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India's Energy Transition Towards A Green Hydrogen Economy

WHITE PAPER ON BUILDING A GREEN HYDROGEN ECONOMY AND POLICY ROADMAP FOR INDIA

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Contents

Executive Summary

India is motivated towards stronger energy transition actions beyond its current climate change initiatives, aggressive renewable energy, electric vehicle (EV) Infrastructure build-out; and energy diplomacy initiatives. The imperative to decarbonise the Indian economy is drawn from the poor air quality in Indian cities, high fossil fuel import bill and concerns about India's energy security. Despite national efforts with climate change actions, India's fossil fuel consumption, of both oil and gas, as well as that of coal, is expected to continue to rise to meet the economy's voracious appetite for energy in any form. Electric vehicles, battery technology and renewable energy growth seemed to offer the only hope to de-carbonise the economy with unanswered questions of energy storage and critical supplies of battery components, including rare earths and metals, creating only a tentative path for energy transition and a zero-carbon future.

The growth of green hydrogen production technologies (hydrogen produced by splitting water molecules with electrolysis using renewable energy sources), falling costs of electrolysers and fuel-cell stacks, and increasingly concerted policy actions to encourage green hydrogen projects in different parts of the world, are coming together to create a paradigm shift for energy transition. With blue or grey hydrogen technologies (produced using natural gas, with or without Carbon Capture Sequestration) as an interim step, stakeholders see green hydrogen become economically viable within a decade in some parts of the world, working closely with battery-tech, EVs and a higher renewable energy generation scenarios, offering scalable zero-carbon scenarios.

Rationale for a Green Hydrogen Ecosystem

Despite an early start (India's first Hydrogen and Fuel Cell Roadmap was announced in 2006 followed by R&D funding), India has lagged other parts of the world in moving towards large-scale demonstration hydrogen projects. Europe and US lead on electrolyser and FCEV technologies, Japan and Korea are investing heavily to become global hydrogen-use champions, while Australia and Chile are building global green hydrogen production hubs to export liquified or pressurised hydrogen. Each of them is building green hydrogen ecosystems for hydrogen's potential as a fossil-fuel replacement and its storage potential, marrying it with renewable energy and battery technologies.

As the global green hydrogen ecosystem matures, cost of hydrogen production is expected to come down and become comparable with fossil-fuels. With hydrogen production and demand increasing globally, there will be green hydrogen winners and losers, placing hydrogen importing economies next to low-cost ones (those who leverage national renewable energy and local manufacturing to make green hydrogen affordable).

India remains one of the large economies that have yet to re-articulate a national green hydrogen policy and it should do so before India assumes the G20 Presidency in 2023. Hydrogen reports published by the Ministry of New and Renewable Energy (MNRE), stated ambition by the by the Office of the Principal Scientific Advisor (PSA) and early pilots by IOCL (and the significant R&D efforts by Indian institutions) indicate a desire for a strong play in the emerging global green hydrogen economy. India can choose to wait till the global green hydrogen ecosystem matures or take a proactive role in developing local manufacturing capabilities to create a local supply chain. The dilemma is one of timing, scope, and economics; and framed by key four questions:

1. If 2030 is the year when green hydrogen is expected to expand globally, what should India do in the preceding five years (from 2025-30), and what should it do in the preceding five years (from 2020-2025) to prepare for this change?
2. What can India do to leverage its position as a large consumption economy and global demand centre, to attract hydrogen investments and build a local manufacturing base?
3. What does India need to do to 'leap-frog' on the adoption curve and earn a seat at the global green hydrogen table? Will it take more R&D investments or large-scale development projects?
4. What are the enabling factors? How much public-private partnership is required? How much funding is required in next five years, and the following five? How will this be raised and utilised?

The white paper has attempted to answer these questions by undertaking a benchmarking of global green hydrogen policies, evaluating three hypothetical adoption pathways and draws inspiration from measures taken in other economies to creating India-specific set of stakeholder and policy interventions.

Methodology

The India Green Hydrogen Roadmap white paper has been prepared as a voluntary initiative, bringing together global developments with inputs from multi-stakeholders. It focusses on policy and partnership approaches with energy industry members, government stakeholders and energy experts that will help create a green hydrogen economy in India over the next two decades. The paper does not make technical comparisons between different hydrogen-based technologies. A global benchmarking of green hydrogen policies and published reports was undertaken followed by a multi-stakeholder consultation on Nov 10 2020. More than 50 stakeholders participated at the consultation and this was followed by direct engagement with individual stakeholders. Stakeholders who have been engaged as part of the preparation of this white paper, include:

- Government of India: NITI Aayog, Ministry of New and Renewable Energy, Ministry of Heavy Industries, Ministry of Road and Highways
- Energy Industry: global and domestic energy companies. The stakeholder e-consultation witnessed participation from 14 global organisations and seven major Indian organisations.
- Energy experts and multi-lateral organisations: think tanks, academics and energy commentators

The industry consultation discussed three possible adoption pathways, focusing on the question of timing and enabling role of policy for the green hydrogen ecosystem to grow.

- First pathway assumes proactive policy role in creating incentives that would encourage the private sector to co-invest (with the government) in building the green hydrogen infrastructure and ecosystem.

— Second pathway spells a cautious wait-and-watch approach till 2030, before taking proactive steps

— Third pathway pushes out any proactive steps to 2040 and is a follower strategy to let developed markets build the global green hydrogen ecosystem first and catch up once the global system is ready.

There was strong support for the first pathway, across the stakeholder group, with concerns/hurdles flagged by stakeholders, namely lack of adequate public funding, public-private partnerships and industry consortia. These are critical and necessary for an early-stage green hydrogen ecosystem to develop in India.

Moving Towards a Green Hydrogen Ecosystem: Recommended Interventions

The first pathway for proactive adoption of green hydrogen strategies assumes the cost of green hydrogen to be USD 2/kg of green hydrogen and a 30 percent[1] fall in cost of production by 2030. This can be complemented by strong policy and industry collaboration, public funding and a clear plan for creating national green hydrogen demonstration projects within specific use cases.

The eight recommendations or interventions are clubbed into three broad categories:

FIVE POLICY-LED GREEN HYDROGEN INTERVENTIONS

1. Creation of a National Hydrogen Policy and Roadmap by 2021, co-created by government and industry
2. Creation of H2India Hydrogen Taskforce and Workgroups to meet roadmap milestones, implementation path
3. Green Hydrogen Investment Fund of USD 100 million to be deployed in next five years till 2025; larger USD 500 million Hydrogen Fund to be raised for 2025-2030
4. National aspiration for four percent hydrogen share in national energy mix by 2030
5. Inter-ministerial green hydrogen government cell to ensure adherence to globally harmonised standards

NATIONAL GREEN HYDROGEN DEMONSTRATION PROJECTS

6. Hydrogen production coupled with use-cases, H20 hydrogen blending in natural gas and exploratory natural gas and coal-gasified grey hydrogen projects
7. Identify at least ten potential H2India national hydrogen projects for large scale demonstration projects:
   a. Long-haul, heavy-duty H2Bharat Trucking project - 10,000 H2 truck fleet and infrastructure on DMIC
   b. Four H2Bharat Port and Logistics clusters, linked to IndiaH2 Trucking project
   c. Four H2India Industrial projects, in high-priority sectors (steel, fertilisers), including brown coal-gasification H2 project in steel/mining cluster
   d. Municipal level H2Maharashtra/ H2Gujarat Urban Bio-Gas project – with urban (solid waste), dairy

GREEN HYDROGEN PUBLIC-PRIVATE PARTNERSHIPS, INDUSTRY CONSORTIA

8. Fiscal incentives for large-scale national H2 projects; partnerships and industry consortiums

The paper recommends a cluster and defined-geography approach, rather than taking a national approach, for planning national hydrogen demonstration projects. This mirrors the EU approach of coupling green hydrogen demonstration use cases with renewable energy corridors; acknowledging the high cost of hydrogen infrastructure and transport networks and draws synergies with national decarbonising initiatives. India-relevant use cases in steel/ mining (using brown coal) and urban municipal waste (urban bio-gas) projects have also been recommended in the proposed national projects, beyond heavy-duty trucking. The paper does not recommend hydrogen for passenger and light-transport vehicles, which may be better served through EV/ battery technologies.

1 https://www.iea.org/reports/the-future-of-hydrogen

Implementation of the above eight interventions, in the first half of the decade, from 2020-2025, should create an enabling environment and momentum for a stronger green hydrogen ecosystem to emerge by 2030. Some assumptions and projections have been made, backed with rationale and underlying assumptions. If all eight interventions are accepted and implemented under Pathway A, India should see the following by 2030*:

H2 ENERGY SHARE 2030 (ASPIRATIONAL)	H2 BLENDING IN GAS 2030, ASSUMED	H2 JOBS BY 2030, PROJECTED	H2 PUBLIC FUNDING, DESIRED
Four percent of total energy consumption by 2030 13 MMT H2 demand	20 percent H2 Blending in Gas	75,000 new H2 jobs – direct and indirect	USD 100 million (2025) USD 500 million (2030)

POTENTIAL MOBILE FCEVS - FLEET & INFRA 2030	H2 DEMONSTRATION STAGE PROJECTS 2030, POTENTIAL	ELECTROLYSER PRODUCTION CAPACITY 2030, ASPIRATIONAL	H2 PRODUCTION FROM COAL-GASIFICATION 2030, ASPIRATIONAL
12,000 heavy-duty FCEVs 10 H2 refueling stations by 2030	10 proposed projects — H2Bharat Trucking — H2Bharat Ports, Logistics Clusters — H2India Industry Clusters — H2State BioGas Production	GW-scale Electrolyser Capacity by 2030	10 percent of Coal Gasification 2030 target (100 MMT) to be converted to H2

*NOTE: All above numbers are aspirational and indicative only; and will depend on a combination of an enabling environment, assumed fall in price of hydrogen production and components, necessary policy and industry actions/ collaboration. The numbers above were discussed with all stakeholders. While representing aspirational numbers, the above chart represents a certain level of ambition that the Indian energy stakeholders and ecosystem should work towards and effort that is required for achieving energy transition and security.


INDIA GREEN HYDROGEN ROADMAP
Energy transition whitepaper prepared by FTI Consulting
POLICY INTERVENTIONS
4% by 2030
Aspirational H2 energy share
India Green Hydrogen Taskforce
USD 100 mn
India Hydrogen Fund
National Green Hydrogen Policy and Roadmap 2021
Inter-govt H2 Group, fiscal incentives, global harmonisation
NATIONAL DEMONSTRATION PROJECTS (Proposed)
H2 Bharat Trucking Project on Delhi-Mumbai Industrial Corridor
H2 Bharat Port & Logistics Clusters
H2 Industrial Clusters (Steel, Fertilizer)
Municipal Bio-Gas H2 project
Coal-Gasification H2 project
DESIRED OUTCOMES BY 2030
India in Global H2 Supply Chain
Domestic Manufacturing of Electrolysers, Fuel-Cell stacks, components; Partnerships and H2 India Consortium
10 National H2 Projects
Large, demonstration -stage, different use cases
USD 500 mn
Expanded Hydrogen Fund (by 2030)
75,000
New Hydrogen Economy jobs, potential
GW-scale
Electrolyser capacity in India
Green Hydrogen economy can scale, working with Renewables, Electric Vehicles and Battery Technology to build India's Net-Zero carbon pathway. An enabling policy environment and cross-industry collaboration are critical for this.
1

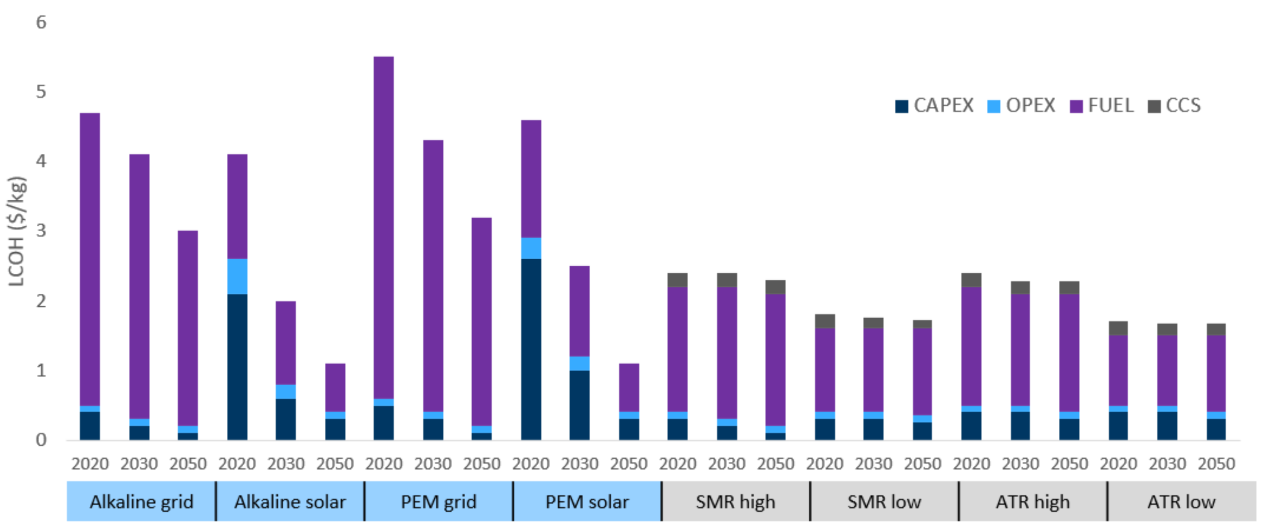
De-carbonising The Economy and Energy Transition – Move to Net-zero

Techno-commercial Developments – Global and Regional

While hydrogen has been around for a long time, most of the hydrogen produced is 'grey hydrogen' i.e., hydrogen produced from fossil fuels. The growth of renewables, and renewable-powered hydrogen production has created global momentum for 'green hydrogen' as a clean fuel as well as an energy storage option.

While still being very expensive, global adoption and faster roll-outs are expected to lead to a drop in the costs of electrolysers, green energy production as well as FCEVs by 2030 – moving from USD 4-6/kg currently to USD 2/kg by 2030 (without government incentives, and USD 1.5/kg with government incentives). As per Wood MacKenzie report,[2] a sharp rise in electrolyser deployments in the 2020-25 period – 3.2 GW of new electrolyzer capacity is going to be added globally (from 252 MW in 2019), leading to further drops in capital costs.

The figure below shows how the different hydrogen production technologies are expected to be priced over the next 10-20 years. Alkaline Electrolyser (AK-EC) technology wins currently on cost but this is expected to change with faster deployment of PEM-ECs, which have shown to work better than AK-EC, for smaller projects.



SOURCE: TERI Analysis; **LCOH:** Levelized Cost of Hydrogen

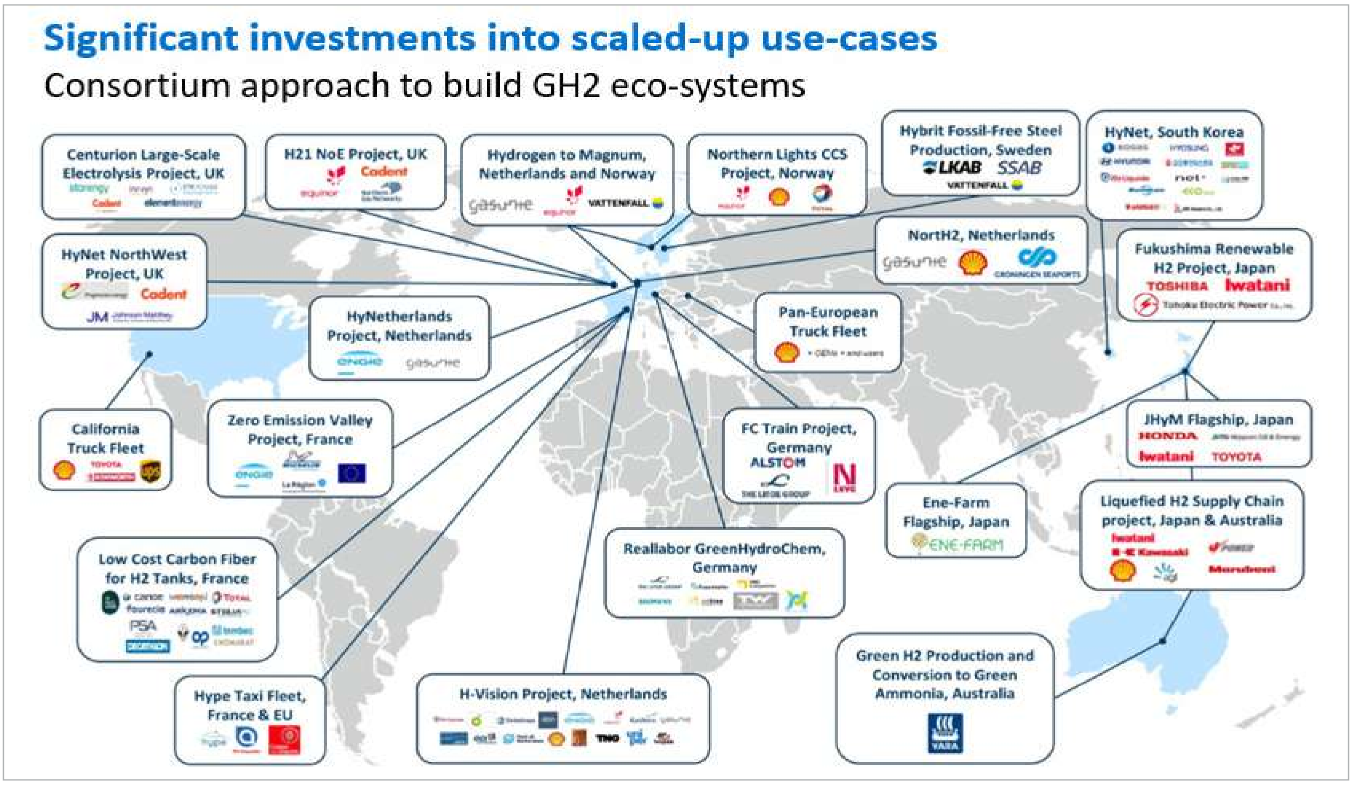
Does not consider Solid Oxide Electrolyser Cells (SOEC). View that SOECs could become cheaper than PEM or Alkaline in long term, but SOECs not commercially available for next 5 years.

2 https://www.woodmac.com/news/editorial/the-future-for-green-hydrogen

Large Demonstration Projects – Global and Regional

Below is a global mapping of active projects that are being discussed and implemented. There are more than 50 viable green hydrogen projects currently being developed. What is common across most projects is that there are multiple players actively collaborating to pursue these different use-case opportunities. The strong pipeline of development-stage projects and the investments (both public and private) going into electrolyser capacities build-outs are an indication of the speed at which the green hydrogen ecosystem is maturing.

These offer some sense of how the green hydrogen ecosystem can be developed in India, scaling up from the existing hydrogen R&D and pilots projects, and most importantly, urgency for articulating a national position.



Source: FTI Consulting

National Policies

A global benchmarking of national green hydrogen policies reveals interesting perspectives – from the manner in which countries are beginning to shape their competitive advantage as producers and consumers. Despite relying on EU and US electrolyser and FCEV technologies, it is interesting to see how Japan and Korea are working to re-cast themselves on the back of public funding for large demonstration projects and industry consortia approaches to build scale and influence in the global hydrogen ecosystem.

Korea and Japan investing significantly on building H2 infrastructure, with industry consortiums leading on transport use cases and infrastructure. Korea has made its ambition to be a global FCEV champion for passenger vehicles very clearly in its national roadmap. Japan recognizes its limited renewable energy options and has made strategic investments and G2G agreements with Australia to import green hydrogen.

Europe currently leads on electrolyser and FCEV technology, as well as demonstration stage projects and public funding into creating the hydrogen economy. While transport is an obvious use case, it is interesting to note Europe's focus on H2 industrial clusters, coupling green hydrogen production sites with use cases close to production. This offers some guidance for India on how it could commercialise hydrogen, without making the expensive infrastructure investments that national transport systems demand. Below is a snapshot of the different hydrogen approaches being taken by key national players, through their national hydrogen roadmaps.

Global benchmarking

GH2 policy roadmaps and strategies

GH2 POLICY	**ADAPTIVE** GH2 EXPORTS	**MATURE** FCEV PV FOCUS	**INDICATIVE** DEV. PROJECTS – CLUSTERS	**MATURE** INFRA FOCUS	**MATURE** TRANSPORT, CALIFORNIA FOCUS	**EARLY STAGE** TECH. DEMOS, ICE-H2 (PAST)
GH2 PRODUCTION	Leveraging RE strengths to produce, export GH2; Carbon capture to be used extensively	GH2 imports from Australia	**6 GW electrolyser capacity, 1 MT GH2 by 2024**; and 2X40 GW electrolysers capacity, 10 MT GH2 by 2030	**World's largest 10 MW** Fukushima Hydrogen Energy Research Field FH2R, GH2 imports	Focussed on RE electrolyser production, exploring biogas/methane (from dairy)	R&D and demonstration pilots on electrolyser and FC tech (across technologies)
GH2 SUPPLY CHAIN & MANUFACTURING	H2 Energy Supply Chain (HESC) Pilot Project, H2 Utility Renewable Hydrogen and Green Ammonia Supply Chain Demonstrator	Global leadership in FC Passenger Vehicles and Power Generation, **constructing new nationwide H2 pipeline network**	**Global lead on PEM electrolyser** tech, FC tech; coupling strategies by use-cases – H2 valleys, industrial clusters	Building GH2 infra, imports and strategic co-production/ transport from Australia, KSA, Brunei	Primarily privately funded initiatives, manufacturing	Domestic manufacturing imperative to bring costs down
FUNDING & INVESTMENTS	Committed **over AU$146 mn on H2 supply chain projects** in last five years	**USD 1.8 bn budget for establishment of a public-private H2 vehicle industry ecosystem by 2022**	Strong state funding, private investments; Country plans (Germany USD 7bn, France, Netherlands, Spain, Portugal)	**Spent $1.5 billion on H2** tech R&D and subsidies, USD 664 mn 2020 budget	DOE has been spending USD 100 mn annually, separate USD 30 mn SO-FC program	R&D spends on demonstration projects, 2 re-fuelling stations in Delhi, CoE established
PRIORITY USE-CASES – TRANSPORT, INDUSTRY, POWER, BUILDING/HEAT	H2 Hubs/Valleys, H2 in remote applications (microgrids for mining)	**By 2030, 800K FCEVs target (100K trucks)** 6.2 mn FCEVs production by 2040. FC Power Generation target is 15 GW by 2040	Global leadership in EC, FCEV, Focus on Industrial Clusters	FCEVs through private sector collaboration and residential use/ building	**Largest FCEV Vehicle population**, focus on refuelling infra and H2 transport (gas/liquified).	Not articulated beyond H2-ICE engines, 2020 targets unmet; bus/vehicle prototypes
PUBLIC & INDUSTRY PARTNERSHIPS	NERA supporting SMEs; legal framework for large-scale production, H2 as energy carrier	**H2Korea PPP, HyNet SPV** – 13 companies, Hydrogen Law	Open, competitive H2 market by 2030; European Clean Hydrogen Alliance, Hydrogen Europe, FCHJU	**JapanH2Mobility (JHyM)** consortium – 11 companies	CEC Clean Transport 64 H2 refuelling program. US DOE Fuel Cell Tech Office H2@Scale research	MoUs with Japan, Korea, US and Australia on G2G collaboration
ECO-SYSTEM DEV STRATEGIES						

NOTE: In addition to above, China and Chile have announced country H2 plans as well.

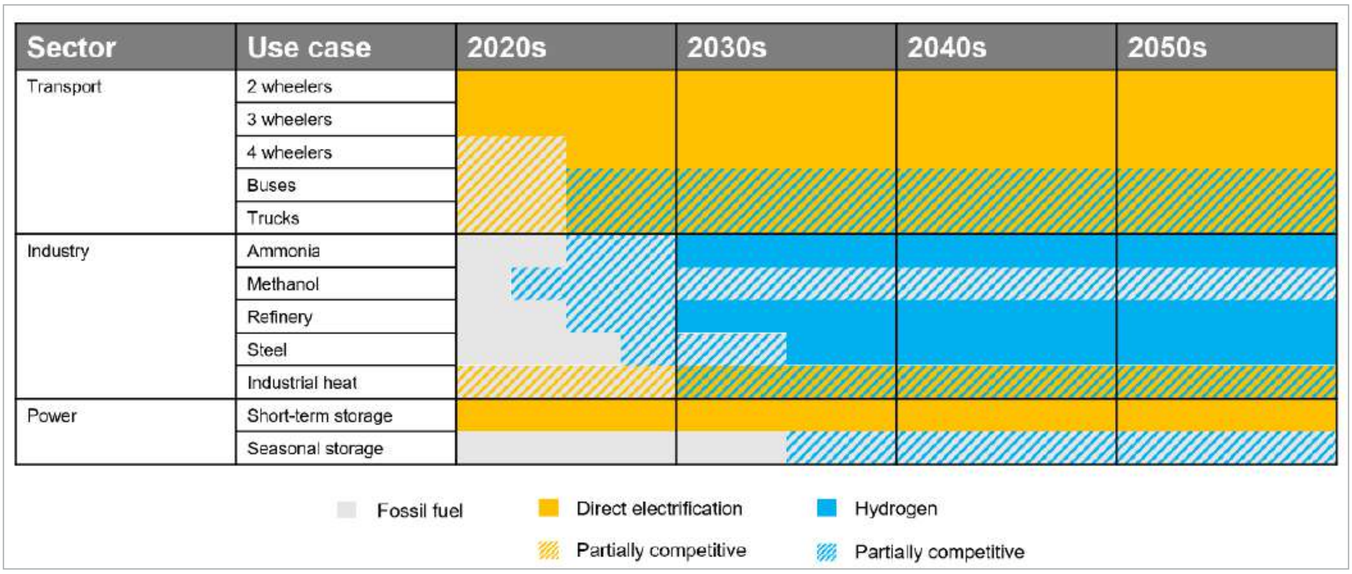
Source: FTI Consulting Analysis

India's Green Hydrogen and Energy Transition Imperative

Aligning Transport Technologies - Fame/EV and Green Hydrogen

Based on the work done by TERI,[3] one can identify opportunities where EV/battery tech will lead, work in tandem with green hydrogen and where green hydrogen has the strongest case (without EV/battery tech).

As per the analysis for transport, passenger and light weight transport are best served by EVs and battery storage technologies with hydrogen being a good proposition for long-haul transport (inter-state trucking and buses). Though the analysis did not consider trains, the white paper does include references to rail (specifically freight rail) within the ambit of long-haul transport as a future opportunity for hydrogen, with the possibility of bi-mode trains that run on both, electricity and hydrogen.



Source: TERI Analysis

Demonstration-stage Projects and Domestic Supply Chain

The white paper emphasises the importance of large demonstration-stage projects for scaling green hydrogen in India, specifically for industrial clusters, as well as solving for demand (use-cases) as well as supply dilemma. Demand needs to be created, to drive supply and creation of an enabling supply chain.

Demand can be induced with the creation of demonstration-stage projects across multiple use-cases and sectors. From a timing perspective, steel and fertiliser industries have been identified as economically better placed to adopt earlier than others. These will need to be supported by public policies, capital as well as enabling mechanisms between central government and local project jurisdictions (in states or across states). The multiplicity of regulatory agencies and policies is a hurdle in national demonstration-stage projects and will need to be adequately supported. Without enabling policies, incentives and patient capital, the industry will not invest sufficiently to develop the hydrogen ecosystem further.

3 TERI report Potential Role of Hydrogen in India, December 2020

Three Hydrogen Adoption and Policy Pathways

The whitepaper considers three green hydrogen adoption pathways for India, making some assumptions on hydrogen production, system and component costs by 2030, borrowing from publicly available scenarios and estimates put out by energy research agencies and think tanks such as IEA, IRENA,[4] ERISA[5] and BNEF[6] – as well as some of the estimates put forward by TERI. Each pathway is accompanied by policy interventions, government-industry collaborations and development-stage projects that need to move in tandem to achieve the stated green hydrogen ambitions. Demonstration-stage projects determine the true extent of ecosystem maturity and coordinated stakeholder actions to grow the green hydrogen ecosystem.

4 https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Apr/IRENA_GRO_Summary_2020.pdf

5 Chapter 4 'The Potential and Costs of Hydrogen Supply', Demand and Supply Potential of Hydrogen Energy in East Asia, ERISA Research Project Report (2019)

6 https://data.bloomberglp.com/professional/sites/24/BNEF-Hydrogen-Economy-Outlook-Key-Messages-30-Mar-2020.pdf

Pathway A – Proactive Policy-led Hydrogen Plan By 2022

Pathway A works with the premise that India wants to increase hydrogen adoption by India in the 2025-30 timeframe for the country to emerge as a significant global green hydrogen champion by 2030, with an integrated view of how India's renewables, electric/battery-power and green hydrogen technologies will work together to help India achieve a net-zero carbon scenario faster.

Economic assumption for hydrogen production by 2030 is that costs would drop to USD 2/kg (without government subsidy, and USD 1.5/kg with subsidy), and capex for electrolysers would be USD 300/kW (for Alkaline Electrolysers) and USD 500/kW (for PEM Electrolysers), as a result of growth in local electrolyser manufacturing and reductions would be between 40-50 percent from the IEA 2030 scenarios (400/kW for AK-EC, 650/kW for PEM-EC).[7] Fuel Cell costs are assumed to be USD 80/kW (20 percent lower than the US DOE target of USD 100/kW, which is the cost at which the systems become comparable with diesel engines) by 2030, with an estimated annual domestic production of 150,000 Fuel Cell systems.

LARGE DEVELOPMENT-STAGE PROJECTS	POLICY INTERVENTIONS AND PARTNERSHIPS
— Ten large-scale H2 national infra projects with state subsidies/ incentives, within 3-5 years i.e. by 2025 INDUSTRIAL CLUSTER CANDIDATES • Ports & Logistics Hubs - Nhava Sheva/Mah, Mundra/Guj, Chennai/TN, Vizag/AP, Paradip/Odisha • Sector-specific H2 Clusters/Valleys – Eastern India Mining/ Steel Cluster (Paradip/Jharsugda/Odisha) with Brown Coal/ Gasification; PetroChem/Fertiliser Plant (Guj) • Municipal / Urban Biogas hubs – Ahmedabad, Pune, Greater Mumbai LONG-HAUL, HEAVY DUTY TRANSPORT • Delhi-Mumbai Industrial Corridor (DMIC), Dedicated Freight Corridors (DFCs) — India H2 manufacturing capability to be part of GH2 global value-chains – inviting global investments, shared IP • Electrolyser design, manufacture (Alkaline, PEM) • Storage & transport systems (pipelines, tanks) • FCEV components, systems/stacks, re-fuelling stations • GH2 engineering and manufacturing jobs/ skills development — National hydrogen infra project & supply chain funding • Incentivize GH2 investments, as carbon-offsets – to encourage industry incumbents to de-carbonise • Multilateral and climate change/energy transition funds for consortium-led hydrogen projects	— Combined GH2-EV national energy transition strategy and roadmap towards net-zero carbon • 20 percent H2 blending in natural gas • Aspirational H2 energy share target of four percent by 2030 • Accelerated EV+GH2 adoption by decarbonising long-haul transport and industry in next 10 years (2020-30), with 10 national H2 infra projects in next 3-5 years • State subsidy/incentives support for national H2 infra projects, ten publicly tendered H2 infra projects, — Formation of India H2 Taskforce • Identify and promote green H2 plan of identified champions in public sector and private sector — Hydrogen Transition Fund for national projects • Funding for national hydrogen projects • Subsidy/incentives, funded by national carbon/energy transition taxes, multilateral funding — 'Make-In-India' domestic manufacturing opportunity in GH2 and FCEV global supply chains • Global Tier I/II supplier to global OEMs within 5 years, with clear 2030 targets, for export markets • Expand Centre of Excellence (CoE), academic collaboration with industry, facilitate co-development

7 Page 18, https://theicct.org/sites/default/files/publications/final_icct2020_assessment_of%20_hydrogen_production_costs%20v2.pdf

Pathway B – Cautious 'Fast-Follower' Approach to Build Green Hydrogen Roadmap by 2030

Pathway B works with the premise that India wants to take a cautious view, identifying a few demonstration in the 2025-2030, which would help it articulate its Green Hydrogen Roadmap by 2030, and work towards faster adoption in the 2030-40 decade after it has built its EV infrastructure. With this approach, the global green hydrogen and supply chain investments would have been made already, and India would be hoping to be a 'fast-follower' putting aside significant public funds to ensure it is able to catch up with other hydrogen-mature economies. India will have to forfeit its ambition of being a significant global green hydrogen champion, and will rely on imported technologies to make the energy transition towards green hydrogen.

The economic assumption for hydrogen production costs would drop to USD 2/kg (without government subsidy, and USD 1.5/kg) by 2040 (i.e. a decade later than Pathway A), and capex for electrolyzers would be USD 400/kW (for Alkaline Electrolysers) and USD 650/kW (for PEM Electrolyzers) by 2030, as a result of growth in local electrolyser manufacturing and reductions between 20-40 percent to be in line with the IEA 2030 scenarios.[8] Fuel Cell costs are assumed to be USD 100/kW by 2030 (in line with US DOE target, at which FC systems become comparable with diesel engines), with estimated annual domestic production of 150,000 Fuel Cell systems.

LARGE DEVELOPMENT-STAGE PROJECTS	POLICY INTERVENTIONS AND PARTNERSHIPS
— Three large-scale H2 national infra projects with state subsidies/ incentives, within 8-10 years INDUSTRIAL CLUSTER CANDIDATES • Ports & Logistics Hubs - Nhava Sheva/Mah, Mundra/Guj, Chennai/TN, Vizag/AP, Paradip/Odisha • Sector-specific H2 Clusters/Valleys – Eastern India Mining/ Steel Cluster (Paradip/Jharsugda/Odisha) with Brown Coal/ Gasification/ PetroChem/Fertiliser Plant (Guj) LONG-HAUL, HEAVY DUTY TRANSPORT • Delhi-Mumbai Industrial Corridor (DMIC) — India H2 manufacturing capability to be part of global value-chains – inviting global investments, shared IP • Electrolyser design, manufacture (Alkaline, PEM) • Storage & transport systems (pipelines, tanks) • FCEV components, systems/stacks • GH2 engineering and manufacturing jobs	— Combined GH2-EV as national energy transition strategy and roadmap in next 10-15 years • 20 percent H2 blending in natural gas • Aspirational H2 energy share target of four percent by 2030 • EV+GH2 adoption by decarbonising long-haul transport and industry in 15-20 years (2035-40), with three national H2 infra projects in 8-10 years — Formation of India H2 Taskforce • Identify and promote green H2 plan of identified champions in public sector and private sector — Hydrogen Transition Fund for national projects • Funding for national hydrogen projects; Subsidy/incentives, funded by national carbon/energy transition taxes, multilateral funding — 'Make-In-India' domestic manufacturing opportunity in GH2 and FCEV global supply chains • Global Tier I/II supplier to global OEMs within 10 years, for export markets

8 https://theicct.org/sites/default/files/publications/final_icct2020_assessment_of%20_hydrogen_production_costs%20v2.pdf

Pathway C – Reactive Approach to Green Hydrogen till 2040

Pathway C works with the premise that India wants to pursue energy transition with EV/battery tech and wait for global hydrogen ecosystem to mature before it develops an India roadmap, assuming that this will take place only in the 2040-50 decade. India would be a 'slow-follower' if it were to take this pathway.

The economic assumption for hydrogen production costs would drop to USD 2/kg (without government subsidy, and USD 1.5/kg) by 2040 (i.e. a decade later than Pathway A), and capex for electrolysers would be USD 400/kW (for Alkaline Electrolysers) and USD 650/kW (for PEM Electrolysers) by 2030[9] – the same as in Pathway B. Fuel Cell costs are assumed to be USD 120/kW by 2030 (20 percent higher than the US DOE target and Pathway B), with estimated annual domestic production of 150,000 Fuel Cell systems.

LARGE DEVELOPMENT-STAGE PROJECTS	POLICY INTERVENTIONS AND PARTNERSHIPS
— H2 to follow EV/battery tech for energy transition, with lag — Large, aspirational national infra projects in 15-20 years • Industrial Clusters • Long-haul Transport Corridors (for heavy trucking) — No India H2 manufacturing capability, Make-In-India plan for green hydrogen	— GH2-EV as aspirational energy transition plan to net-zero carbon • 10 percent H2 blending in natural gas • Aspirational H2 energy share target of four percent by 2040 — EV+GH2 adoption by decarbonising long-haul transport over next 20-25 years (2040-45 timeline), scaling up from national H2 infra projects in next 15-20 years

9 https://theicct.org/sites/default/files/publications/final_icct2020_assessment_of%20_hydrogen_production_costs%20v2.pdf

India's Green Hydrogen Roadmap and Energy Transition Vision

Building on Pathway A and a proactive role for policy and partnerships in creating a green hydrogen ecosystem, eight key interventions or recommendations are being made in the white paper. These eight recommendations provide important inputs for creating a green hydrogen roadmap for India, moving beyond the five policy interventions, to include key opportunities and hurdles for both government and industry to resolve together – from questions around the scope and scale of demonstration projects to building collaborative frameworks between stakeholders.

Recommended Policy Interventions for Creating A Green Hydrogen Ecosystem In India

1. NATIONAL HYDROGEN POLICY AND ROADMAP BY 2021, CO-CREATED BY GOVERNMENT AND INDUSTRY

Articulating the importance of a hydrogen economy and ecosystem in India's energy transition journey should start with a national hydrogen policy and creation of a roadmap or blueprint that signals regulatory certainty when it comes to hydrogen projects. This can be a 'rolling' framework that is refreshed every five years, to acknowledge the rapidly changing hydrogen ecosystem and strategic fit between green hydrogen adoption strategies and those for EVs and battery technologies. A look at global hydrogen policies reveal a range of approaches – from a broad and indicative framework in the case of Australia, to detailed frameworks used by the US State of California, with detailed economic modelling and assumptions on costs and pricing.

The recommendation for India is to signal policy intent with a national policy, provide an implementation timeline for large-scale hydrogen demonstration projects and funding so that India is considered a serious global hydrogen player. Due to the commercial nature of large demonstration projects, the paper recommends that an India green hydrogen policy should be prepared by the government with active involvement of hydrogen-champions from the industry.

2. H2INDIA GREEN HYDROGEN TASKFORCE AND WORKGROUPS TO IMPLEMENT THE ROADMAP

Moving beyond stated green hydrogen ambitions in the long term, it is important to create an executive body, in the form of an H2India Green Hydrogen Taskforce that will act on the national policy and implement the steps in the roadmap. This will ensure that there is accountability and a sense of urgency in creating in the green hydrogen ecosystem in India. The Taskforce should be constituted with members from industry, the government and hydrogen experts; drawn from global as well as Indian organizations, to ensure that India has access to the best available global expertise on the hydrogen economy. The India Taskforce would have multiple Work Groups to address the different policy and implementation issues pertaining to the different stages of the hydrogen value chain – from production, storage and distribution, to the appropriate use cases. In many ways, the taskforce (along with the policy and roadmap) provides a governance framework that will govern hydrogen-related policy and decision making. The India Taskforce would also ensure hydrogen strategies are being considered in national as well as sectoral net-zero carbon plans and aligned with the EV, battery storage, and energy transition policies across multiple agencies and ministries of the government.

3. USD 100 MILLION GREEN HYDROGEN INVESTMENT FUND TO BE RAISED, FOR DEPLOYMENT OVER NEXT FIVE YEARS

Funding is a key for building out large, demonstration projects at an early stage of green hydrogen ecosystem development. Moving beyond R&D spending in hydrogen, India should raise a USD 100 million Green Hydrogen Investment Fund, supported by bilateral and multilateral agencies, to take the first step towards scoping, funding and executing large development stage projects, over the next five years.

The USD 100 million fund corpus for five years (about USD 20 million per year) is indicative amount for identifying and implementing at least 4-5 of the identified 10 national hydrogen demonstration projects. The corpus for following five years, possibly five-fold, to meet 2030 ambitions and increasing scale of the first set national demonstration projects.

The Green Hydrogen Investment Fund can fit within the existing institutional framework for Climate Change funds, governed by the Climate Change Finance Unit in the Ministry of Finance (MoF) or under the Ministry of Environment and Forests. An alternative would be to create a co-funded mechanism (with global pension, climate change funds, multi-lateral funding agencies) within the National Infrastructure and Investment Fund (NIIF), formed by the Government of India (governed by Ministry of Commerce or Ministry of Heavy Industries), to be deployed for national hydrogen projects.

4. NATIONAL ASPIRATION FOR FOUR PERCENT HYDROGEN SHARE IN NATIONAL ENERGY MIX BY 2030

India should put forward an aspirational H2 economy target of four percent energy share by 2030 – this works out to a little over 50 percent of natural gas share in 2018. In volume terms, this would represent about 13 MMT of hydrogen demand by 2030 and is comparable to the 17 MMT being targeted by US and 15 MMT by EU.

A national hydrogen demand of 13 MMT by 2030 represents about 10 percent of India's total hydrogen potential by 2040 (as per ERISA 2019 study, India's total hydrogen potential in 2040 is estimated to be 600 MMTOE or 127 MMT of hydrogen).[10]

5. INTER-MINISTERIAL GREEN HYDROGEN GOVERNMENT CELL TO ENSURE FOR GLOBALLY HARMONISED STANDARDS

Creation of an inter-ministerial green hydrogen government agency or department will be important to ensure coordination between new energy policies, national demonstration projects that will require strong centre-state collaboration, Climate Change funding, Make-In-India domestic manufacturing initiatives with the FAME and Renewables expansion initiatives.

A central agency will also ensure adherence to globally harmonised and safety standards that are critical for commercialisation of hydrogen technologies in India.

INTENDED OUTCOMES BY 2030

1. New 'Hydrogen-focused' Climate Change Funding – estimated USD 100 million for five-year period, potentially grow to USD 500 million till 2030
2. Increase H2 demand – through H20 blending in gas by 2030, new and scalable H2 use cases
3. Provide policy clarity to sectors, public and private investors, citizens– charting out a clear green hydrogen roadmap that aligns EV-New Energy investments, with Renewable Energy plans, to move India towards net-zero carbon.
4. Encourage co-funding, consortia formation for large national demonstration-stage projects
5. Bring in global hydrogen investors to create domestic manufacturing capability, bring in critical electrolyser and FCEV technology know-how
6. Create new green hydrogen economy jobs, create momentum for energy transition in different sectors

10 Chapter 4 'The Potential and Costs of Hydrogen Supply', Demand and Supply Potential of Hydrogen Energy in East Asia, ERISA Research Project Report (2019)

National Green Hydrogen Demonstration Projects and Use Cases

6. GREEN HYDROGEN PRODUCTION COUPLED WITH USE-CASES, H20 HYDROGEN BLENDING IN NATURAL GAS

The white paper emphasises that India should develop the national green hydrogen ecosystem by evaluating and implementing large green hydrogen demonstration projects in regions with high solar or wind energy potential. This mirrors the approach taken by EU and avoids expensive hydrogen transportation across large distances. The renewable-energy rich states of Rajasthan, Gujarat, Maharashtra, Karnataka, Andhra Pradesh and Tamil Nadu will emerge as natural destinations for hydrogen projects and will require capacity building at the state department level.

Some blue and grey hydrogen production (using Steam Methane Reformation) could be considered, as an interim step, and encouraged to evaluate unique Indian use-cases in coal-gasification, or urban/municipal biogas, with the long-term intent of transitioning them towards zero-carbon.

Hydrogen-blended Compressed Natural Gas (H-CNG) is already being evaluated for mainstream adoption as a clean fuel automotive alternative and interim step. The government is currently working on 18 percent hydrogen blending and the Bureau of Indian Standards (BIS) is developing domestic specifications for it after due testing. Globally, hydrogen-blending of 20 percent in natural gas is being considered and this could be the aspirational target for India by 2030. This is the fastest route to increase hydrogen demand without investing in expensive hydrogen infrastructure.

7. TEN NATIONAL H2INDIA INFRASTRUCTURE PROJECTS FOR LARGE SCALE DEMONSTRATION

The white paper proposes that India should explore ten potential large-scale demonstration projects, across different use-cases – from long-haul, heavy duty transport (trucking, trains), to industrials clusters (ports, logistics hubs), sectoral clusters (steel, fertiliser, cement, mining) and urban municipal (waste). These are based on hydrogen use-cases in other parts of the world and have to be evaluated further for techno-commercial and financial viability before they are designated national hydrogen projects.

a. H2Bharat Long-Haul Trucking project - 10,000 H2 truck fleet and infrastructure on DMIC

Green hydrogen-powered long-haul and heavy duty-trucking has been growing within the transport segment, working in tandem with battery-powered EVs passenger cars, light-transport and buses. The white paper proposes an aspirational H2 trucking corridor, as part of the Delhi-Mumbai Industrial Corridor (DMIC), with at least 10,000 hydrogen truck-fleet (in two phases) and 10 hydrogen refuelling stations along this corridor by 2030 (based on the 1:1000 ratio between fleet size and refuelling infra, as planned in EU and California). This avoids the challenges of a nation-wide initiative that would require hydrogen re-fuelling infrastructure to be built nationally. This is akin to the EU H2Haul and EU HyAMMED1 project in Europe.

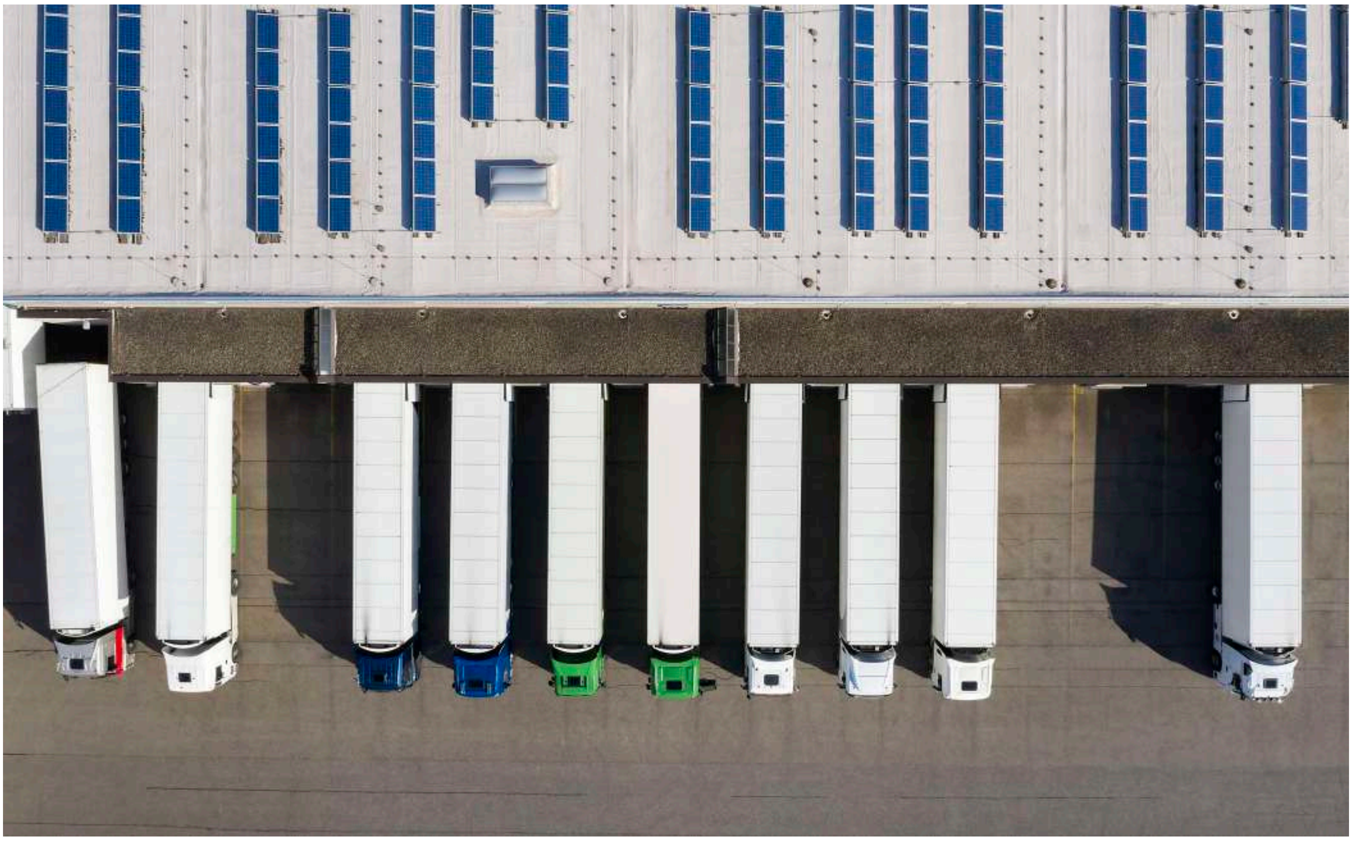
The industry and government should work together to grow H2 truck fleet along this corridor, to target conversion of about 10 percent of long-haul trucking along the DMIC route to be hydrogen-fuelled truck FCEVs. This would allow existing truck manufacturers as well as new FCEV truck manufacturing players, plan for new investments and take focused, informed decisions to manufacture mobile FCEV stacks for heavy, long-haul trucking, thereby bringing FCEV costs down. With an aspirational H2 truck fleet of 10,000 vehicles by 2030, India would have 25 percent of planned H2 trucks in EU by 2030 (and three percent of the global 350,000 H2 trucks estimates[11] by 2030 as per the Hydrogen Council; 10,000 trucks represents one percent of new truck sales in 2019).

The white paper is working with the hypothesis that that industry will be able to come together, to form an H2Bharat Trucking consortium, that works with the government to implement a national project of this scale and ambition, necessitated by the risk profile and economic costs associated with such a project.

EV-hydrogen bi-mode Freight Trains along the DMIC – a possibility

A similar H2Bharat Rail Consortium (starting with rail freight) along the same corridor, bringing together India Railways and other private operators could also be explored. Bi-mode trains that run on both electric/ batteries and hydrogen have already been launched in Europe. India could aspire to have an aspirational 10 electric-hydrogen bi-mode freight trains within the next decade.

11 https://hydrogencouncil.com/wp-content/uploads/2017/11/Hydrogen-scaling-up-Hydrogen-Council.pdf



b. H2Bharat Port and Logistics Clusters – linked to H2India Trucking project along DMIC

Two major seaports (Mundra and Nhava Sheva) and multiple logistics clusters along the DMIC provide an organic link to any proposed H2India Trucking project and use diesel-powered machinery (fork-lifts, cranes, trucks) to move heavy equipment, containers and freight within their periphery. Decarbonizing such fleets, swapping diesel with locally produced hydrogen (with small/ midsized electrolysers or natural-gas powered production plants) and incorporating hydrogen-powered heavy equipment could create 'green ports' and 'green logistics hubs' over time.

Starting with modest targets such as swapping 30 percent of heavy-equipment and fleets to be hydrogen-powered by 2030 is one to start with this transition – supported by fiscal incentives for achieving these targets. Port Authorities and Logistics Cluster Concessionaires/ Authorities that choose to adopt and increase hydrogen use should be designated H2Bharat Ports and Logistics Clusters, and on submission of their hydrogen plans, supported with fiscal incentives by the government. Once successful, this can be replicated in other major ports (including on the east coast) as well as at other logistics clusters.

c. H2India Industrial Clusters– in high-priority sectors (steel, fertilisers, cement, mining)

The above approach (b) can be replicated in other specific sectors, particularly large plants in steel and fertiliser sectors, linked to the sectoral energy transition roadmaps. Given the current high costs of hydrogen, sectoral adoption should be encouraged by larger players or industrial plants first, offering them incentives for putting up small and midsized electrolysers or H2 production plants within their premises and adding hydrogen-powered FCEVs and heavy equipment within plant premises. This could start with a similar 30 percent target across the plant by a 2030 timeline, with fiscal incentives for achieving such a plan.

The choice of production technology, plant size or hydrogen type (green, blue/grey) should be left to the plant owners/leads so that they can make an informed choice based on suitability, with the highest fiscal incentives for green hydrogen production and use. Detailed sectoral studies have been prepared by TERI for India use-cases in steel and the fertiliser industries, with recommendations on the hydrogen adoption paths that could be pursued by key players.

Leveraging India's coal reserves in Eastern India, and its proximity to iron ore deposits and steel plants, it may be prudent for India to evaluate blue or grey hydrogen production in the eastern region, using brown-coal and coal-gasification. Blue or grey hydrogen that is produced in the region can be consumed at the steel plants and mines (mine equipment, heavy earth-moving evacuators) close to the production centres. While this merits further study, it could open the possibility of a coal/synthetic-gas powered Grey Hydrogen Valley in the eastern states of Odisha-Jharkhand-Chattisgarh. To be effective, state-owned and private players will have to come together to invest and co-build such grey hydrogen production facilities, and pledge to targets such as transitioning 20 percent H2 heavy mining equipment (earth-movers, excavators, dampers, trucks) in the ore mines belts by 2030 or introducing in 2000 FCEVs heavy vehicles in the mining belts.

d. Municipal-level H2Maharashtra / H2Gujarat Urban Bio-Gas projects – solid waste, dairy cluster

Green hydrogen production from bio-waste or bio-gas reformation is being explored in some parts of the world and can be evaluated by certain large municipal bodies that can guarantee a significant and steady supply of solid waste input for a bio-gas reformation plant.

From a structuring and financing point, municipal bodies in specific states may have an advantage to be able to finance and fund such a green hydrogen production plant and find local use cases in industries or industrial clusters close to the city/municipal area. Given past success with green bonds by municipal bodies from Gujarat and Maharashtra, the white paper has proposed that the demonstration projects should include possibly one such green hydrogen production plant. A similar approach can be taken with small/medium green hydrogen production centres that are linked to large dairy clusters that can guarantee an assured and sustained supply of biogas.

INTENDED OUTCOMES BY 2030

1. Case for domestic manufacturing of 12,000 heavy-duty FCEVs by 2030, FCEV capex costs expected to come down significantly (TCO differential between H2 and diesel expected to come down from 3x currently to 1.2x by 2030)
    a. Domestic manufacturing opportunity for 10,000 FCEV systems/ stacks, 10 H2 re-fuelling stations, storage and H2 system components – estimated as a direct result of H2India Trucking Project, by 2030
    b. 1000 Mobile FCEVs for heavy-duty machinery/ equipment in ports and logistics clusters estimated, by 2030
    c. 1000 Mobile FCEVs for heavy-duty machinery/ equipment, plant fleet/trucks in steel, fertiliser, mining clusters
2. Aspiration to build GW-scale electrolyser capacity by 2030 for key use cases and develop the domestic supply chain
3. 10 percent of Coal Gasification 2030 target (100 MMT) to be converted for H2 production
4. 75,000 hydrogen-related direct and indirect jobs to be created (25,000 direct, 50,000 indirect) – H2 trained operations personnel, FCEV drivers and systems engineers, electrolyser and FCEV manufacturing and design

Green Hydrogen Public-private Partnerships, Industry Consortia

Reviewing how green hydrogen ecosystems have developed in other countries, availability of public funding, large-scale demonstration projects and the formation of partnerships / industry consortia are three key imperatives. India lacks both at present and should prioritize them if it wants to develop a green hydrogen ecosystem to develop.

8. FISCAL INCENTIVES FOR LARGE-SCALE NATIONAL H2 PROJECTS; PARTNERSHIPS AND INDUSTRY CONSORTIUMS

The white paper recommends the formation of an India Green Hydrogen Taskforce, comprising of public and industry representatives, as part of the policy interventions. While this will be useful for public-private collaboration.

India can take a leaf out of the practice in Japan and Korea to create an industry consortium that is committed to building a green hydrogen ecosystem in India. The government should encourage the formation of such an industry consortium and can play an enabling role by extending fiscal incentives to industry consortia-led hydrogen demonstration projects. This is a critical intervention to address the current gap in the ecosystem. Such consortia should be represented by multiple players that operate across the hydrogen value chain, rather than a single part or use-case. Sectoral or production-focussed players can form work-groups to ensure expertise is pooled but the benefits should accrue to the entire ecosystem e.g. a long-haul H2 trucking project should be connected to industrial clusters that are serving by the trucking route as well as seaports (seeing trucking in isolation as part of automotive will be counter-productive).

The Government of India as well as industry consortia, once formed, should focus on the following priorities:

- Promote electrolyser and FCEVs domestic manufacturing - systems, components
- Work towards creating Global Tier I supplier relationships between Indian players and global H2 OEMs within five years, with a clear target for what needs to be achieved by 2030 and grown as H2 exports.
- Leverage strategic G2G partnership for green hydrogen development - partnerships with Japan (DMIC), Korea (H2) – to attract inward H2 investments from lead companies in those countries.
- Develop local policy and industry capacity – this would include training and awareness about green hydrogen, the energy transition imperative, how green energy fits with EV/battery tech and renewable as well as ensuring that Indian stakeholders are well equipped to take hydrogen related decision (for projects or capital allocations).

INTENDED OUTCOMES BY 2030

1. Draw the interest of global FCEV truck/heavy duty transport players to India, invite investments and create incentives by offering them economic incentives, opportunity to scale.
2. Encourage industry to invest in local manufacturing, research/testing and implementing large demonstration-stage projects.
3. Commercialise indigenous GH2 tech, systems and explore its export potential.

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