Accelerating Green Hydrogen Economy

Prepared for Green New Energy for a Net Zero India

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Foreword

The impacts of the COVID-19 pandemic and the ongoing conflict in Ukraine are a stark reminder of how India's dependence on energy imports and other commodities linked to global supply chains can threaten its strategic interests. In this context, the emergence of green hydrogen as a promising low carbon feedstock and energy carrier for industrial applications is a boon for India's long-term energy security, sustainability and self-reliance.

Green hydrogen is likely to be at the heart of the global race to achieve economy wide net zero emissions. The competitiveness of green hydrogen derived commodities with traditional fossil fuels will determine the speed and scale of the transition in future.

India's thriving renewable energy markets and enabling policy ecosystem have helped the country retain its position among the top 3 markets globally in the EYs 'Renewable Energy Country Attractiveness Index' (RECAI). By leveraging low-cost intermittent renewable electricity produced at scale, India could become a global hub for production and export of green hydrogen based commodities.

In August 2021, Hon'ble Prime Minister announced the launch of 'National Hydrogen Mission (NHM)' to scale up green hydrogen production, utilization and align India's energy transition efforts with global best practices in technology, policy and regulation. Subsequently, India's leading energy conglomerates both in public and private sectors have announced their ambitions, initiated pilot projects and strategic partnerships to boost the green hydrogen supply chain.

The recently announced 'Green Hydrogen Policy' is a timely intervention for the industry betting on the promise of green hydrogen/ammonia production at competitive prices. The policy will kick start India's energy transition efforts, particularly in the emission intensive industrial sectors such as oil refineries, fertilizers, metals, chemicals, cement, etc.

In this report, EY has contextualized the role of green hydrogen for achieving India's long-term energy security and environmental sustainability objectives. The report presents key insights on demand outlook, applications, emerging technologies, techno-economics of the supply chain (viz. production, storage and transportation/distribution) and evolving policy ecosystem, particularly the role of state governments in driving both demand and competitiveness of green hydrogen. The report also presents a pipeline of 'shovel-ready' investment opportunities at various stages of development.

Mr. Somesh Kumar
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Acronyms

°C	Degree Celsius
AEC	Alkaline Electrolysis Cell
BOO	Build Own Operate
CAGR	Compound Annual Growth Rate
CAPEX	Capital Expenditure
CEA	Central Electricity Authority
CII	Confederation of Indian Industry
CNG	Compressed Natural Gas
CO_2	Carbon dioxide
CTU/STU	Central/State Transmission Utility
CUF	Capacity Utilization Factor
DAM	Day Ahead Market
DISCOM	Distribution Company
DRI	Direct Reduced Iron
EAF	Electric Arc Furnace
EV	Electric Vehicle
EY	Ernst & Young
FCEV	Fuel Cell Electric Vehicle
g	Grams
GH_2	Green Hydrogen
GHG	Green House Gas
GIS	Geographic Information System
GST	Goods and Services Tax
GW	Gigawatt
H_2	Hydrogen
HEV	Hybrid Electric Vehicles
ICE	Internal Combustion Engine
IEA	International Energy Agency
INR	Indian Rupee
IOCL	Indian Oil Corporation Limited
ISTS	Interstate transmission network
kg	Kilogram
kW	kilowatt
kWh	Kilo Watt Hour
LCOH	Levelized Cost of Hydrogen
LT/MTOA	Long Term/Medium Term Open Access
LULC	Land Use - Land Cover
m^3	Cubic meter
MJ	Mega Joule
MNRE	Ministry of New and Renewable Energy
MoP	Ministry of Power
MPa	Mega Pascal
Mt	Million tons
Mtoe	Million tons oil equivalent
MW	Megawatt
NHM	National Hydrogen Mission
Nm3	Newton Meter Cube
NTPC	National Thermal Power Corporation Limited
O&M	Operation and Maintenance
OPEX	Operating Expenditure
PEM	Proton Exchange Membrane
PLI	Production Linked Incentive
PNG	Piped Natural Gas
PPP	Public Private Partnerships
PUS	Public Sector Undertakings
PV	Photovoltaic
R&D	Research and Development
RE	Renewable Energy
REOA	Renewable Energy Open Access
RPO	Renewable Purchase Obligation
RTC	Round-the-clock
SECI	Solar Energy Corporation of India Limited
SEZ	Special economic zone
SLDC	State Load Dispatch Centre
SMR	Steam Methane Reforming
SOEC	Solid Oxide Electrolysis Cell
STOA	Short Term Open Access
USD	United State Dollar

CONTENT

1 Executive summary

The major consumption of green hydrogen is expected in the form of feed stock in various industrial processes and as an energy carrier. In the year 2018-19, ~5.5 million tons of grey hydrogen was consumed as a feedstock in fertilizer and crude oil refining industries. However, to meet the national and international clean energy transition, the adoption of green hydrogen will play a major role in hard to abate sectors. The industrial sectors that are likely to adopt green hydrogen and drive demand in the long term are:

GH_2 as Feed stock	GH_2 as energy carrier
Ammonia production	Transportation
Iron and steel production	Industrial heat
Crude oil refining	Power generation
Methanol production	Blending with natural gas

Hydrogen demand for ammonia production in fertilizer industry would be ~ 4.5 and 7.5 million tons in the years 2030 and 2050, respectively. Similarly, demand for desulphurization in crude oil refining industry would be ~3.2 and 5 Million tons in the years 2030 and 2050, respectively.

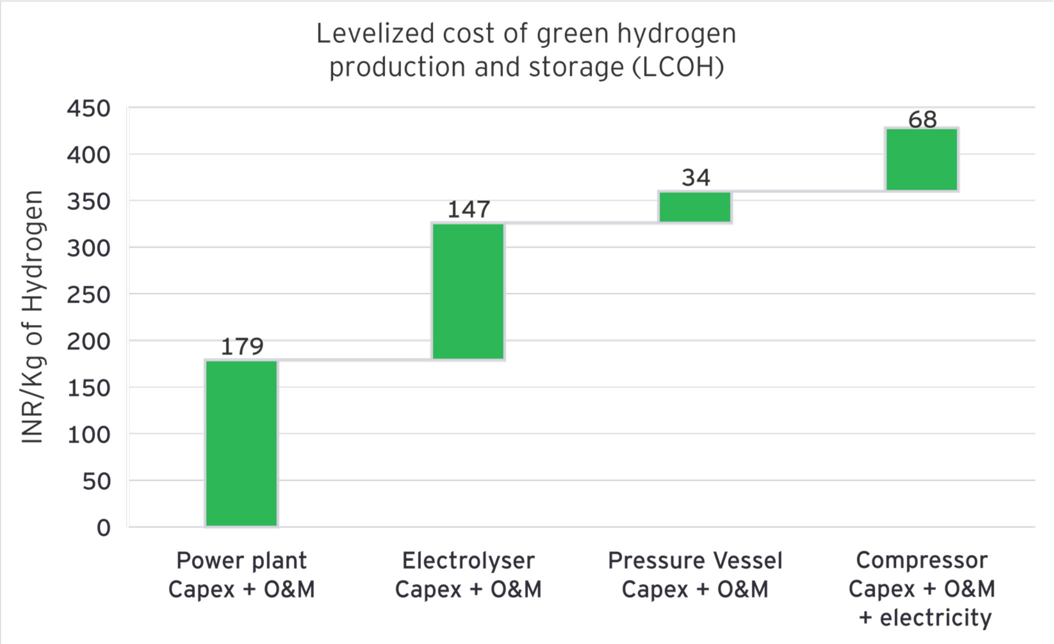
The government has set an ambitious green hydrogen production target of ~5 million tonnes by 2030 under the green hydrogen mission. To achieve this production target, India will need the support of ~115 GW of round-the-clock renewable power generation capacity and ~50 billion liters of fresh water supply. The private sector industries have shown keen interest in green hydrogen market and with the economies of scale the cost of production is believed to reduce.

Hydrogen production cost by following methods in the present scenario

Steam Methane Reforming	Coal Gasification	Biomass Gasification	Alkaline Electrolyzer
1.3 INR/ MJ	2.0 INR/ MJ	2.2 INR/ MJ	3.6 INR/ MJ

Note: Cost of hydrogen is exclusive of storage and transportation

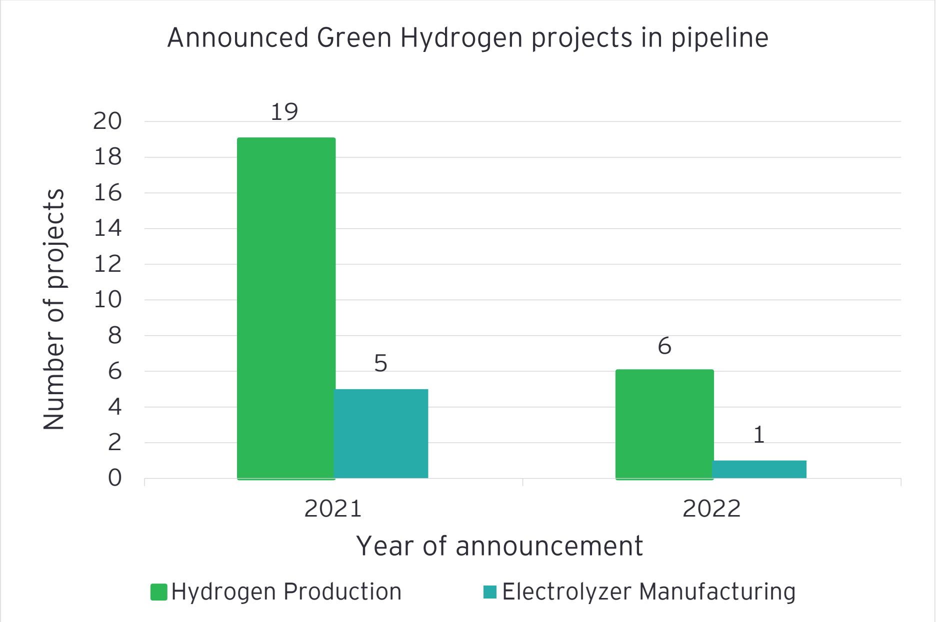
The levelized cost of green hydrogen estimated for a 1MW Alkaline electrolyzer would be approximately INR 430/kg. Amongst this, LCOH ~42% would be contributed for setting up a RTC (round-the-clock) RE power plant, 34% for electrolyzer stack, 16% for compressor and 8% for pressure vessel/storage.

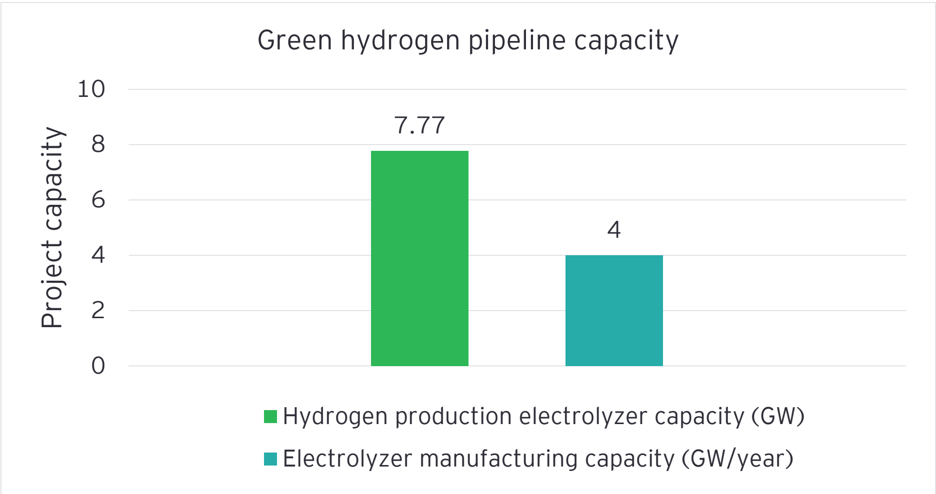


Recommendations

1. Reducing the cost of renewable power generation and supply for GH2 production
   - Waiver of Intra-state transmission charges for GH2 production
   - Waivers, clarity and certainty of open access charges for GH2 production
   - Allow banking of surplus energy in the production of GH2
   - Fungibility of green hydrogen and renewable purchase obligations
2. Improve ease of doing renewable energy open access (REOA) transactions
3. GIS mapping and identification of GH2 clusters for development
4. Establish state level mission for advancing GH2 economy, formulate and adopt GH2 production targets separately for industries, transportation and other sectors of the economy
5. Single window portal for all statutory clearances, permissions required for manufacture, transportation, storage and distribution of green hydrogen / ammonia
6. Production linked incentives and fiscal benefits for high efficiency and durable electrolyzer systems
7. Enhance public funding support towards R&D programs calling for demonstration of projects that support the competitiveness of GH2 supply chain and end-use

Project Pipeline





Source: EY Analysis based on JMK Research

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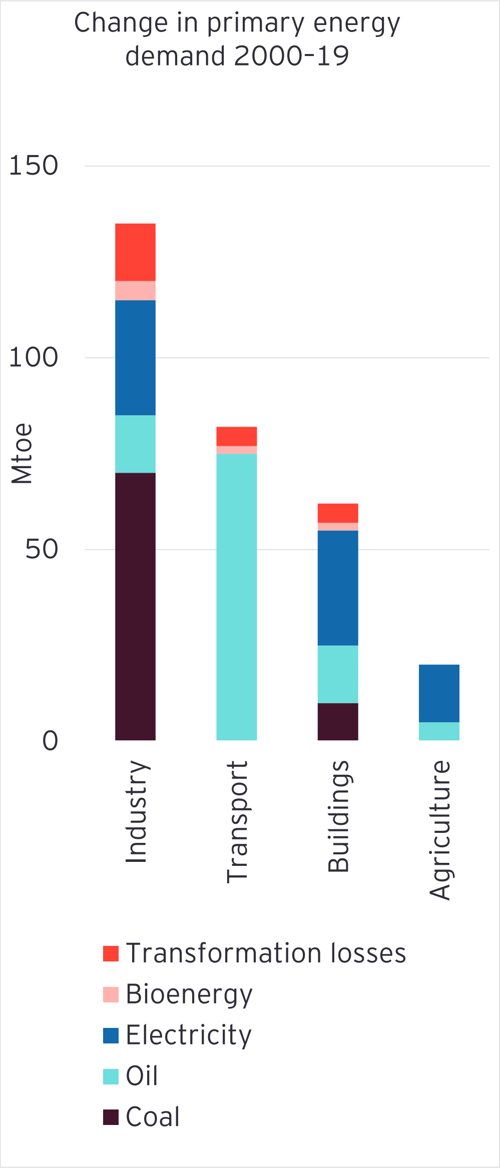
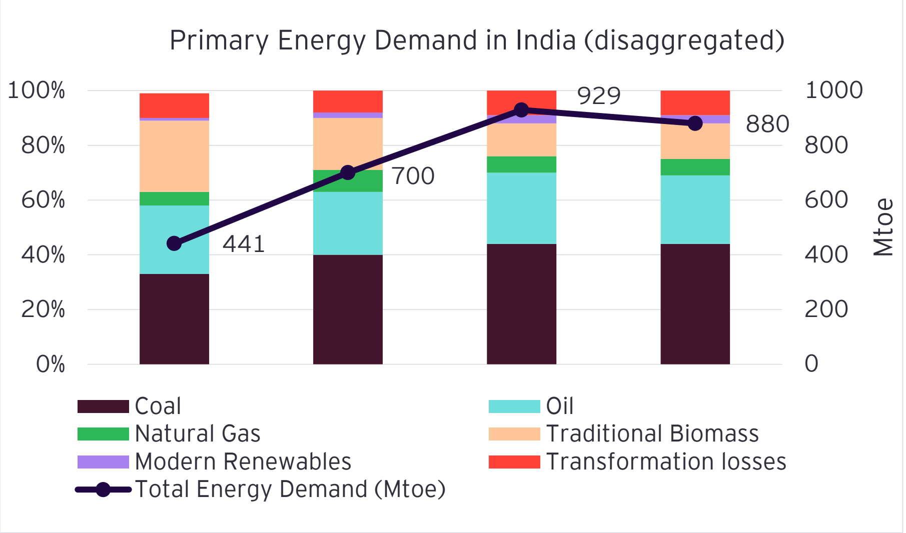
Setting the context for advancing green hydrogen economy

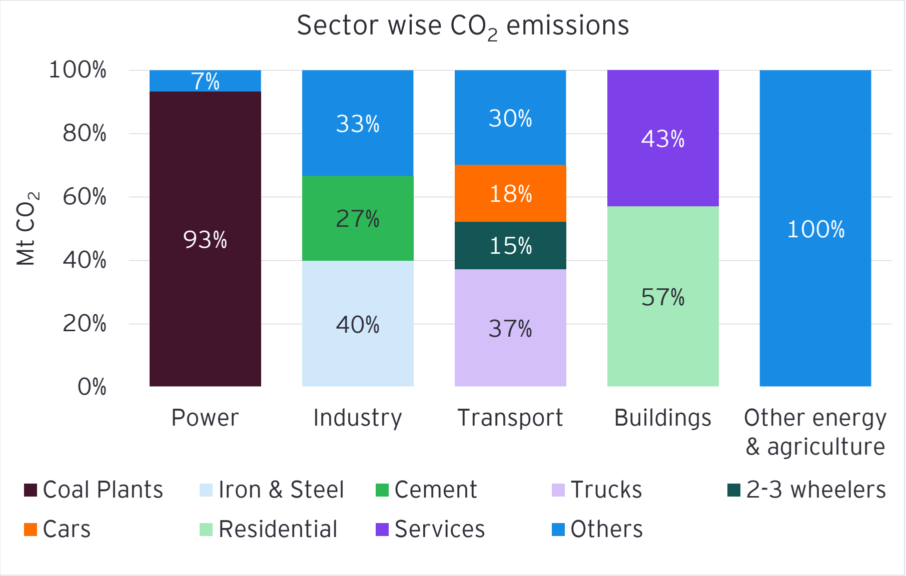
Long-term energy security, self-reliance and environmental sustainability are the key drivers for advancing green hydrogen (GH2) economy

As per the IEA's 'India Energy Outlook 2021', the primary energy mix is currently dominated by coal and oil contributing ~44% and ~25% respectively in 2020. Modern renewables contribute only ~3% of all India primary energy mix in the present scenario. The total primary energy demand has grown at ~4% (CAGR) in the last two decades. The industrial sector witnessed the highest incremental primary energy demand in the last two decades. Coal is the mainstay for industrial energy use. As per the 'India Energy Statistics 2021', net energy import dependency is a whopping 42%. Further, India's CO2 emissions are increasing rapidly from 0.98 billion tons in the year 2000 to ~2.5 billion tons in 2019 as per IEA 2021.

In this context, long-term energy security and environmental sustainability naturally become the key drivers for advancing GH2 economy. Green hydrogen will become one of the principal pathways to decarbonize the industrial and transportation sectors of the economy, which cannot be addressed by direct electrification technologies alone.







*Note that 'Modern Renewables' depicted in the charts above includes all uses of renewable energy (hydro, nuclear, solar, wind, modern biofuels etc.) with the exception of traditional use of solid biomass. Source: IEA, India Energy Outlook, 2021

In a net-zero economy, GH2 will be the dominant feedstock and energy carrier for industrial applications, where direct electrification technologies have limitations

GH2 is a critical piece of energy transition to achieve economy wide net-zero emissions. As industrial feedstock / process gas, GH2 can substitute grey H2 (derived from fossil fuels) used in oil refineries, fertilizer plants, methanol producing chemical plants and treatment of metals. As energy carrier / vector, GH2 can be used for blending with piped natural gas (PNG) used in domestic, commercial and industrial applications, electrification of heavy-duty long-haul transportation such as trucking and maritime shipping through H2 fuel cells, energy storage coupling with renewable rich power systems, etc.

Green hydrogen as 'Feedstock'


Crude oil refining


Fertilizers


Metals


Bulk chemicals

Green hydrogen as 'Energy carrier'


Industrial process heat


Blending with piped natural gas


Transportation


Power generation & storage

Source: EY Analysis

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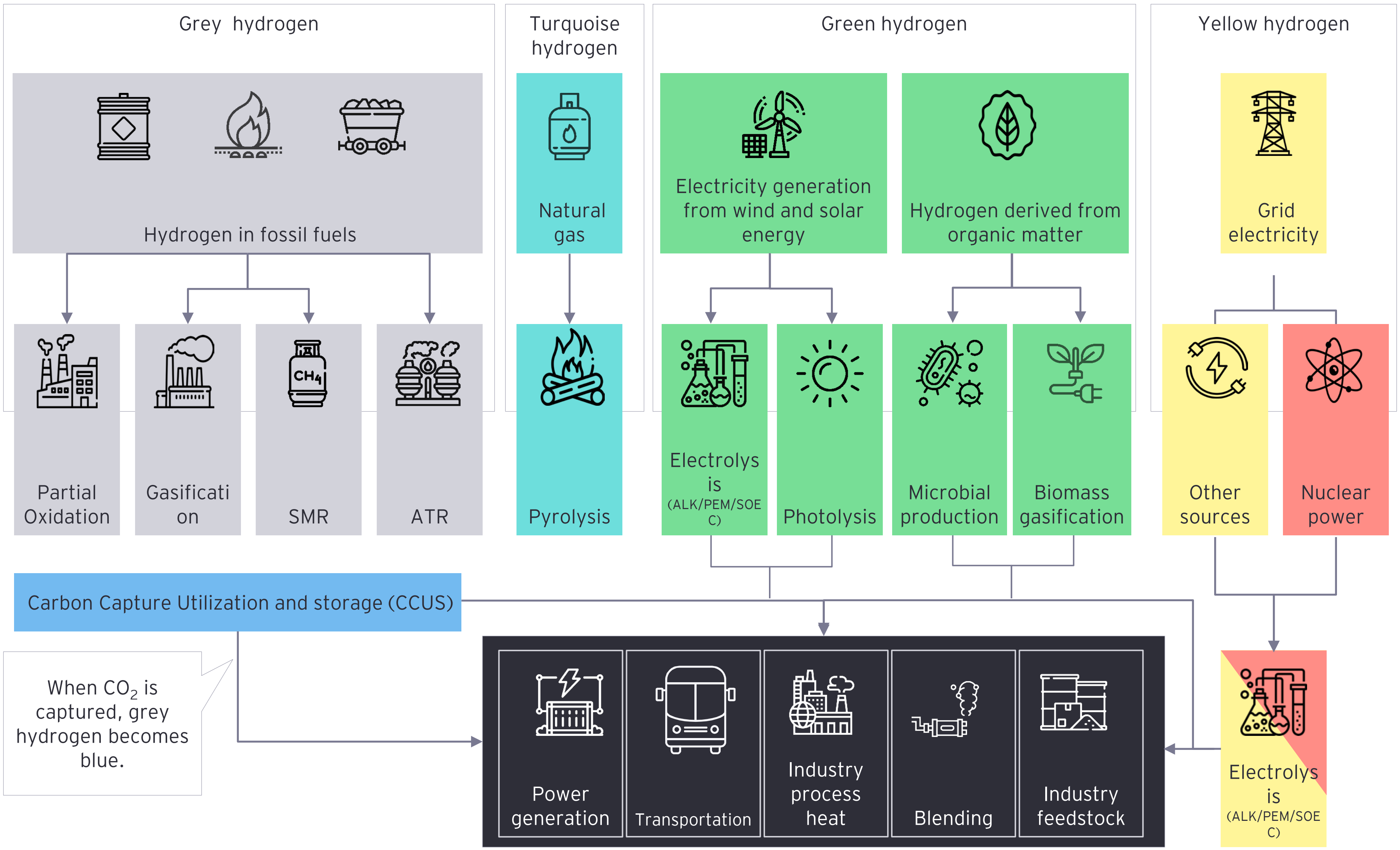
Hydrogen properties, emerging markets and demand outlook

Hydrogen production nomenclature



Physical properties of hydrogen warrant additional infrastructure for storage, handling and transportation

- Hydrogen is the simplest substance (one proton and one electron), non-toxic, colorless, odorless, or tasteless.
- At ambient conditions (temperature and pressure of 20°C and 1 bar respectively), the hydrogen molecule is extremely small and about 14 times lighter than air at 2.016 g/mol and has a high diffusion rate (0.61 cm2/s) and buoyancy.
- The flashpoint of hydrogen is −231°C, which is the lowest compared to other fuels. As the flashpoint indicates easy fuel combustion, the very low flashpoint of hydrogen is advantageous because of the possibility of a simpler system to ignite and combust hydrogen.
- At ambient pressure (1 bar), hydrogen liquifies at a temperature of −253°C, leading to a significant increase in its density.
- When hydrogen burns, the only combustion product is water vapor. Clean hydrogen/air mixtures burn with a non-luminous, almost invisible, pale blue hot flame, liberating the chemically bound energy as heat (gross heat of combustion).
- When comparing all safety related properties for hydrogen and methane in gaseous form, it is assessed that the properties of hydrogen result in a higher risk of explosion. The most important reasons are hydrogen's larger flammability range, which means that a larger part of the gas can be ignited; hydrogen's lower ignition energy (for the high concentrations). This warrants additional infrastructure for safe handling and operations.

Physical properties of H_2

Property	Unit	Value
Molecular weight	g/mol	2.016
Lower heating value (heat of combustion)	MJ/kg	120
Boiling point (Liquefaction temperature)	Degree C	- 253
Melting point (Solidification temperature)	Degree C	- 259
Density (@ STP)	Kg/m3	0.084
Density of liquid hydrogen at −253°C	Kg/m3	71
Density of solid hydrogen at −259°C	Kg/m3	858

Source: https://h2tools.org/hyarc ; Aziz, M. Liquid Hydrogen: A Review on Liquefaction, Storage, Transportation, and Safety. Energies 2021, 14, 5917. https://doi.org/10.3390/en14185917

Power and water intake for H_2O *electrolysis*

Item	Unit	Value
Electrical energy input	kWh/kg of H_2 production	50 - 55
Power intake (Instantaneous load)	kW/Nm3 of H_2 production	4.5
Water intake for H_2 production	Litres / m3	0.9
	Litres / kg	10
Water quality for H_2 production	µS/cm	< 5

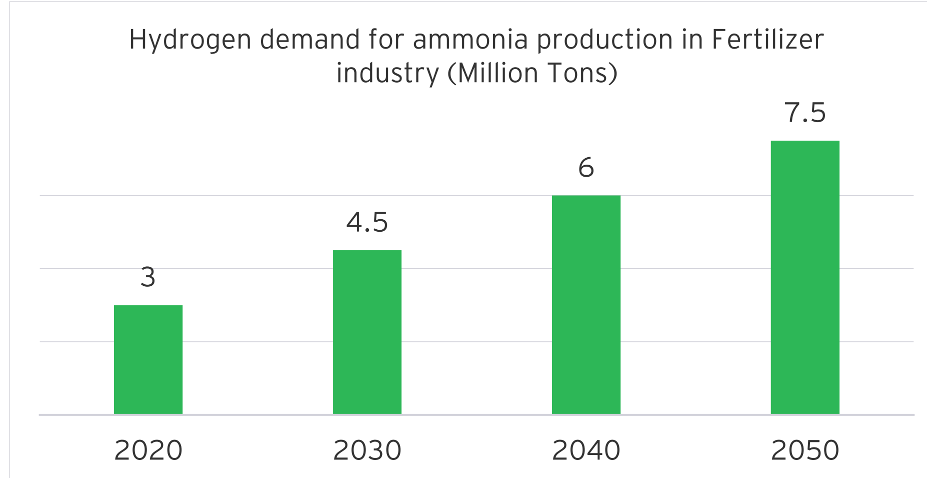
Source: EY Analysis

~5.5 million tons of grey hydrogen was consumed in 2018-19 mostly as feedstock for fertilizer and crude oil refining industries

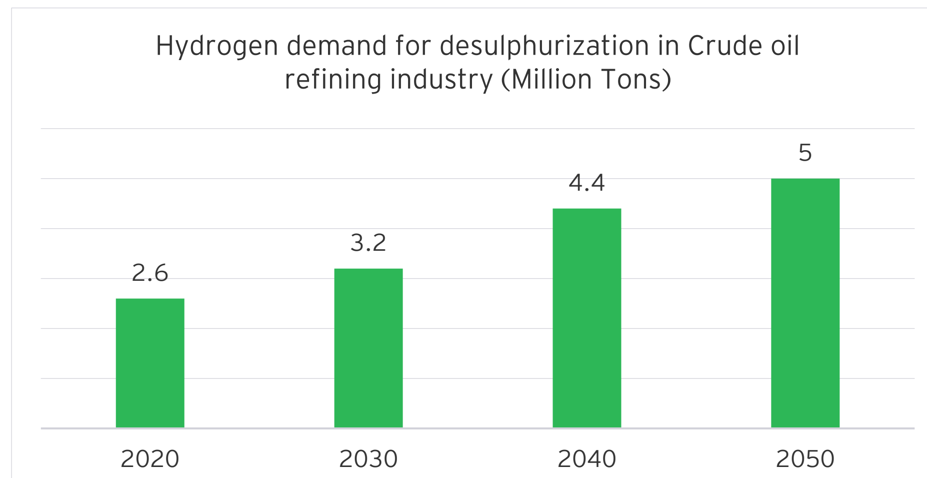
National Hydrogen Mission targets production of five million tonnes of Green hydrogen by 2030: The first leg of green hydrogen policy announcements aim to reduce the cost of green hydrogen production from renewable energy sources and position India a major export hub for green hydrogen and ammonia commodities.

Industrial sector	Hydrogen consumption in 2018-19 (in thousand Metric Tons)	Production method
Crude Oil Refining	2,600.00	Hydrocarbon reforming
Ammonia production in fertilizer industry	2,850.00	
Methanol production	51.67	
Chlor-Alkali Industry	34.37	Electrolysis
Chemical Industry	29.25	
Other industries	9.51	
Total	**5,575.00**	

Source: Compiled by Mr. Vivek Jha, Indo-German Energy Forum 2021



Source: Hall, W., Spencer, T., Renjith, G., and Dayal, S. 2020. The Potential Role of Hydrogen in India: A pathway for scaling-up low carbon hydrogen across the economy. TERI



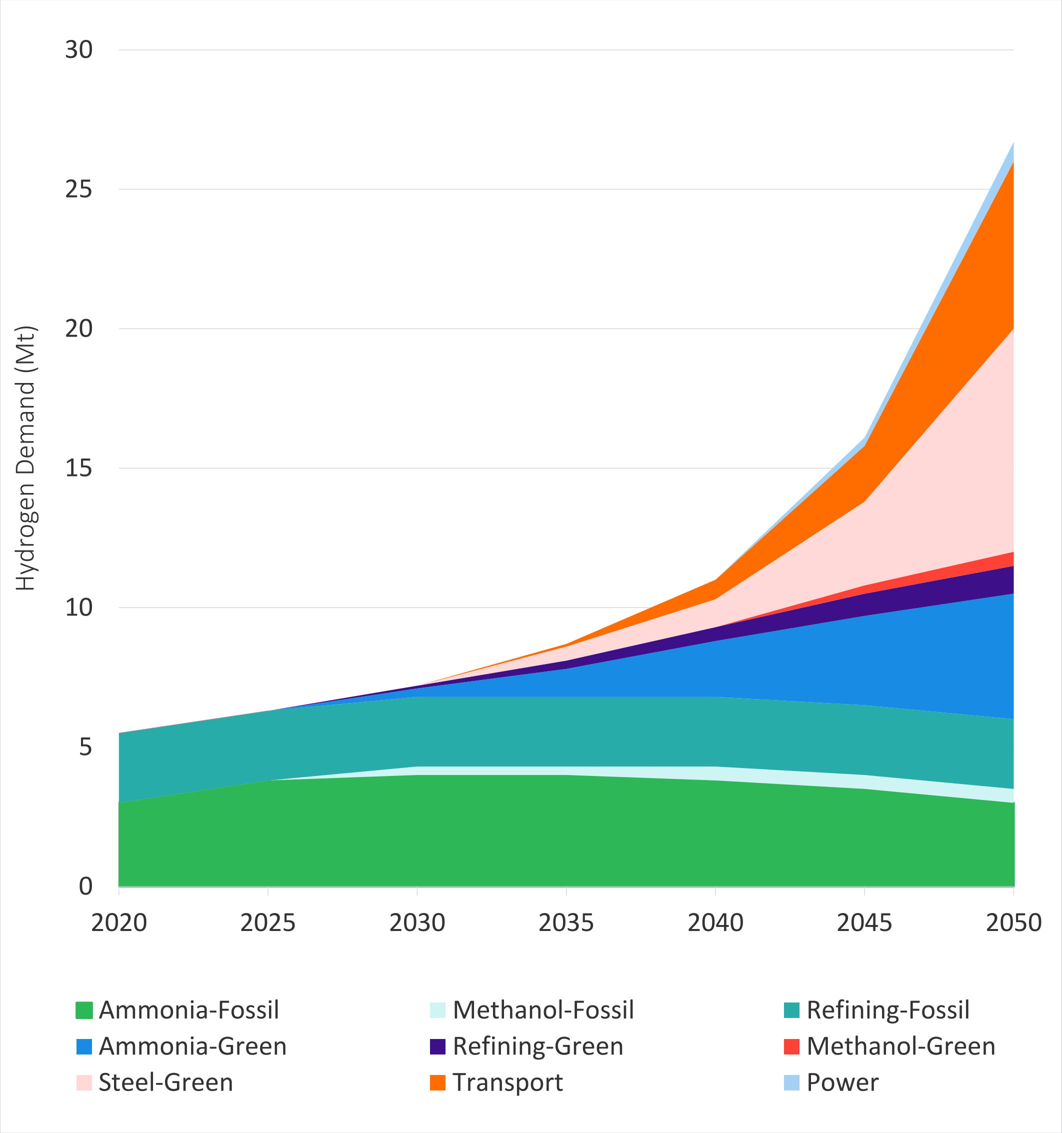
Source: Hall, W., Spencer, T., Renjith, G., and Dayal, S. 2020. The Potential Role of Hydrogen in India: A pathway for scaling-up low carbon hydrogen across the economy. TERI

Green hydrogen applications, challenges and emerging markets in India

Use case	Challenges and drivers	Emerging market description
Industrial feedstock	Price parity between green and grey hydrogen production will determine the speed and scale of transition; H2 DRI production will result in 0% CDRI increasing the cost of EAF steel production	▶ Ammonia production in fertilizer industry ▶ Desulphurization in crude oil refineries ▶ Hydrogen based Direct Reduced Iron (DRI) - Electric Arc Furnace (EAF) steelmaking ▶ Methanol production
Process heating	Direct electrification will be competitive wherever feasible; Significant investment in H2 transportation and distribution infrastructure required Hydrogen embrittlement is a major technical challenge for the durability of blending in existing pipelines Technical and regulatory barriers need to be addressed with the adoption of robust standards	▶ Blending in piped natural gas grids (~15%) ▶ Industrial boilers, furnaces and heating applications, domestic cooking and other commercial end uses
Transportation	Significant investment in H2 storage, handling and bunkering / refueling infrastructure required Competition with battery electric vehicles will determine speed and scale of transition	▶ Long-haul heavy-duty trucking ▶ Maritime shipping for freight transportation ▶ High speed passenger ferries, boats and cruising for tourism industry
Power generation and energy storage	Significant capital expenditure and low round-trip efficiency (~30-40%) lowers the cost-competitiveness storage applications Batteries are already competitive for short duration storage applications	▶ Long-duration (>20 hours) energy storage applications for high shares of renewable energy integration in power grids ▶ Power generation for peak demand supply

Source: EY Analysis

Industrial sectors will drive the demand for green hydrogen in the long term



Source: Hall, W., Spencer, T., Renjith, G., and Dayal, S. 2020. The Potential Role of Hydrogen in India: A pathway for scaling-up low carbon hydrogen across the economy. TERI

- The following industrial sectors are likely to adopt green hydrogen as feedstock and drive demand in the long term.
  - Ammonia production
  - Iron and steel production
  - Crude oil refining
  - Methanol production
- The demand for green hydrogen as an energy carrier for process heating applications will depend on the economics of appropriate blending concentrations in existing pipelines and creation of dedicated infrastructure in the long term. Any introduction of a hydrogen blend concentration in existing gas grids would require extensive study, testing, and modifications to pipeline integrity monitoring and maintenance practices. Additional cost incurred must be weighed against the benefit of providing a more sustainable and affordable energy carrier to end-users. The benefits of blending, extent of the natural gas pipeline network, impact on end-use systems, safety, material durability and integrity management, leakages and downstream extraction need to be studied thoroughly for before taking decisions.
- Transport sector demand for green hydrogen will be limited to long-haul heavy-duty trucking, maritime shipping and high-speed long-haul passenger ferries, boats and cruising applications. The competitiveness of hydrogen fuel-cell technologies with evolving battery powertrains will be a key determinant of this demand.
- Demand for power generation will be limited to specific long duration renewable energy storage applications

4

Green hydrogen supply chain, technologies and techno-economics

Overview of hydrogen value chain and technologies

Hydrogen supply chain

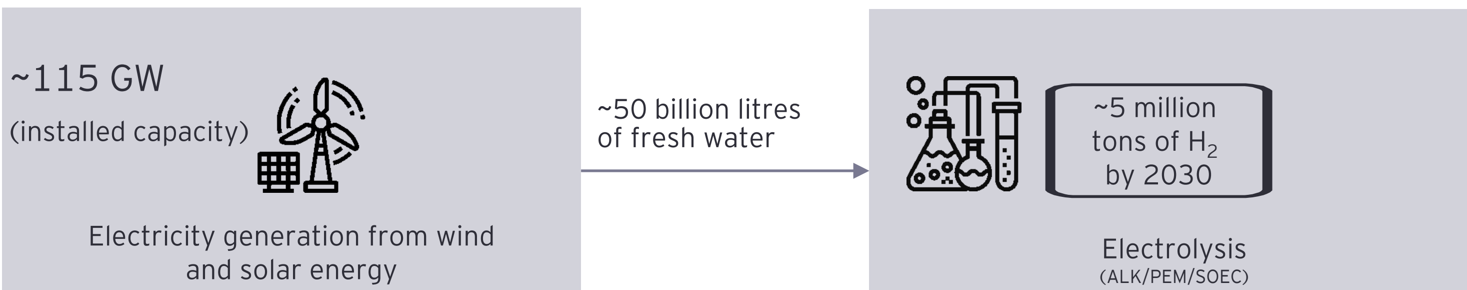
	Generation	Storage	Transportation and distribution	Retail	End use
Grey hydrogen	Steam methane reforming (SMR)	Liquefaction	Membrane transportation	Distribution logistic and private storage (secondary)	Industrial Feedstock (ammonia, methanol)
Blue hydrogen	SMR combined with carbon capture	Compression	Pipeline distribution (pure and blended)	Hydrogen filling stations (compressed and liquid)	Industrial energy supply (heat generation)
Green hydrogen	Electrolysis from renewable electricity	Methanation	Road and rail transportation		Transportation (private and public)
	Biomass gasification and reforming	Ammonia			Power generation and storage (fuel cells, mini-CHP)
	Biogenic / Waste treatment				

*Note: Only key elements of the value chain are shown
Source: EY Analysis

India will need ~115 GW of renewable power generation capacity and ~50 billion liters of fresh water for achieving the production target of ~5 million tons of green hydrogen by 2030

In August 2021, India announced the launch of 'National Hydrogen Mission' to scale up green hydrogen production and align India's energy transition efforts with global best practices in technology, policy and regulation. The Mission aims to support the government's efforts in meeting climate targets and making India a green hydrogen hub. The target for green hydrogen production is ~5 million tonnes by 2030 under this mission. In Feb 2022, the Ministry of Power (MoP), the Government of India notified the 'Green Hydrogen Policy' as the first leg of policy instruments to further bolster efforts in this direction.

Most efficient alkaline electrolyzers today consume ~50 kWh of electricity and 10 liters of fresh water to produce 1 kg of hydrogen. Therefore, if all the ~5 million tons of green hydrogen production target by 2030 were to be achieved via alkaline electrolysis, India would require ~50 billion litres of fresh water and 250 billion kWh of electricity supply from renewable sources of energy, primarily wind and solar PV. This translates to ~115 GW of installed renewable power generation capacity @ 25% CUF (for hybrid round-the -clock supply). To get a sense of this scale, the current all India installed capacity of renewable power generation is ~106 GW as of Feb 2022 (Source: CEA, Installed capacity report, 2022, https://cea.nic.in/wp-content/uploads/installed/2022/02/installed_capacity.pdf).



Source: EY Analysis

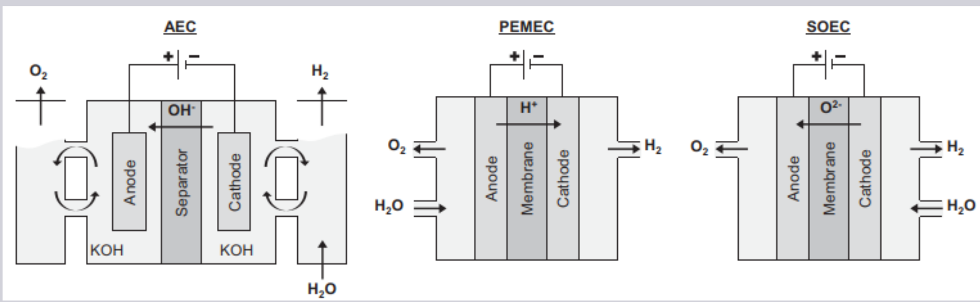
India's green hydrogen market is currently in the nascent stages of development. The supply chain for green hydrogen needs sufficient economies of scale and innovation to achieve competitiveness through 2030. More importantly, robust and predictable demand for green hydrogen through 2030 is fundamental for accelerating investments to expand the supply chain. By leveraging low-cost domestic renewable electricity produced at scale, India could become a regional hub for exporting green hydrogen at competitive prices and command a reasonable share in the global hydrogen demand of 200 million tonnes (Source: IEA, Global Hydrogen Review, 2021) by 2030.

The supply chain of GH2 is complex like any other fossil fuel commodity and includes production from renewable energy sources, storage, transportation, distribution, and handling. Beyond this, the physical properties of hydrogen warrants additional infrastructure for safe handling and operations. Many potential end-use applications may need technology and infrastructure to support energy transformations such as H2 to electricity and vice versa, H2 to ammonia, H2 to methanol etc. GH2 production, storage, and supply needs to meet the purity, pressure, and volume requirements of specific industries and applications.

Electrolytic production of green hydrogen: India will need ~50 GW of electrolyzer capacity (installed) to achieve 5 million tons of production target for green hydrogen by 2030

Hydrogen supply chain

Generation → Storage → Transportation and distribution → Retail → End use



Green hydrogen production methods

- Alkaline electrolysis (AEC)
- Proton exchange membrane (PEMEC)
- Solid oxide electrolysis cell (SOEC)
- Biomass gasification and reforming

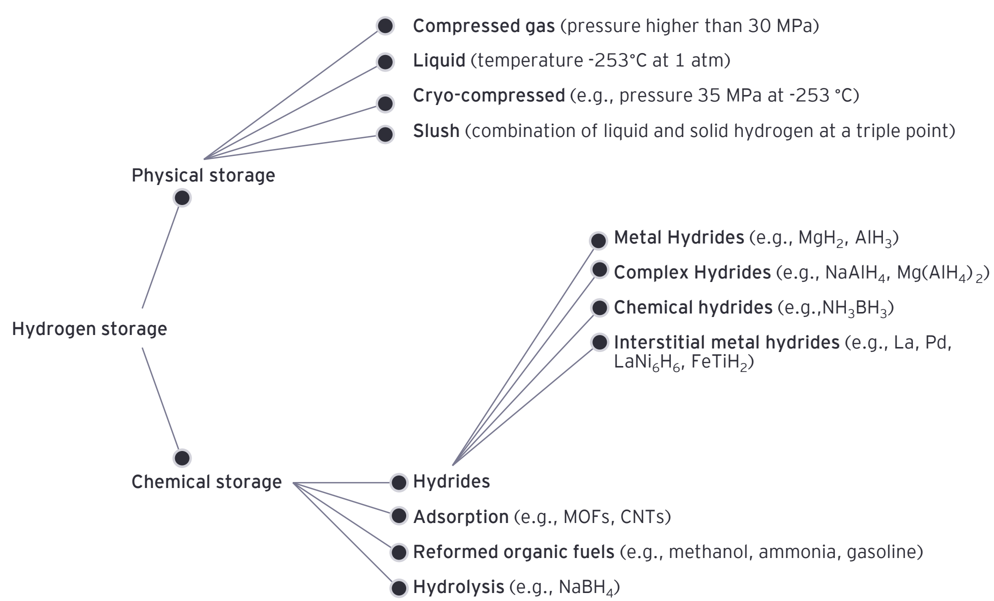
Present electrolyzer capacity	~5 MW(largest by NTPC)
Electrolyzer capacity outlook in India by 2030	~50 GW for producing ~5 Million tons of green hydrogen

Characteristic	AEC	PEMEC	SOEC
Electrolyte	Aqueous potassium hydroxide	Polymer membrane	Yttria stabilised Zirconia
Cathode	Ni, Ni-Mo alloys	Pt, Pt-Pd	Ni/YSZ
Anode	Ni, Ni-Co alloys	RuO2, IrO2	LSM/YSZ
Temperature	60-80 °C	50-80 °C	650-1000 °C
Operating pressure	<30 bar	<200 bar	<25 bar
System energy	4.5-6.6 kWh/m3	4.2-6.6 kWh/m3	>4.7
Gas purity	>99.5%	>99.9%	>99.9%
System response	Seconds	Milli seconds	Seconds
Stack lifetime	60-90k hours	20-60k hours	>10k hours
Maturity	Mature	Commercial	Demo
Capital cost INR/kWe	0.75 - 1.5 lakhs	1 - 2 lakhs	>2 lakhs

Source: O. Schmidt, et al., Future cost and performance of water electrolysis, Hydrogen Energy 2017

Geological storage of hydrogen could emerge as the scalable and affordable alternative in the long term

Hydrogen supply chain



Hydrogen Storage Insights

- Hydrogen is usually compressed to pressures ranging between 100 to 825 bars for large-scale storage, transport and end-use applications.
- In physical storage systems, advanced materials for pressure vessels are required, such as carbon fiber and glass fiber-reinforced plastics to achieve higher density. Hydrogen embrittlement is a technical challenge for metallic components used in physical storage.
- Geological storage of hydrogen could likely emerge as scalable and affordable alternative in the long term. Salt and rock caverns, depleted oil and gas reservoirs, aquifers are the possible options for geological storage.
- Methane and ammonia synthesized from green hydrogen can be effective chemical storage techniques for specific applications. However, the Haber-Bosch process widely adopted for making ammonia from hydrogen and the Sabatier's reaction to methanation are both energy and GHG intensive, require high temperatures in the presence of catalysts (e.g., Nickel).

Source: Aziz, M. Liquid Hydrogen: A Review on Liquefaction, Storage, Transportation, and Safety. Energies 2021

Hydrogen embrittlement is the biggest technical challenge for storage and transportation

Hydrogen supply chain

Generation → Storage → Transportation and distribution → Retail → End use

Hydrogen Transportation Ecosystem

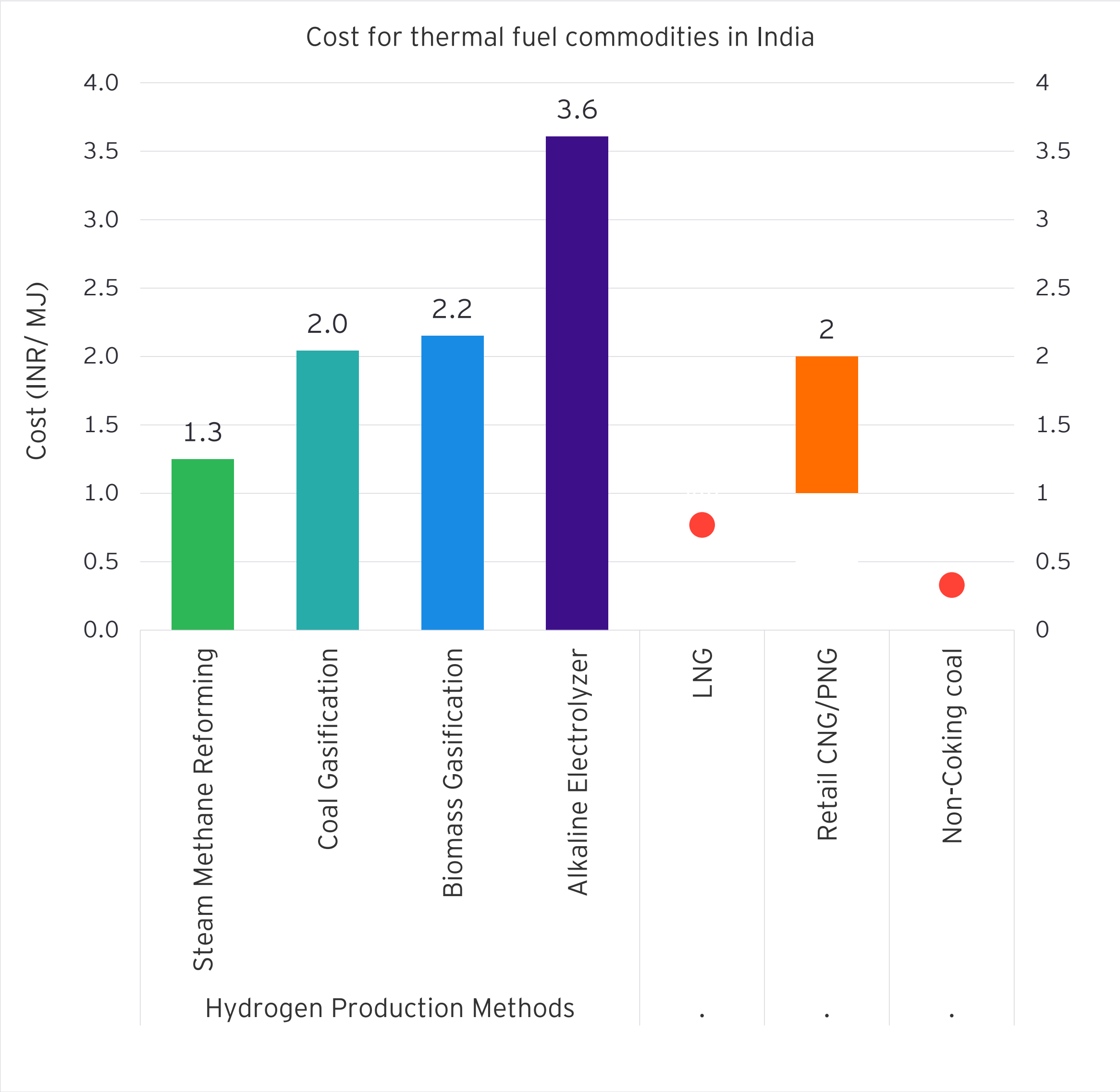
Modes of transport	Relevance	Challenges	Economics
Trucks, trailers and tankers (compressed gas tube trailers and liquid hydrogen trucks)	Suitable for lower volumes and short distances in compressed gas, liquid (cryogenic) and chemical forms	Pressurized tube trailers operate at pressures 200 - 500 bar; Cooling, refrigeration / liquefaction and regasification is energy intensive and vulnerable for losses (25-35%)	~ 0.5 USD/kg of gaseous H2 for every 50 kms distance
Pipelines (Retrofitting existing pipelines Or creating dedicated infrastructure)	Suitable for large volumes and long distances in compressed gaseous form	Hydrogen embrittlement is a challenge for blending hydrogen (up to 15%) in existing natural gas pipelines; High capital costs for creating dedicated hydrogen pipeline infrastructure	~ 0.3 - 1 USD / kg H2 for every 500 kms distance; Retrofitting existing pipelines is cheaper subject to overcoming hydrogen embrittlement challenges
Shipping	Suitable for large volumes and long distances in liquid cryogenic form or other derivatives such as ammonia	Cooling, refrigeration / liquefaction and regasification is energy intensive and vulnerable for losses (25-35%)	> 2 USD / kg of liquid H2 for every 3000 kms distance; ~ 2 USD / kg ammonia for every 3000 km distance;

Hydrogen Storage Insights

- In the present scenario, most of the hydrogen is produced and consumed at the same location.
- Hydrogen is generally transported by trucks/trailers/tankers in pressurized gas containers and in cryogenic liquid tanks to some extent. Transporting hydrogen in compressed gas tube trailers will be the cost-effective alternative for short distances.
- Shipping is likely to remain a high-cost option even in the long term due to costs of liquefaction, refrigeration, and regasification
- There is ~5000 km of dedicated hydrogen pipeline network around the world today. This network is operated by large industrial producers to deliver hydrogen to bulk chemicals and refinery facilities.
- Hydrogen embrittlement is the biggest technical challenge for retrofitting existing pipelines for blending applications

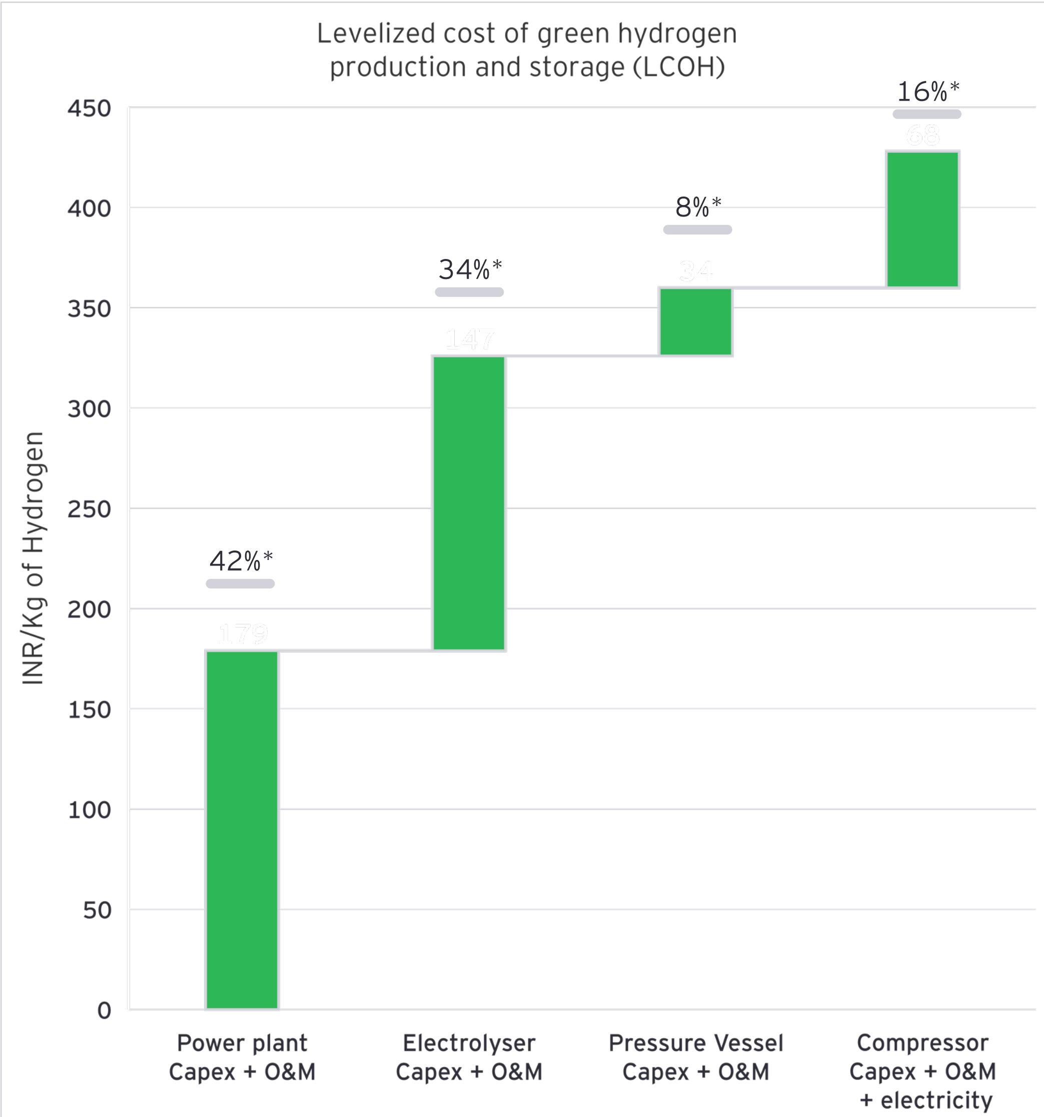
Source: EY Analysis; CEEW, 2020; https://cef.ceew.in/masterclass/analysis/catalysing-green-hydrogen-growth-in-india; TERI 2020

Tipping points for cost competitiveness of green hydrogen



Source: DST 2020; IEA 2021; Indraprastha gas limited; National coal index (December 2021)
Note: Cost of hydrogen is exclusive of storage and transportation

- Grey H2 production costs (steam methane reforming) vary from 75-150 INR/kg depending on the price of natural gas.
- The domestic retail CNG / PNG prices vary from approx. 40-90 INR/kg, which translates to approx. 1-2 INR/MJ of energy considering the lower heating value of this fossil fuel commodity.
- Achieving parity with these commodity prices will determine the speed and scale of GH2 adoption. This requires boosting demand for GH2 in a manner that helps achieve economies of scale across the supply chain, indigenization of supply chain and technology improvement to enhance efficiencies of GH2 production and transformations with earth abundant raw materials. R&D investments and programs are crucial for technology indigenization across the supply chain.
- Government intervention and pilot projects must also address and demonstrate the cost effectiveness of GH2 storage and delivery systems.
- The cost of utility scale intermittent renewable power generation has been declining over the last decade, settling between INR 2-3.0 / kWh in the present scenario. This cost does NOT include transmission, wheeling, banking and other charges specific to local state regulations. Moreover, this declining trend is expected to reverse in the immediate future driven by a global spike in commodity prices, import duties and domestic policy commitments to boost adoption of locally manufactured PV cells, modules, etc.



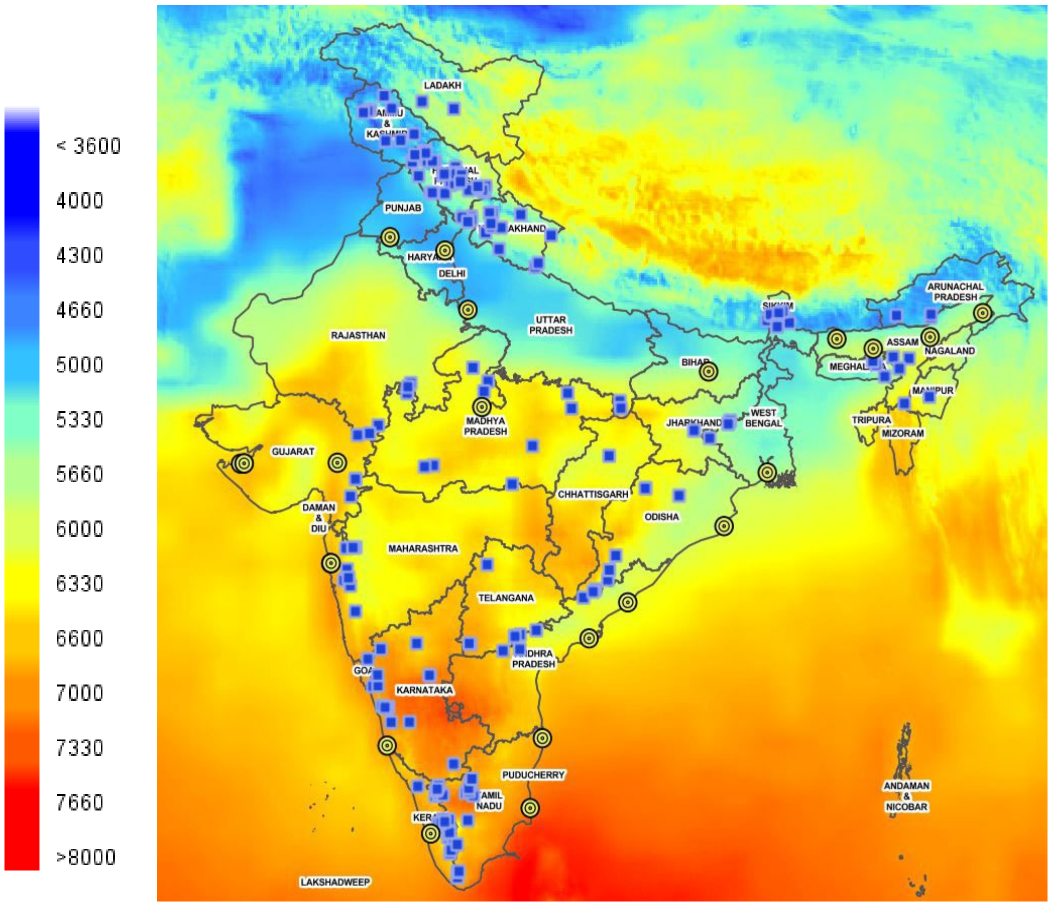
Source: EY analysis for a small scale 1MW equivalent electrolyzer system
*Indicate the % share of overall cost of production and storage

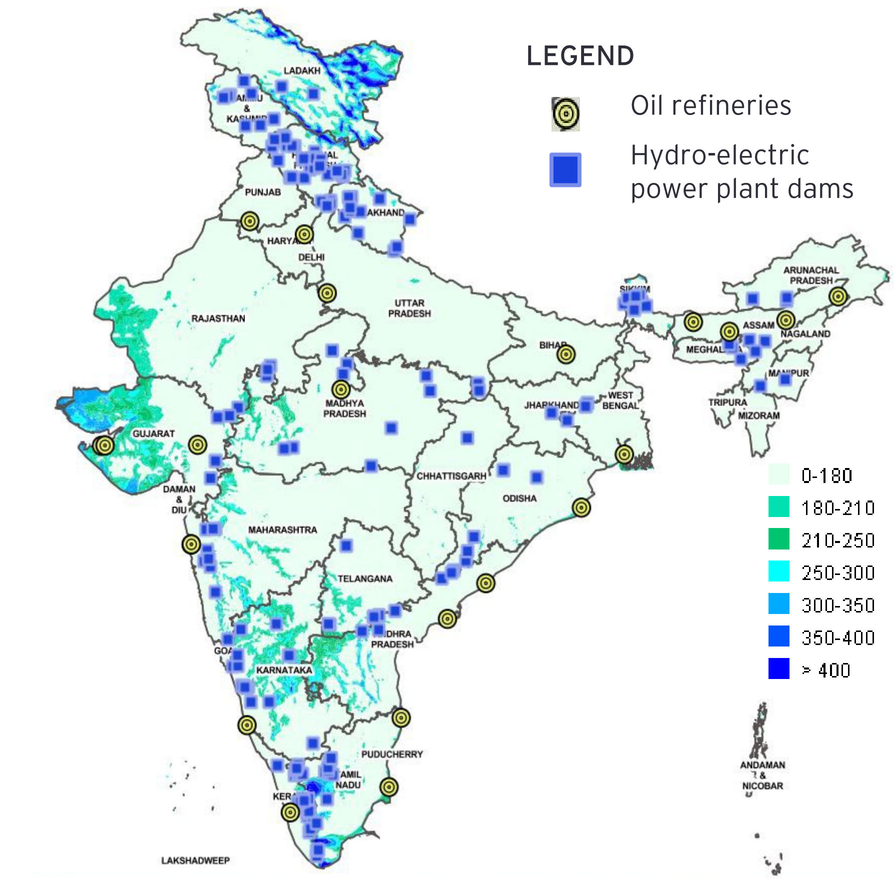
There are multiple factors that drive the techno-economics of the green hydrogen supply chain.

- **Renewable energy resource availability and economics of round-the-clock power supply:** This includes geographical location and proximity of RE resources, CAPEX and OPEX of round the clock power supply designed for optimum CUF (>70%) w.r.t electrolyzer stack load, interstate / intra-state transmission/wheeling charges, banking and other grid support charges if any. This component typically accounts for 40-50% in the overall LCOH. Round-the -clock systems are typically oversized (2-3 times demand) and therefore results in surplus / excess generation in the range of 10-20%. Mechanisms to buy back or sell curtailed power in open markets can help reduce costs.
- **Electrolyzer system efficiency, stack durability and economics:** This includes CAPEX and OPEX of electrolyzer stack, water supply, treatment and balance of system. Energy consumption per unit of H2 production (efficiency) at different load factors, stack durability and response for intermittent supply also affect the economics of production operations. This component typically accounts for 30-40% in the overall LCOH.
- **Energy efficiency and economics of compression and storage:** This includes CAPEX and OPEX for compression system, energy efficiency and consumption, pressure vessel, type of pressure vessel, end-use pressure requirement, days of autonomy for sizing pressure vessel, etc. This component typically accounts for up to 25% of overall LCOH.
- **Demand profile of end-use application:** This includes the pressure requirement for hydrogen end-use application, hourly and seasonal variations in demand profile and inherent flexibility of end-use application to minimize curtailment.
- **Geospatial characteristics of renewable power generation, GH2 production, and end-use:** This determines the need for additional storage and transportation / distribution infrastructure.

Cluster-based models of GH2 production close to demand centers can help optimize supply chain costs

Geospatial maps of green hydrogen demand centers (e.g., crude oil refineries) with annual average solar insolation (MJ/m2) and wind power potential (W/m2)





5

Evolving the ecosystem of green hydrogen policy and shovel-ready project pipeline

Green hydrogen policy enablers:

Policy enabler					
Panchamrit of India's climate actions announced during COP26 Glasgow	500 GW of non-fossil energy capacity by 2030	50% of electrical energy capacity from renewable energy sources by 2030	Reduce total projected carbon emission by one billion tonnes by 2030	Reduce 45% carbon intensity of economy by 2030	Achieve net-zero emissions by 2070
Definition of 'Green hydrogen / ammonia'	Produced by way of electrolysis of water using renewable energy including production from biomass				
Waiver of inter-state transmission (ISTS) charges	Granted for a period of 25 years for projects commissioned before 30 June 2025				
Grant of Open Access	Open access for sourcing renewable energy will be granted within 15 days of receipt of application complete in all respects	Open access charges as per existing rules			
Banking of surplus renewable energy	Banking permitted for a period of 30 days for renewable energy used in the production of green hydrogen/ammonia	Banking charges fixed by state commissions not more than cost differential between average tariff of procurement and market clearing price in DAM			
Grant of ISTS connectivity	Connectivity granted on priority under the Electricity (Transmission System Planning, Development and Recovery of Inter State Transmission Charges) Rules 2021				
Land acquisition for green hydrogen production	Allotment of land in renewable energy parks for green hydrogen/ammonia production				

Source: Ministry of Power, Government of India, 2022

Green hydrogen policy enablers (cont.):

Manufacturing zones	Manufacturing zones proposed to be set up for cluster-based development of green hydrogen supply chain
Bunkering and storage	Manufacturers of green hydrogen / ammonia allowed to set up bunkers near ports for storage and exports by shipping. Land to be provided for storage by port authorities at applicable charges.
RPO compliance	Renewable energy consumed for production of green hydrogen / ammonia shall count towards RPO compliance of the end-user entity. Renewable energy consumed beyond obligation of end-user shall be counted towards RPO compliance of DISCOM in whose area the project is located.
Single window portal	MNRE will establish a single window portal for all statutory clearances, permissions required for manufacture, transportation, storage and distribution of green hydrogen / ammonia preferably within 30 days of data of application
Demand aggregation	MNRE may aggregate demand from different sectors and have consolidated bids for procurement of green hydrogen / ammonia through designated implementing agencies

Source: Ministry of Power, Government of India, 2022

Green Hydrogen Policy notified in Feb 2022 is a timely intervention for the industry betting on the promise of establishing competitive supply chains

India's 'Green Hydrogen Policy' will kick start energy transition efforts, particularly in the emission intensive industrial sectors.

One of the key highlights of this policy, the waiver of inter-state transmission charges for green hydrogen production plants commissioned up to June 2025 sourcing electricity produced from renewable energy sources was already existing from the order dated 23 November 2021. However, this order had provisioned waiver for first 8 years of operations only. The 'Green Hydrogen Policy' has extended the waiver for 25 years of plant operations, which is a welcome step in ensuring long-term cost reduction of green hydrogen production for the industry. One must note that green hydrogen production units must be connected with ISTS network at the point of GH2 production to fully realize the benefits of this waiver. Otherwise, respective state transmission charges may still apply. **Therefore, states which extend similar waivers for intra-state transmission could become preferred locations for green hydrogen production units.**

The policy also provides 30 days banking facility and limits the applicable banking charges for the renewable energy used in the production of green hydrogen. This is also a significant step, especially when the restrictions on banking provisions for renewable energy are increasing in many states. Banking is permissible only for intra-state transactions and therefore, the industry will benefit from this provision only when the state electricity regulatory commissions amend their banking regulations accordingly. Renewable energy systems designed for green hydrogen production are typically oversized to account for variability. Banking allows green hydrogen producers to supply excess renewable electricity to the grid, with the option of drawing back the same amount of power within a certain period and against the banking charges specified by State Electricity Regulatory Commission. Until recently, many states offered annual banking provisions but have now moved to a monthly banking period, and in some cases have completely withdrawn banking facilities for renewable energy projects. Therefore, the industry will watch closely on how the states which have already restricted banking provisions will adopt the 30 days banking facility, and the formula specified for limiting banking charges specified in the green hydrogen policy.

Similarly, the effectiveness of few other provisions in the green hydrogen policy such as granting open access for renewable energy sourced within 15 days and land allocation in renewable energy parks will depend on the efforts from state governments towards proper adoption and enforcement.

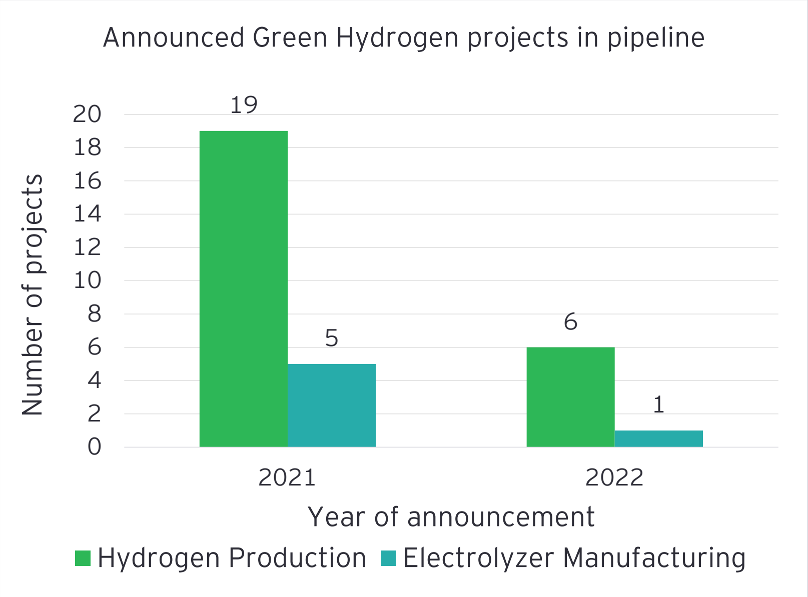
By leveraging low-cost renewable electricity produced at scale, India could become a regional hub for exporting green hydrogen at competitive prices and command a reasonable share in the global hydrogen demand of 200 million tonnes (Source: IEA) by 2030. In this context, India's green hydrogen policy must further evolve to boost demand for green hydrogen, particularly in those markets where grey hydrogen is currently produced and used as feedstock or process gas. Green hydrogen blending with piped natural gas is another major market for boosting demand. The policy must focus on boosting R&D investment with public-private partnerships (PPP) and grand challenges to demonstrate efficient and cost effective GH2 electrolyzers, storage and delivery solutions using earth abundant electrocatalysts and materials. A concrete roadmap towards developing testing facilities and certification mechanisms relying on globally harmonized standards and regulations for Green hydrogen production, storage and delivery is needed. Viability gap funding could focus on projects where green hydrogen could act as alternate energy carrier for enabling low carbon steel, cement, trucking and maritime shipping. The policy must also endeavor towards creating world class talent in the value chain of green hydrogen by way of introducing dedicated academic programs/ degrees and establishment of national research institutes. This is important to kick start the indigenization of technology development and support the industry ambitions towards R&D, product development and services in the entire value chain.

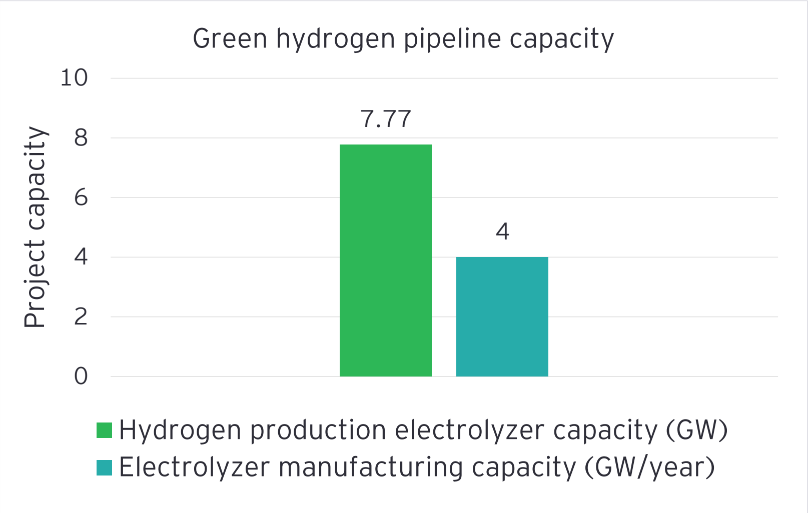
Shovel-ready project pipeline to scale up adoption of GH2

Many leading Indian public sector undertakings (PUS) and private corporations operating in the fossil fuel industry (e.g., oil and gas, thermal power generation) have announced pilot projects, including their long term ambitions and goals in the development of green hydrogen production, storage, transportation and end use ecosystem. In the public sector, IOCL has invited expressions of interest from global players for setting up green hydrogen production units at Mathura and Panipat Refineries with installed capacities of 5,000 Mt per annum and 2,000 Mt per annum respectively on Build Own Operate (BOO) basis. GAIL has launched a global tender to procure 10-megawatt electrolyzer capable of producing 4.5 tonnes of green hydrogen per day. The Solar Energy Corporation of India (SECI) has invited tenders to set up a green hydrogen pilot plant. Most importantly, a 10 per cent purchase obligation for green hydrogen in refineries and fertilizer plants is awaiting Cabinet approval. NTPC is currently exploring a pilot project for standalone hydrogen fuel cell based power-backup solution replacing the diesel power generator. The hydrogen will be produced with an in-house electrolyzer in its Noida and Vishakhapatnam premises. NTPC is also working on a hydrogen fueling station in Leh for green hydrogen mobility. The project shall have two electrolyzer with a daily production capacity of ~80 kg/day power with renewable energy of 6500kWh/day. A pressure vessel to store 100 kg of compressed fuel at 450-500 bar pressure. NTPC will be pushing the hydrogen mobility program with 5 hydrogen fueled buses in the region.

In the private sector space, Reliance Industries, as part of its commitment to invest USD 10 billion (INR 750 billion) in new energy businesses, announced plans to build a giga-factory to manufacture electrolyzers. Adani group has plans to invest $70 billion in this decade to become the world's largest renewable energy company and produce the cheapest hydrogen on the Earth. These measures and proposed projects would pave the way for a robust green hydrogen market growth in this decade.

EY has identified ~41 shovel-ready projects in the green hydrogen supply chain, out of which 31 are commercial projects and 10 are R&D projects funded by the Department of Science & Technology (GoI). The projects database comprises green hydrogen production, electrolyzer manufacturing, hydrogen retail and R&D projects. These projects are under permitting or announced stage from year 2021 till May 2022. In the year 2022, only 7 projects are announced as compared to ~24 commercial projects in the year 2021. Currently, not all the projects have announced the project capacity, however, project capacity is assessed from the announcements with declared capacity. The green hydrogen production pipeline project plans to install ~7.77 GW electrolyzer plants, while the cumulative electrolyzer manufacturing project capacity stands as ~4 GW/year.





Source: EY Analysis based on JMK Research

The following sections highlight key policy interventions to be adopted by states (sub-national actors) until the green hydrogen supply chain and adoption achieves sufficient economies of scale.

1. Reducing the cost of renewable power generation and supply for GH2 production

Round-the-clock renewable power generation accounts for 40-50% of the levelized cost of green hydrogen production and storage (LCOH). Sub-national policy frameworks should aim to minimize the cost of this critical supply chain component and significantly improve the ease of doing open access transactions. In this regard, the draft Electricity (promoting renewable energy through Green Energy Open Access) Rules, 2021 notified by Ministry of Power, Government of India in August 2021 is a step in the right direction. However, the responsibility of facilitating open access lies with the State Electricity Regulatory Commission, as per Section 42 and Section 86 of the Electricity Act, 2003. Therefore, the central rules and other state level policy interventions should ultimately manifest as amendments to existing open access regulations at state level for meaningful outcomes.

- **Waiver of Intra-state transmission charges for GH_2 production**

The national green hydrogen policy notified in Feb'22 has announced the waiver of inter-state transmission charges for a period of 25 years for green hydrogen production units commissioned before 30 June 2025. However, green hydrogen production units must be connected with ISTS network at the point of GH_2 production to fully realize the benefits of this waiver. Otherwise, respective intra-state transmission charges may still apply. In this regard, states that extend similar waivers for intra-state transmission charges will enable industry to gain competitive advantage in the production of green hydrogen. Such waivers can extend for limited periods or be limited for first 0.5 - 1 million tons of annual GH_2 production to help achieve economies of scale. Open access regulations could explore mechanisms to socialize the cost of this waiver to reduce fiscal burden.

- **Waivers, clarity and certainty of open access charges for GH2 production**
State governments should extend waivers for levy of open access charges (e.g. banking, cross subsidy, additional surcharge etc.) for the first 0.5 - 1 Million tons of GH_2 production to reduce cost and encourage GH_2 adoption. If not viable, open access charges should be kept at minimum with clarity and certainty of its validity period in the regulations.

- **Allow banking of surplus energy in the production of GH2**
Existing open access regulations should be amended for allowing banking of at least 10% annual generation for min. 30 days in line with national green hydrogen policy.

- **Fungibility of green hydrogen and renewable purchase obligations**
Open access regulations should specify mechanisms for monitoring, verification, certification and accounting to enable such fungibility of purchase obligations.

2. Improve ease of doing renewable energy open access (REOA) transactions

Rule#6 and 7 in draft Electricity (promoting renewable energy through Green Energy Open Access) Rules, 2021 focus on streamlining, centralizing and standardizing open access approval processes for renewable energy transactions. Given delays in processes and existing complex processes, such an approach is needed. A centralized registry is proposed to enable single window clearance for REOA applications. The applications are to be routed through the state nodal agency, which as per Rule 6 (2) would either be the SLDC for STOA and the CTU/STU for LT/MTOA. As per Rule 7 (2) complete applications are to be uploaded by the nodal agency and in order to prevent delays, applications are deemed approved after 15 days subject to technical requirements specified by the ERC. Further, as per Rule 7 (4) and (5) denial of open access should take place with a written order and the applicant has the right to be heard. Further appeal against orders by the nodal agencies is to be processed by the State Commission. Existing open access regulations should be amended suitably with above provisions.

3. GIS mapping and identification GH_2 clusters for development

States should undertake GIS mapping of renewable energy resource rich locations, GH_2 demand centers - for example crude oil refineries, fertilizer industries, iron and steel manufacturing units, ports, industrial SEZs and transport corridors (roadways, railways, inland waterways), land use – land cover (LULC) in the vicinity of GH_2 demand centers, water bodies for sourcing fresh water used in the production of electrolysis, etc. GIS mapping along with other geospatial characteristics, potential demand for GH_2 and other relevant attributes should be gathered to rank / prioritize various clusters with respect to their inherent capability of supporting a GH_2 economy, supply chain and consumption.

4. Establish state level mission for advancing GH_2 economy, formulate and adopt GH_2 production targets separately for industries, transportation and other sectors of the economy

States must establish GH_2 mission with a governance mechanism for interdepartmental coordination, monitoring and evaluation of policy interventions. The governance mechanism should include be represented by energy, industries, and transport departments at the minimum.

Robust and predictable demand for GH_2 is essential for accelerating investments in the supply chain. In this regard, states must adopt short, medium and long term GH_2 production targets separately for crude oil refineries, fertilizer industries, iron and steel manufacturing units, other industries, transportation sectors etc.

5. Single window portal for all statutory clearances, permissions required for manufacture, transportation, storage and distribution of green hydrogen / ammonia

States should establish sing window mechanisms in coordination with central institutions for facilitating all statutory clearances, permissions required for manufacture, transportation, storage and distribution of green hydrogen / ammonia within defined

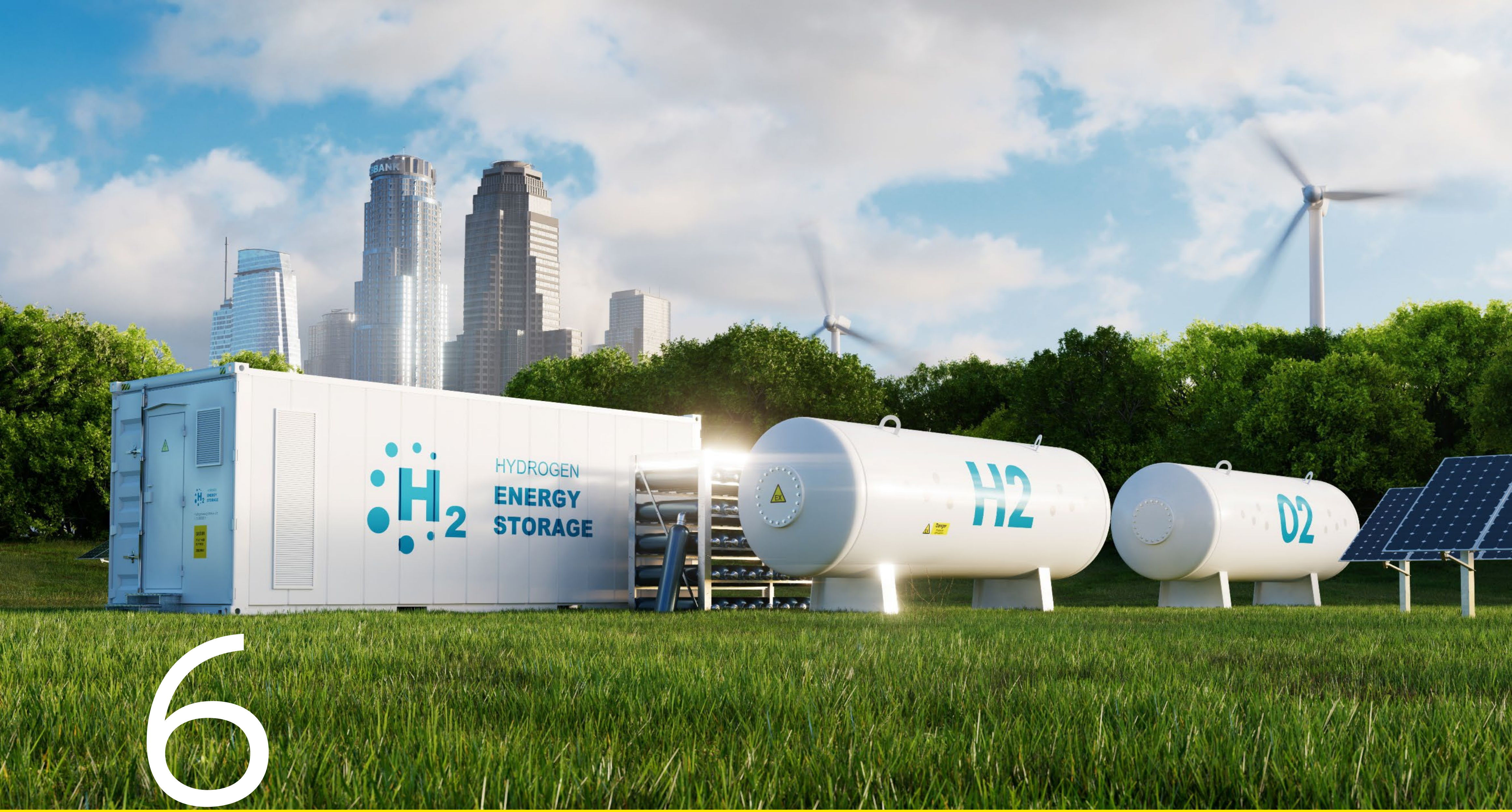
6. Production linked incentives and fiscal benefits for high efficiency and durable electrolyzed systems

Electrolyzed systems account for 30-40% of the levelized cost of green hydrogen production and storage (LCOH). Sub-national policy frameworks should aim to minimize the cost of this critical supply chain component. Therefore, states should offer additional incentives (apart from national PLI scheme if any) linked to production of high efficiency and durable electrolyzed systems. Electrolyzed systems used in the production of GH_2 should be brought in the lowest GST slab or waived off completely.

7. Enhance public funding support towards R&D programs calling for demonstration of projects that support competitiveness of GH_2 supply chain and end-use

State budgetary resources should be allocated towards creating centers of GH_2 excellence, robust coordination mechanisms to aggregate demand, cutting edge R&D calling for demonstration of following projects:

- Cost effective high efficiency durable electrolyzers made with earth abundant electrocatalyst materials
- Hydrogen based direct reduced iron (H2-DRI) and electric arc furnace steel projects
- Cost effective Hydrogen fuel cell powered transportation solutions capable of competing with conventional ICE engine and / Or battery electric systems
- Cost effective hydrogen storage materials and solutions made from earth abundant materials



6

International experience and lessons for India

Unique levers of hydrogen strategies adopted in developed countries

Hydrogen strategies

	Germany	Norway	Japan	Australia
Hydrogen plan and targets	▸ ~GBP8 billion allocated to hydrogen economy development; ~GBP6 billion to domestic hydrogen capabilities and ~GBP2 billion overseas investments ▸ Target of 5GW wind-based generation capacity by 2030 and an additional 5GW latest by 2040 ▸ 90-110TWh of hydrogen targeted by 2030	▸ ~GBP8 billion allocated to hydrogen economy development; ~GBP6 billion to domestic hydrogen capabilities and ~GBP2 billion overseas investments ▸ Target of 5GW wind-based generation capacity by 2030 and an additional 5GW latest by 2040 ▸ 90-110TWh of hydrogen targeted by 2030	▸ Y70 billion allocated to hydrogen in financial year ending March 2021 ▸ Target of 800,000 FCEVs by 2030 and 900 refuelling stations by 2030 ▸ Commercial hydrogen-based power generation by 2030 targeted ▸ 300,000 tonnes/year hydrogen production by 2030	▸ Target of 500-1,000MW or equivalent clean hydrogen production ▸ Aim to become one of the top three exporters of hydrogen globally
Unique features of hydrogen strategy	▸ Emphasis on green hydrogen from the start ▸ Dedicated governance for hydrogen ▸ Direct investment in developing overseas supply centres ▸ Repurposing the extensive gas network ▸ Preferential status for green hydrogen	▸ EV like privileges for FCEVs ▸ Leveraging strong maritime capabilities ▸ End-user engagement through information dissemination on refuelling and costs	▸ Strong focus on mobility applications ▸ Point-to-point supply chain development plans ▸ Focus on the residential fuel cell market ▸ Specific cost targets across the supply chain	▸ Strong focus on export capability development ▸ State-specific hydrogen strategies ▸ Dedicated fund for hydrogen

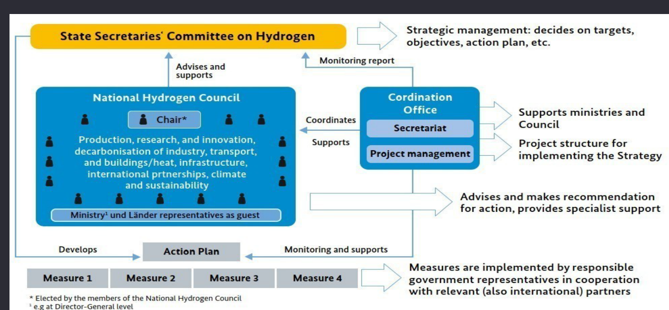
Germany's Hydrogen Strategy - Key differentiators (1/2)

Dedicated governance for hydrogen

A well-structured governance comprising three key entities is being established to manage the National Hydrogen Strategy.

- Germany is establishing a sound governance structure with clear responsibilities and mandates for involved entities
- A State Secretaries' Committee on Hydrogen, comprising the relevant ministries, will be formed to monitor and develop Germany's National Hydrogen Strategy
- A 26-member National Hydrogen Council will be appointed by the State Secretaries' Committee on Hydrogen, with representation from business, science, and civil society. The council will advise and support the State Secretaries' Committee through proposals and recommendations for action in implementing and enhancing the Hydrogen Strategy.
- A Hydrogen Coordination Office is also being established, which will assist the ministries in implementing the Hydrogen Strategy and the Hydrogen Council in coordinating and drafting recommendations for action.

Germany's governance structure for hydrogen



Emphasis on green hydrogen from the start

Green hydrogen is central to Germany's hydrogen strategy.

- In its National Hydrogen Strategy, the federal government of Germany lays significant focus on production and use of green hydrogen, compared to other forms (grey and blue)
- The Federal Government considers only hydrogen that has been produced using renewable energy (green hydrogen) to be sustainable in the long term. The role of blue hydrogen is largely transitional.
- A significantly large part of the government's research and technology development is focused on green hydrogen

Germany's Hydrogen Strategy - Key differentiators (2/2)

Developing international partners

Germany will develop overseas sourcing centers to fulfil domestic shortfall of green hydrogen.

- Estimated domestic production of green hydrogen will be inadequate to meet targeted requirements, with insufficient renewable power generation being a major challenge.
- In addition to imports, the German government will develop infrastructure in partner countries for sourcing green hydrogen. Investments are planned for a 100 MW green hydrogen facility in Morocco.
- ~GBP2 billion has been earmarked for developing global supply chains

Repurposing the extensive gas network

Existing gas pipelines will act as the foundations for a nation-wide hydrogen grid.

- A blueprint for the world's largest hydrogen grid, covering about 5,900 kilometers, has been announced. The first phase of 1,200 kilometers will be ready by 2030.
- The existing gas pipeline network will form a large part of the hydrogen grid. Only 100 kilometers of the first phase will be built, while the rest will be converted gas pipelines.
- At a cost of ~GBP585 million, the grid will connect the green hydrogen producing regions in the north to the demand centers in the south

Preferential status for green hydrogen

Preferential status has been accorded to green hydrogen transmission and distribution.

- Green hydrogen falls within the definition of biogas and will enjoy preferential network connection, network access and balancing
- Under Germany's Network Access Regulation, the injection of biogas (and hence hydrogen produced from electrolysis) into the gas transmission grid and distribution network is free of charge

Australia's Hydrogen Strategy - Key differentiators

EV privileges for FCEVs

Replication of the success of EVs is being attempted through concessions for FCEVs and other means.

- Almost all financial concessions and other rebates available to EVs in Norway are also being provided for FCEVs by the Norwegian government
- FCEVs (until 2025 or 50,000 vehicles) are exempt from vehicle registration tax and VAT until 2023. They are also exempt from road traffic insurance tax and registration transfer fee.
- Toll fee has been limited to not more than half of normal rates for FCEVs. A proposal to limit the parking charges is also underway.

Leveraging maritime capabilities

Norway's well-developed maritime sector has been identified to adopt and drive the hydrogen market.

- Norway's maritime sector will play an integral role in the country's drive towards hydrogen.
- Several research and pilot projects are under process to shift domestic maritime operations to hydrogen. A hydrogen-powered ferry will start operating this year onwards.
- Norway also has large-scale fuel transport facilities along its coastline. As part of its hydrogen strategy, LNG bunkering, storage and processing competencies will be used for hydrogen trade in the future.

Engaging end-users

End-users are being enabled to adopt hydrogen by providing them necessary information.

- Recognizing that market information available to users will drive hydrogen adoption, measures to provide information about available refueling and charging stations for alternative fuels are being developed. A list of infrastructure for alternative fuels for road transport and maritime will be available to the public.
- Comparable price data will also be accessible to the public in the future

Australia's Hydrogen Strategy – Key differentiators

Strong export focus

Australia plans to emulate its LNG export successes with hydrogen.

- The Australian hydrogen strategy places significant focus on developing export capabilities aimed at the Japanese and South Korean markets. It is targeting to become one of the top hydrogen exporters globally by 2030.
- The government of Australia has granted 'major project status' to the Asian Renewable Energy Hub, which will produce green hydrogen (using a 14MW electrolyzer capacity) for exports to Asia
- Australia has partnered with Japan for establishing a fully integrated hydrogen supply chain (PROJECT X), starting with production in Australia's Victoria and transportation to Kobe, Japan. The world's first liquid hydrogen carrier has been deployed as part of the supply chain.

Regional strategies for faster growth

All Australian states are pursuing their hydrogen strategies.

- Sub-national hydrogen strategies and action plans have been framed by states such as Queensland, South and Western Australia, and Tasmania
- These states are bringing forth their specific advantages in the hydrogen value chain and are pursuing opportunities in both the domestic and international markets.
- For instance, the state of South Australia that derives around 50% of its energy needs from renewable sources is inviting investment in green hydrogen production for exports.
- The Victorian state government is partnering with Japanese government for the PROJECT X that will be used for supplying hydrogen to Japan

A hydrogen fund

A dedicated fund exists for hydrogen projects.

- Australia has established the ~GBP167 million Advancing Hydrogen Fund, which is one of the largest national funds globally dedicated to hydrogen
- The fund will be provide concessional finance for projects that boost Australia's hydrogen production, develop export and domestic supply chains, establish hubs and build domestic demand
- In addition, the government has provided another ~GBP39 million to seven projects under the 'Renewable Hydrogen Deployment Funding Round'

Japan's Hydrogen Strategy – Key differentiators

Strong focus on mobility applications

Japan has set aggressive targets for FCEVs to further consolidate its leadership position globally.

- Japan is aiming for 200,000 FCEV units by 2025 and 800,000 units by 2030. Technology developments, public-private coordination and regulatory frameworks have been planned to make FCEVs affordable and competitive.
  - Through these initiatives, the government plans to bring down the cost of FCEVs to the level of hybrid electric vehicles (HEVs) by 2025
  - In addition, FCEVs for personal use are subsidized and eligible for tax breaks
- 320 hydrogen refueling stations will also be set up by 2025. Capex and opex reduction of filling stations through technology development and efficiency enhancement is being pursued.
  - At present, construction of hydrogen refueling stations are subsidized
  - To reduce the construction and operating costs of hydrogen filling stations, revisions have been made to several items in the Regulatory Reform Implementation Plan
  - Specific cost targets for components of a filling station have been set for 2025 by the government

Point-to-point supply chains development plans

Japan is creating hydrogen supply chains across parts of the globe.

- Japan has stated an intent to import substantial quantities of hydrogen from abroad to supplement domestic production
- Pilot projects are being run on international supply chain developments with other countries
- Recently, Saudi Arabia has transported blue hydrogen in the form of ammonia to Japan
- A project (mentioned under Australia) to extract hydrogen from brown coal in Australia, liquefying it and transporting that to Japan is underway
- In another project with Brunei, hydrogen is being extracted using the organic hydride method from unused gas for transport to Japan

7 Annexures

ANNEXURE II: Green Hydrogen Projects under Pipeline

Green Hydrogen production projects				
Project Location	Date of announcement	Project Promoter (Public / Private)	Type of Project	Hydrogen production or Electrolyzer capacity
PAN India	Mar-21	Private	Partnership for Green Hydrogen Production	
Tamil Nadu	Mar-21	Private	Partnership for Green Hydrogen Production	
Uttar Pradesh	Jun-21	Public	Green Hydrogen Production	500 kW - 1000 kW
PAN India	Jul-21	Private	Partnership for Green Hydrogen Production	
Andhra Pradesh	Jul-21	Public	Green Hydrogen Production	50kW, 0.13 TPD
Ladakh	Jul-21	Public	Green Hydrogen Production	1.25 MW solar plant for green electricity generation source
PAN India	Aug-21	Public	Pilot Green Hydrogen Plant	
Karnataka	Aug-21	Private	Electrolyzer Manufacturing	Manufacturing capacity: 500 MW/year; can be scaled to 2GW/year
Ladakh	Aug-21	Public	Green Hydrogen Production	25 kW
Gujarat	Sep-21	Private	Electrolyzer Manufacturing	2.5 GW Electrolyzer Manufacturing plant
PAN India	Sep-21	Private	Partnership for Green Hydrogen Production	
PAN India	Oct-21	Private	Green Hydrogen Production	
Madhya Pradesh	Oct-21	Public	Tender for Green Hydrogen Production	4.3 Ton per day (TPD) Hydrogen production
Gujarat	Oct-21	Private	Green Hydrogen Production	2 MW Solar plant to be used for electricity production for electrolyzer
Madhya Pradesh	Oct-21	Public	Green Hydrogen Production	5 MW PEM Electrolyzer project- 2TPD Hydrogen production plug power make
	Oct-21	Private	Partnership for Electrolyzer Manufacturing	
PAN India	Nov-21	Public	Tender for Green Hydrogen Production	100 MW in the first phase + a 25 kW self-developed Fuel cell pilot project
Madhya Pradesh	Nov-21	Public	Tender for Green Hydrogen Production	20 MW electrolyzer
PAN India	Nov-21	Public	Tender for Green Hydrogen Production	200MW - 2GW

ANNEXURE II: Green Hydrogen Projects under Pipeline

Green Hydrogen production projects				
Project Location	Date of announcement	Project Promoter (Public / Private)	Type of Project	Hydrogen production or Electrolyzer capacity
Uttar Pradesh and Haryana	Nov-21	Public	Tender for Green Hydrogen Production	40 MW/5000MT per annum (Uttar Pradesh) and 15 MW/2000 MT per annum (Haryana)
Madhya Pradesh	Nov-21	Private	Green Hydrogen Production	50 kiloton per annum
PAN India	Dec-21	Private	Partnership for Green Hydrogen Production	
PAN India	Dec-21	Public	Partnership for Green Hydrogen Production	
PAN India	Dec-21	Private	Partnership for Green Hydrogen Production	>2 GW
PAN India	Dec-21	Public	Partnership for Green Hydrogen Production	
Maharashtra	Jan-22	Private	Electrolyzer Manufacturing	1 GW
PAN India, Europe and UK	Jan-22	Private	Partnership for Green Hydrogen Production	1 GW
PAN India	Feb-22	Private	Partnership for Green Hydrogen Production	
PAN India	Apr-22	PPP	Partnership for Green Hydrogen Production	

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About SED Fund

The SED Fund was set up in 2018 to deliver an ecosystem of actions mapped to nine of the United Nations' Sustainable Development Goals by raising ambitions through philanthropic support. The breath of the SDGs to which our work is linked highlights the systemic nature of the approach needed to support economic development according to our vision of sustainability, equity, and diversity.

The SED Fund catalyses resources and leadership for an equitable energy transition and climate action, by raising the ambitions of civil society through philanthropic support. We use a venture philanthropy model that provides seed funding to early-stage organisations or programmes and continues to support them in their growth and scale-up journey. The SED team uses its extensive networks to identify bold ideas with unique models and enables them to be effective towards climate action. We provide timely, reliable, and relevant data, sharing learning on the issues and solutions, working towards effective implementation at a local, national, regional, and sectoral level and funding work aligned with our mission. We apply a strategic focus, and an independent, analytical, and fact-based approach in co-developing strategy with partners and stakeholders.

Since many of the grantees are new organisations, the SED team directly invests time and effort in mentoring and capacity building. Organisation development support is also provided in areas such as strategy, fundraising, systems, and processes.

We believe an innovative and multi-partner approach, operating at the required scale and pace is imperative to address the scale of the challenge. We also seek to remain nimble and adapt in real time to the context, needs and opportunities that arise.

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