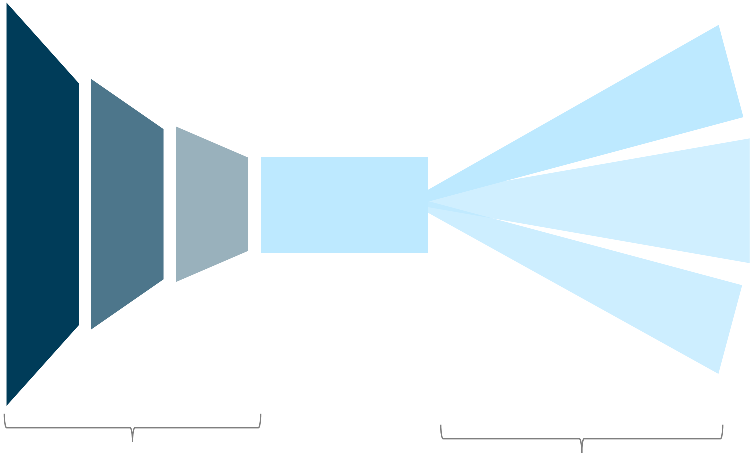
- Total electrolyser size in the valley to be less than 1 GW as the Kochi Valley would also have a potential demand of 0.5 to 1 GW (approximate size)

Type of Demand

- Valley selected to have internal use cases as demand drivers. Valley can have multiple use-cases and external demand (exports) could be one of them

Stage of Development

- Valley selected to be beyond the concept or feasibility study stage ideally in the construction stage or post-FID



Qualification

These parameters are to remain same for all the valleys considered. This includes the size of the valley, stage of the valley and the demand focus of the valley (internal vs external)

Diversification

These parameters vary across selected valleys, ensuring diverse use-case coverage and governance models.Also, this helps understand how some of the opportunities foreseen (industry cluster, port proximity etc) in Kochi can be leveraged

Valley Advantage

- Advantage in terms of availability of RE, raw materials for electrolyser manufacturing, proximity to ports, industrial clusters

Industry Focus

- Valleys considered are to have diverse set of use cases ranging between industrial use cases, mobility, power generation, exports etc

Governance Structure

- Valleys with diverse governance models are considered to understand the different roles that private and govt. bodies can play in the valley

Source: MEC+ analysis

5 valleys are selected

Selection Methodology

80+ valleys across geographies have been considered in the qualifying stage. The qualification stage consisted of three parameters:

- Electrolyser size envisioned in the valley (<1 GW)
- Major demand driver in the valley (Internal/Domestic)
- Stage of development in the valley (Post FID stage)

15 valleys qualified for stage 2 – diversification stage where these valleys were subjectively assessed on the following parameters:

- Industry coverage/Multiple use-cases
- Opportunities similar to Kochi in terms of proximity to ports, similar industrial clusters, emerging gas distribution pipelines etc
- Valleys with varied governance models with different levels of public-private participation

5 Valleys were selected: Hamburg Green Hydrogen Hub - Germany, HEAVENN – Netherlands, Basque Hydrogen Corridor – Spain, Green Hydrogen and Chemicals – Oman, Flemish Ports Hydrogen Valley - Belgium

Selected Global Valleys

Hamburg Green Hydrogen Valley, Germany	Use cases in industries, mobility, heat and port. Active participation of private and public bodies. Decarbonisation of a port economy with green H_2
HEAVENN, Netherlands	Leveraging local RE availability. Valley integrating multiple clusters. Association model of governance. Offtake demand from govt. in transport.
Basque Hydrogen Corridor, Spain	Defined hydrogen Strategy in which this valley has a role. Multiple use-cases envisioned. Domestic driven demand. Leveraging existing infrastructure
Green Hydrogen and Chemicals, Oman	Government led project. Leveraging abundant solar resources. Project with secured offtake. Green Hydrogen to Ammonia conversion focussed project
Flemish Ports Hydrogen Valley, Belgium	Integration of 3 port clusters into a valley. Leveraging existing gas pipelines. Part of the National Hydrogen Policy Vision. Presence of multiple H_2 use cases

Source: MEC+ analysis