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Hydrogen as a Lever for Decarbonisation

Ashim Sharma

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Nomura Research Institute (NRI) Consulting & Solutions India Pvt. Ltd.

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1. Global Hydrogen Landscape
2. Hydrogen as a Lever for Decarbonisation (India)
3. Looking at the Value Chain for Unlocking Potential
4. Summary

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1. Global Hydrogen Landscape

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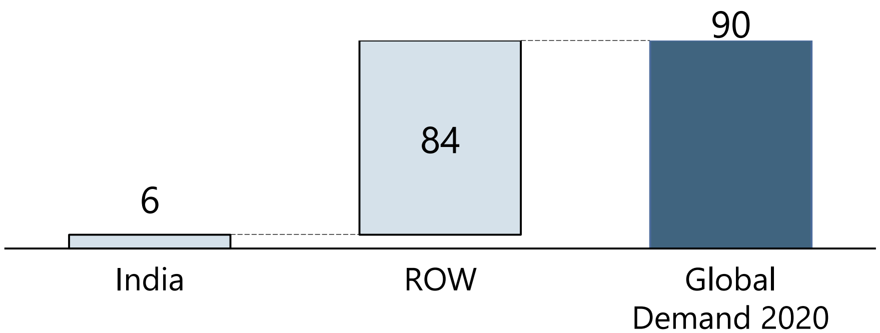
Global hydrogen demand stood at ~90Mt in 2020, majority is used for industrial applications, which contributed to ~900 Mt of direct CO_2 emissions in 2020

Global Hydrogen Demand



- India constituted **~7% of global hydrogen demand** in 2020

Types of Hydrogen	Source	Manufacturing process	CO_2 emissions
Black / Brown H_2	**Coal / Lignite**	Gasification (adding steam and oxygen)	Extremely high
Grey Hydrogen	**Fossil gas**	Steam Methane Reformation (SMR)	Very high
Blue Hydrogen	**Fossil gas**	SMR with carbon capture, utilisation & storage (CCUS(	High
Green Hydrogen	**Water**	Renewable powered electrolysis	Negligible (Cleanest form)

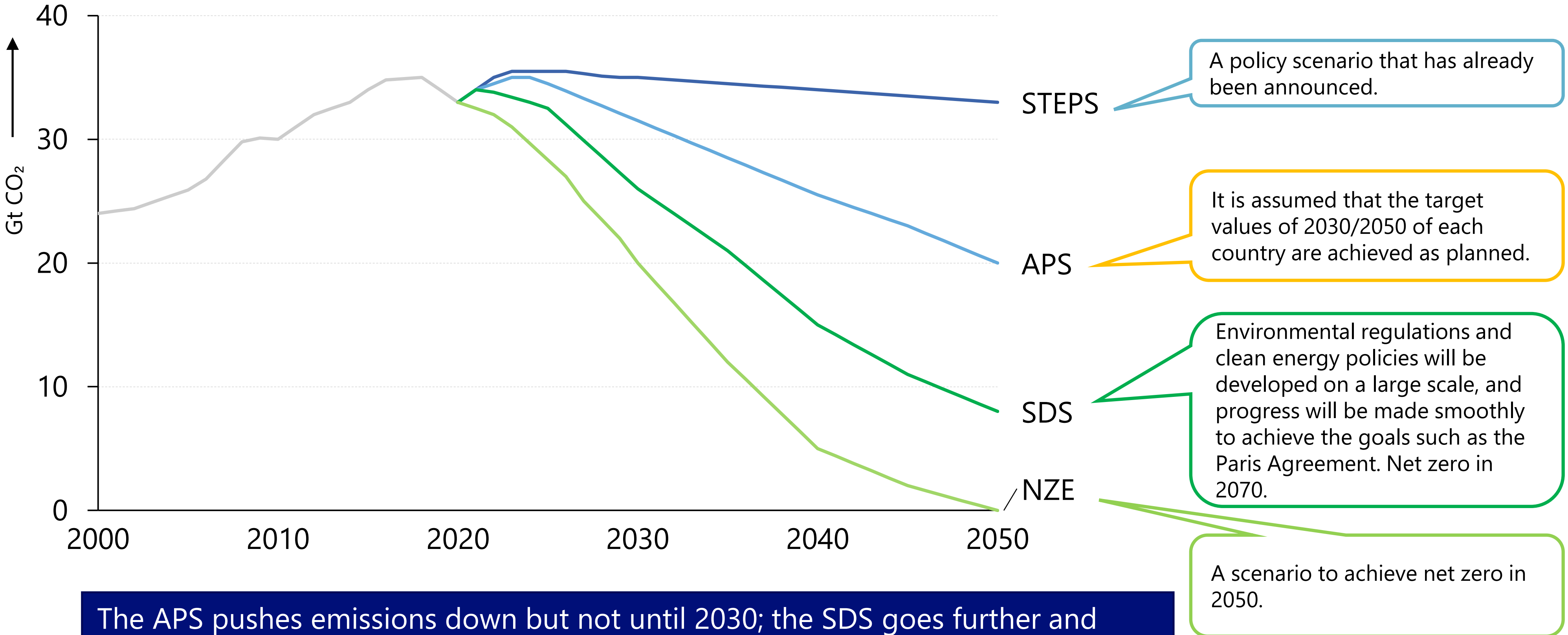
- Green Hydrogen is a major vector to achieve net zero emission targets because it can abate **80 gigatons of CO2 by 2050** and limit **global warming to 1.5 degrees Celsius**

Major Uses of Hydrogen

- **Refining:** Desulfurizing , catalytic cracking of long chain hydrocarbons
- **Chemicals:** Ammonia synthesis for use in fertilizers
- **Others:** Smaller proportion of demand from transport, grid injection & Electricity generations

Source: IEA Hydrogen Review 2021, MoPNG,

IEA has announced 4 scenarios of H_2 demand & supply in mid to long term based on policies of each country, and ambition targets in addition to policies



The APS pushes emissions down but not until 2030; the SDS goes further and faster to be aligned with the Paris agreement; the NZE delivers net zero by 2050

Note: APS=Announced Pledges ; SDS= Sustainable development scenario; NZE= Net Zero Emissions by 2050 scenario

Source) IEA：IEA_GlobalHydrogenReview2021, Energy_Technology_Perspectives_2020

Europe leads globally in number of announced projects in Green Hydrogen & in targets for electrolysers installation by 2030

Criteria	Parameter	Details		
Hydrogen Usage	• Hydrogen Production 2020 (MT)	8.2 MT (9% of Global)	10.0 MT (11% of Global)	21.0 MT (23% of Global)
Green Hydrogen Promotion Measures	• Planned Investment	• **€180-470 Bn** ($220-570 bn) in renewable H_2 in **EU by 2050** • **€24-42** billion (USD 27 bn. - USD 47 bn.) **by 2030** on electrolysis	• **$ 52.5 million** to accelerate transition to clean H_2 technology • Investment to support clean H_2 project with CCUS (Blue H2)	• China Petroleum & Chemical Corp, **Sinopec has announced $ 4.63 Bn** into green H_2 projects by 2025
	• Electrolysers Deployment Targets in EU	• **6 GW** renewable H_2 electrolysers by **2024** • **40 GW** electrolysers by **2030** in EU • **Electrolyser deployment target 2030:** France (6.5 GW), Germany (5GW), Netherlands (3-4 GW), Spain (4GW) & Portugal (2-2.5 GW)	• **~17 MW** of electrolysis for **dedicated green H_2 production** is operative, **~1.5 GW** project in **pipeline** • **13.5 GW** of electrolysis projects to be online **by 2030** as per DOE projection **(~44GW electrolyser capacity needed** for net-zero goals by 2030)	• Chinese Hydrogen Alliance is urging govt. to increase renewable hydrogen electrolyser capacity to 100GW by 2030
	• Green H_2 production target	• **1 million tons/ year** by **2024** • **10 million tons /year** by **2030**	• N/A	• **50% of H_2 production** is expected to come **from renewable by 2030** • **Sinopec targets 500,000 T** of 'green' hydrogen capacity **by 2025** • Inner Mongolia **approved massive power project** (1.85 GW of solar and 370 MW of wind) to produce 66,900 tons of Green H2, project to be operational by 2023
	• Focus Sector	• Mobility & Industrial (Steel Production, Power Sector) & domestic Heating • Germany has reserved 2GW for transport sector decarbonisation • **FCEV target :** 500,000 fuel cell LCVs, 45,000 fuel cell trucks and buses by 2030	• Data centers, ports, steel manufacturing, and medium- and heavy-duty trucks • California Fuel Cell Partnership aims for 1 million FCEV deployment by 2030	• Industrial, Chemical Processes & Mobility • **FCEV target** ~50,000 (2025), ~ 1 million (2030)

Source: Secondary Research, IHS Markit, IEA Hydrogen Review 2021

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2. Hydrogen as a Lever for Decarbonisation (India)

India's COP26 commitments has triggered enhanced need to adopt & scale up green hydrogen production

India COP26 Commitments

1. To cut total projected carbon emissions by 1 billion tonnes by 2030
2. Reducing carbon intensity of nation's economy <45% by 2030 from 2005 levels
3. Net-Zero carbon emissions by 2070

- Increase in share of renewables in the energy mix ~50% by 2030
- Expanding India's renewable energy capacity to 500 GW by 2030 (from earlier 450 GW,)
- In order to achieve reduction in carbon intensity, there will be increased emphasis on green hydrogen

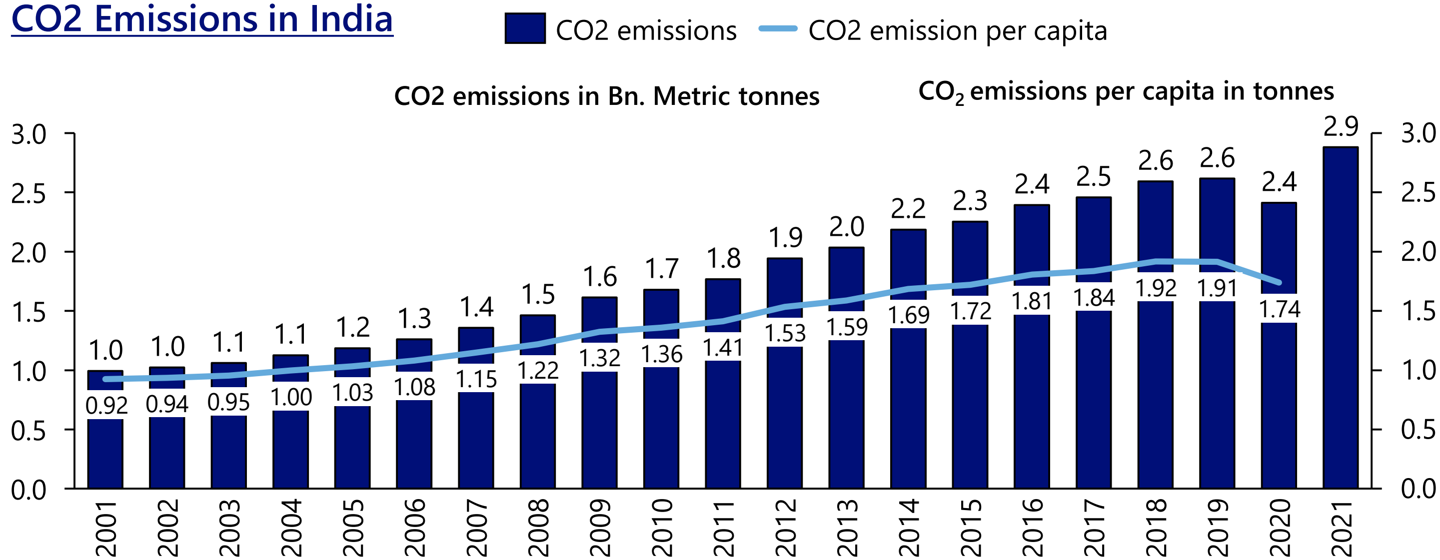
India Green Hydrogen Policy 2022

- Waver of inter-state transmission charges for **25 years** to producers of green hydrogen for projects commissioned before 30th June 2025
- Green Hydrogen plants will be granted Open Access for sourcing of renewable energy
- Government of India proposes to set up manufacturing zones for green hydrogen production plant, MNRE to establish single portal for all statutory clearances/ permissions required to manufacture, transport, store & distribute green hydrogen
- Renewable Energy consumed for production of Green Hydrogen shall count towards RPO* compliance of consuming entity
- Ministry of New & Renewable Energy (MNRE) to aggregate green H_2 demand from different sectors and have **consolidated bids** conducted for procurement to achieve competitive prices

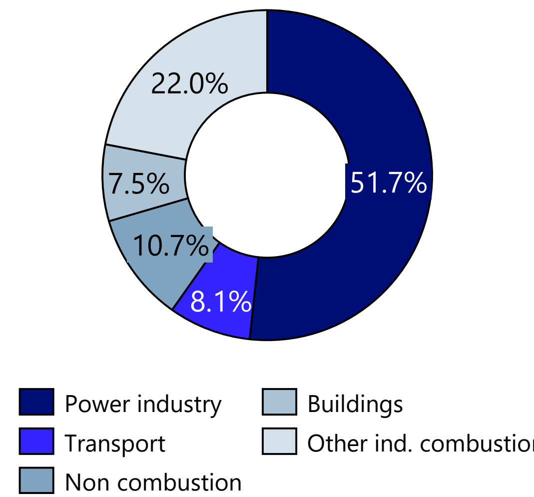
Source: Ministry of Power, Secondary Research RPO*: Renewable Purchase Obligation

India emitted ~2.88 Billion Metric Tonnes of CO_2 in 2021; Power and Transport sectors are top emitters, India's crude oil import has been increasing ~11% CAGR

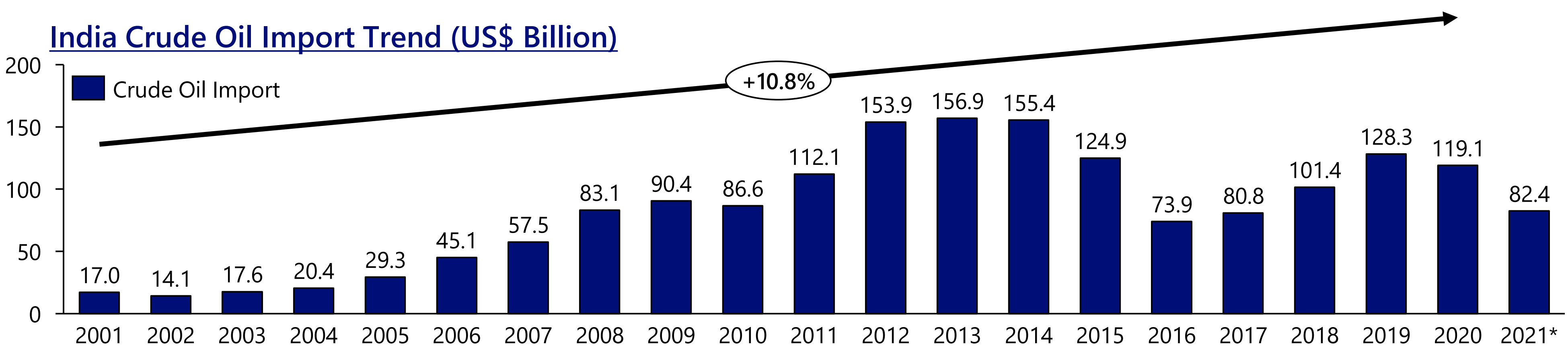
CO2 Emissions in India



Sector wise CO2 emissions India (2019)



India Crude Oil Import Trend (US$ Billion)

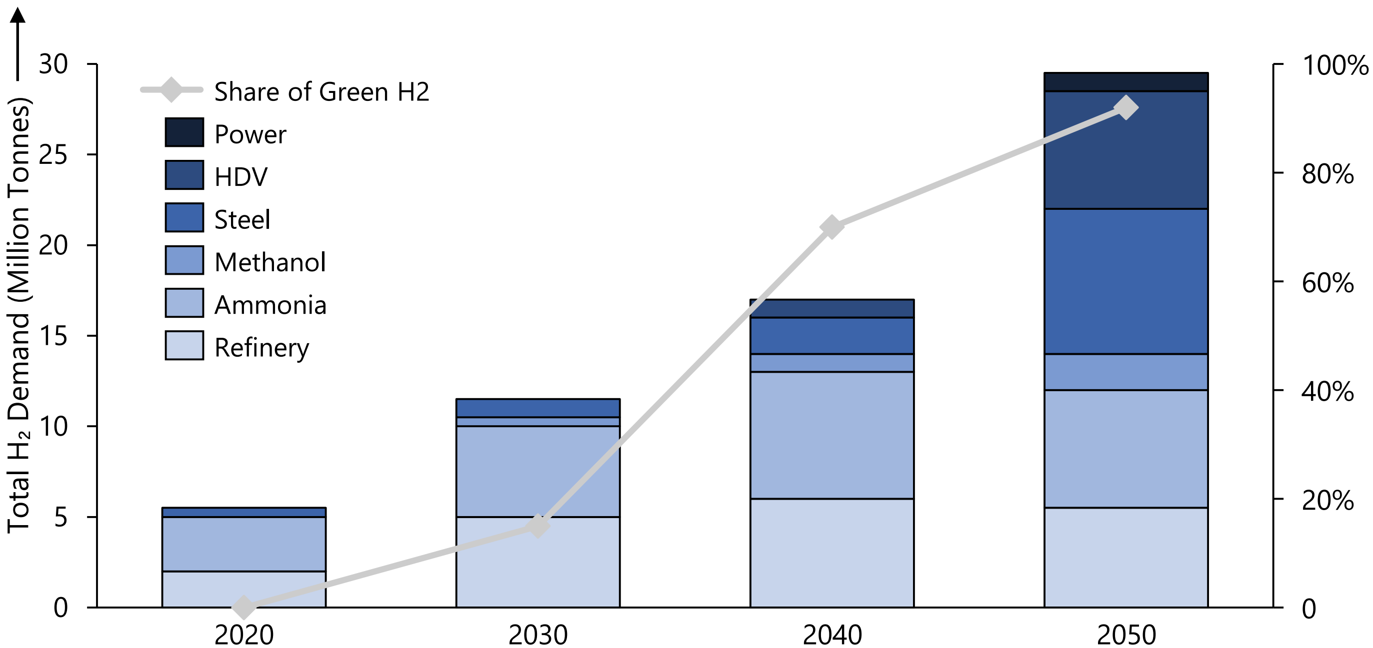


Source: PPAC, Secondary Research

Note*: 2021 crude oil import Apr-Dec

Hydrogen demand in India could be 29 mn tonnes by 2050. Usage in green steel & transport is likely to pick up post 2030, and in power from 2040

Hydrogen Demand Outlook & Share of Green Hydrogen (Without Policy Intervention)



By 2050 Hydrogen demand in India will be almost 10% of global hydrogen demand, growing 4x from current levels

Green hydrogen's share as compared to total demand could grow from 16% in 2030 to almost 94% by 2050

Cumulative value of green hydrogen market in India could be $8 billion by 2030 and $340 billion by 2050

- **Initial demand growth** (by 2030) is expected from **mature markets like refinery, ammonia, and methanol**, which are already using hydrogen as industrial feedstock and in chemical processes
- **In longer term** (after 2030), **steel & heavy-duty trucking** are likely to drive majority of demand, accounting for ~52% demand by 2050

Source: MoS, MoC&F, MoPNG, IEA, TERI,, World Bank, NTI Aayog Report

Green Hydrogen can be leveraged as a raw material and utility across sectors for emission reduction effectively

Potential Impact of Green Hydrogen on India's Carbon Intensity

Industry

- Refineries
- Steel
- Chemicals
    - Caustic Soda
    - Methanol
- Industrial Heat
- F&B
    - Hydrogenation

Fertilizers

- Urea Production
- DAP Production
- Ammonium Nitrate Production
- Ammonium Phosphate Production

Gas Economy

- Blending with National Gas Grid
- CGD Networks

Transportation*

- Fuel Cell Electric Vehicles
- Hydrogen Blended ICE Commercial Vehicles
- Trains
- Aviation
- Shipping

Power

- Ammonia Seasonal Power Storage
- Gen-sets
- Gas Turbines

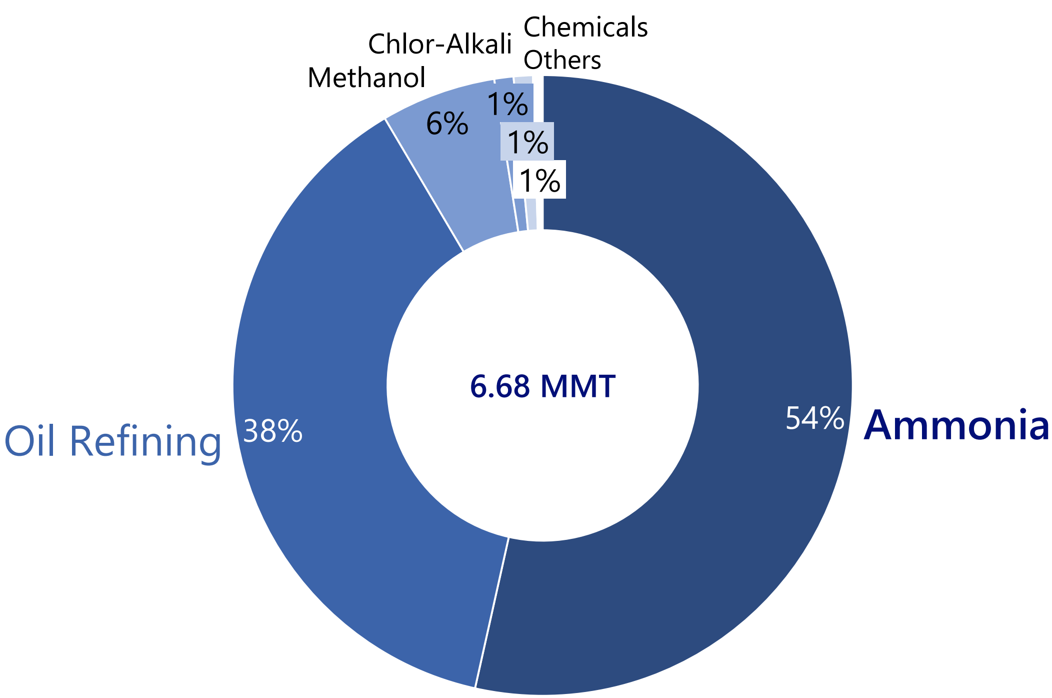
*It is possible to use hydrogen in internal combustion (IC) engines, directly or mixed with diesel and compressed natural gas (CNG) or hydrogen can also be used directly as a fuel in fuel cells to produce electricity.

Source: Published reports, Press Articles

Currently, India's H2 consumption is ~6.7 MMT, with more than 95% grey H2 usage; Industry (Oil refining & ammonia for fertilizers) is the primary end user

Hydrogen Production and Consumption in India

In 2019, India contributed **around 3% of world's hydrogen consumption** at 6.68 million metric tonnes (MMT)



Current Status

Almost all hydrogen (>95%) produced in India is from fossil fuel, primarily methane (Grey Hydrogen)

In India, Most of Hydrogen <u>**generation plants are captive**</u>, with production to consumption being done at end-user facility based on requirements

Expected Trends

Hydrogen use as fuel in transport sector is almost negligible, with only a few projects in pilot and demonstration stage. However, hydrogen use as fuel is expected to increase

It is expected that in long term, <u>**India will transition into Green Hydrogen production using methane from biomass**</u> (SATAT policy scheme) and renewable energy

India has set up goal of generating 175 GW of power by Renewable Energy Sources (exc. Hydro) by 2022

Source: IGEF, MoPNG, Statista, NRI Analysis

Refineries, Fertilizers and Chemicals are immediate opportunities, however H_2 costs are critical. For steel, transport & power gen; existing capabilities can serve

Demand Sector		Size	Readiness for Hydrogen			Govt Focus
			Cost	Tech	Logistics	
Feedstock	Oil Refining	●	○	◎	◎	○
Feedstock	Fertilizers	◎	○	◎	◎	○
Feedstock	Chemicals	◎	○	◎	◎	NA
Feedstock	Iron & Steel	◎	△	○	△	NA
Energy Carrier	Road Transport	◎	◎	○	△	△
Energy Carrier	Power Gen	◎	△	△	△	NA
Energy Carrier	Buildings	△	△	○	×	NA
Energy Carrier	Ship Fuel	○	△	△	×	NA
Energy Carrier	Aviation Fuel	○	×	△	×	NA

◎ High ○ Mid △ Low NA Not Applicable × No

Short – mid term opportunities (Oil Refining, Fertilizers, Chemicals)
- Important to manage **cost of H_2** *(through supply)*

Mid – long term opportunities (Iron & Steel, Road Transport, Power Gen)
- Leveraging existing network in Overseas and Indian market, POCs can be conducted

Limited opportunity in India for the time being (Buildings, Ship Fuel, Aviation Fuel)

Source: NRI Analysis

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3. Looking at the Value Chain for Unlocking Potential

- **Production**
- Transportation
- Retailing
- Fuel Cell Use Cases

Drop in Solar prices will drive green hydrogen cost reduction significantly from by 2030 with scale, PLIs etc.

Decarbonisation Potential = **Cost of Production** × **Adoption**

Levers	Description	Elements impacted
1. Scale	❑ Matching scale of Chinese PV manufacturing	• Modules and BOS[1)]
	❑ For bigger projects like 450,000 acres of land in Gujarat for setting up renewable energy projects which will bring down costs	• Solar Park Charges
	❑ CAPEX of storage will decrease due to industrialization of equipment	• Compression & Storage
2. Government Support	❑ Government support to manufacturing through schemes such as PLI	• Modules and BOS
3. Tech and Innovation	❑ Robotic Cleaning / Self cleaning modules ❑ Water conservations / recycling techniques deployed at scale	• O&M
4. Debt Servicing	❑ Due to lower debt servicing cost, i.e. as low as 5%	• Debt Servicing

1) Balance of System

At low scale production, Alkaline electrolysers are a better option for India, PEM is more suitable at higher volumes

	Capex	Scalability	Cost Reduction
Alkaline Electrolyzer	• Lower initial investment and higher lifespan than PEM • **More suitable for low cost countries like India with low off-take initially**	• Scalability challenges in BOP cost due to complex system design • **Higher space requirement for larger capacity plants**	• Most of the cost reduction potential will come only from economies of scale • **Other levers such as electrode material, transport layer etc. have limited scope left**
PEM Electrolyzer	• Higher than Alkaline by ~40% making it less viable for small scale production; Capex cost for PEM will mirror Alkaline post GW levels for single installation; GW level capacity at centralized costs will significantly increase the transportation costs	• Simpler construction takes less space • High scalability in BOP • More cost effective at larger scale plants	• Apart from scale, cost reduction will be achieved from bipolar plate design and change of electrode / catalyst material
Solid Oxide Electrolyzer	• Less commercial deployment leading to very high capex currently		• Better scope but controlled only by few companies

Major Indian companies have already announced plans for green hydrogen & electrolyser manufacturing in alignment with Govt. vision & COP26 commitment

Institution	Date Announced	Project/Product	Brief Description
Reliance Industries Limited	Oct' 2021	Investment in Hydrogen, Solar firms	• **Partnered Danish company Stiesdal** to manufacture hydrogen electrolysers in India • **Invested $29mn in German NexWafe**, a photovoltaic product maker
	Sep' 2021	Target 100 GW of renewable energy by 2030	• **Outlined 1:1:1 vision** to bring cost of hydrogen down to **under $1 per kg** in 1 decade by enabling a capacity to **generate 100 GW of electricity** from renewable sources and convert it into carbon-free hydrogen
	Oct' 2021	Use 3 GW solar power at electrolyser gigafactory	• Plan to use **3 GW of solar energy** to **generate 400,000 tonnes** of hydrogen at it proposed electrolyser gigafactory
L&T	Jan' 2022	MoU with HydrogenPro	• Signed **MoU with Norwegian electrolyser firm HydrogenPro** for setting up Gigawatt-scale mfg in India for alkaline water electrolysers
Adani Group	Jul' 2021	Build India's first green hydrogen plant	• Plan to set up '**Green Hydrogen' plant in Uttar Pradesh at Mathura** Refinery, project aims to introduce green H_2 in Indian O&G sector
Indian Oil Corporation Limited	Oct' 2021	Aims to be one of the largest green H_2 producers	• Plan to **spend $70bn to amass 45 GW renewable energy** portfolio by 2030 and produce the world's cheapest green hydrogen. • Plan to invest with potential partners for electrolyser manufacturing, **backward integration for solar/ wind generation**
Gas Authority of India Limited	Nov' 2021	EOI to select partners for setting up electrolyser facility	• Gas Authority of India has issued **expression of interest for setting up electrolyser facility to produce green hydrogen**
Bharat Petroleum Corporation Limited	Dec' 2021	BPCL & BARC collaborate to scale up tech for green hydrogen production	• **collaborated with Bhabha Atomic Research Centre** (BARC) to scale up **Alkaline Electrolyser technology** for Green Hydrogen production. • Intent is to **commercialize it for large scale usage for refineries**

Source: Press Release & Media Articles

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3. Looking at the Value Chain for Unlocking Potential

- Production
- **Transportation**
- Retailing
- Fuel Cell Use Cases

Based on volume and distance to be transported the transportation methods may vary; In Indian context, Type 1 Gaseous Tube Trailers are best suited

Tube Trailers (Gaseous)

- Gaseous hydrogen is most commonly transported by type-1 tube trailers.
- Tube Trailers can carry smaller quantities of compressed hydrogen in gaseous form over short to medium distances
- Transporting Hydrogen in Type 1 Gaseous Tube Trailers is the most cost effective way

Type-1 Tube Trailer

Pipeline (Gaseous)

- Gaseous hydrogen can be transported through pipelines much the way natural gas is today.
- Dedicated H2 pipeline are a new concept for India and need a lot of work for development and localisation
- For small distances, dedicated H2 pipelines will be inefficient

Dedicated Pipeline

Cryogenic Tankers (Liquid)

- Hydrogen is transported as a liquid when high-volume transport is needed in the absence of pipelines.
- Liquid Cryogenic Trailers have very high carrying capacity for a single consumer destination, leading to lower asset utilisation

Liquid Tankers

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3. Looking at the Value Chain for Unlocking Potential

Retailing costs could drop due to scale, industrialisation of equipment used for dispensing

Decarbonisation Potential = **Scale of Retail Operations** ✖ **Retail Price**

Levers	Description	Elements impacted
1. Technical	❑ Decrease in underground storage due to industrialization of equipment & scale benefits due to commonalty with other sectors	• Low pressure Storage
	❑ Decrease in tube cascade storage due to sacle and industrialisation	• High Pressure storage
2. Scale	❑ Cost reduction due to industrialization	• Compressor
		• Dispenser
		• Chiller
		• Other systems
3. Subsidy on land/ Lease optimization	❑ Large corporate houses in India can leverage their existing land ❑ Government subsidy, tax benefits on related real estate transactions	• Land/ Lease Price

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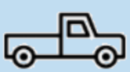
3. Looking at the Value Chain for Unlocking Potential

- Production
- Transportation
- Retailing
- **Fuel Cell Use Cases**

FCEV being an alternate powertrain is only forward compatible for all vehicle segments

Segment	Forward Compatibility	Viability	Remark
	✓	◕	• Global 2W FCV pilots/ prototype underway (Segway & Xidea in China)
	✓	◑	• Due to cost & complexity of cryogenic tanks make it less attractive for small vehicle usage
	✓	◔	
	✓	◕	• For LCVs with payload >4tons FCEV's are better solution to BEV in terms of negating heavy battery weight for having equivalent energy & range
	✓	●	• The **range and refueling advantage** for FCEV is more suited to heavy-duty applications • Hydrogen fuel cells have a far greater energy storage density than lithium-ion batteries offering range advantage & being lighter
	✓	●	

Major automotive OEMs have announced their plans to venture into Hydrogen based mobility options such as FCEVs

Institution	Date Announced	Project/Product	Brief Description
Tata Motors	Jun' 2021	**Hydrogen bus based on PEM Fuel Cell**	• Tata Motors won tender in Jun, 2021 to provide 15 hydrogen fuel cell-powered buses to Indian Oil Corporation Ltd (IOCL) • IOC will use buses evaluate the potential of developing hydrogen-based PEM fuel-cell technology in India
Daimler Trucks	Oct' 2021	**Hydrogen solutions for Heavy duty segment**	• Daimler trucks announced shift to Hydrogen solutions for Indian market • The Hydrogen solution will address the long-haul, heavy-duty segment
Toyota	Oct' 2022	**Flex fuel-strong hybrid electric vehicle (FFV-SHEV)**	• Launched first-of-its-kind pilot project on flex fuel-strong hybrid electric vehicle (FFV-SHEV) that can run on 100 per cent ethanol.
	Mar' 2022	**Green H2-based advanced fuel cell EV (FCEV)**	• Launched India's first green hydrogen-based advanced fuel cell electric vehicle (FCEV), Toyota Mirai
Quatron & ETO Motors	Sep' 2022	**Quantron and ETO Motors are planning a cooperation for the India and Europe**	• ETO and QUANTRON is to develop BEV and possibly FCEV conversion kits for applications targeting a global market –trucks, buses or even trains (for FCEV), depending on cost and feasibility

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4. Summary

Summary

Relevance of Green H2 in Indian Context

- India emitted ~2.88 Billion Metric Tons of CO2 in 2021 and crude oil import has increased at~11% CAGR
- India's COP26 commitments has triggered enhanced need to adopt & scale up green hydrogen production
- The Govt. of India has come up with a **Draft Hydrogen Policy** and major players have moved to harness potential in India's Green Hydrogen potential
- The **immediate focus** of all Green Hydrogen announcements and measures by large industrial houses in India is in **the Industrial use of Hydrogen** – COP commitments would necessitate use of some amount of Green H_2

Unlocking levers to cost reduction and hence adoption

Production Cost

- **Electrolyser cost reduction** will be driven by **Scale, technology and efficiency** learning curves, and expected increase in its efficiency by 2030.
- **Solar Power cost reduction** will be based on incentives, large scale facility development e.g. Large conglomerates matching scale of Chinese facility today as well as lower cost of funds
- **Equipment cost reduction** will be based on scale benefits and price drops due to industrialisation of compression and storage equipment

Transportation Cost

- **Trip length reduction and route optimization on account of scale** in case of large conglomerates. The Hub and spoke model of pan India distributed Hydrogen production will reduce the running distance of trucks carrying Hydrogen from plant to pump, thereby bringing down the cost of transportation than others

HRS

- **Reduction in cost of equipment** on account of Scale effects & industrialisation of equipment manufacturing would decrease costs of equipment such as compressors, high and low pressure storage, dispensers and chillers
- **Reduction in lease/cost of land** due to scale will help large conglomerates to source land for stations at lower price leading to a further cost reduction

Dream up the future.

Nomura Research Institute India Pvt. Ltd.

ASHIM SHARMA
Senior Partner & Group Head
Ashim.Sharma@nri.com
+91 95991 87825

NRI Consulting & Solutions
7th Floor, Tower A, Building 5
DLF Cyber City, Phase III
Gurgaon 122002 India

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