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MINISTRY OF
NEW AND
RENEWABLE ENERGY

INVESTMENT LANDSCAPE OF GREEN HYDROGEN IN INDIA

SOUTH ASIA REGIONAL ENERGY PARTNERSHIP (SAREP)

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FOREWORD

As the world is moving towards Net Zero targets to fight climate change, efforts are being deployed to decarbonise the energy sector, which is the biggest contributor to carbon emissions. A lot has been achieved in creation of renewable energy capacity to generate clean electric power for domestic, commercial, and industrial applications. To further meet the clean energy requirements of global economies, reliance is being placed on hydrogen as an alternative, which on combustion does not produce greenhouse gas. When clean electric power is employed in its production, this hydrogen is termed as 'green hydrogen' which has both domestic and industrial applications. Green hydrogen is being recognised worldwide as an attractive source of clean energy and multiple governments have made policy announcements and provided incentives to promote early adoption.

India has taken steps to move its enormous economy towards Net Zero by 2070 and has articulated more near-term targets under its Nationally Determined Contribution (NDC), including reducing the carbon intensity of India's economy by 45%. Adoption of green hydrogen within the economy will help India in achieving this key objective. To help drive this process, India has recently launched the 'National Green Hydrogen Mission'.

USAID is committed to continue our strong partnership with India to help achieve these NDCs through various activities including the South Asia Regional Energy Partnership (SAREP). Though green hydrogen is still in a nascent stage of development throughout the world, USAID has undertaken various initiatives to promote its development. For example, USAID assessed the opportunities for hydrogen in South Asia, developed a techno-commercial feasibility study for a pilot project in India, disseminated information through reports, and promoted capacity building through training classes and workshops.

This report was developed under USAID's SAREP for the interest of multiple stakeholders including project developers, financiers, consumers, and policymakers. The report provides a comprehensive guide for investments into India's green hydrogen ecosystem, seeking to demystify the fundamentals, and provide a perspective on investment in green hydrogen projects in India. This report is an outcome of rigorous research and includes insights from various stakeholders gathered for the purpose.

I sincerely hope that this report will assist readers to understand the intricacies of the sector and undertake informed investment decisions while deploying adequate risk mitigation measures. Beyond this report, USAID's SAREP will continue to undertake activities intended to promote early adoption of green hydrogen in the region.

John Smith-Sreen
USAID/India Indo-Pacific Director

ABBREVIATIONS USED

AEM:	Anion Exchange Membrane
B:	Billion
BF:	Blast Furnace
BOF:	Basic Oxygen Furnace
CAGR:	Compound Annual Growth Rate
CAPEX:	Capital Expenditure
CCUS:	Carbon Capture, Usages and Storage
CFR:	Cost and Freight
CGD:	City Gas Distribution
DAP:	Di Ammonium Phosphate
DFI:	Development Finance Institution
DRI:	Direct Reduced Iron
EAF:	Electric Arc Furnace
ECA:	Export Credit Agency
EPC:	Engineering Procurement and Construction
EU:	European Union
GDP:	Gross Domestic Product
GHPO:	Government Hydrogen Purchase Obligations
GoO:	Guarantees of Origin
GT:	Giga Ton
H2/H_2:	Hydrogen
ICE:	Internal Combustion Engine
IPP:	Independent Power Producer
kWh:	Kilo Watt Hour
LCOA:	Levelized Cost of Ammonia
LCOH:	Levelized Cost of Hydrogen
LCOS:	Levelized Cost of Storage
LD:	Liquidated Damages
LOHC:	Liquid Organic Hydrogen Carriers
MDB:	Multilateral Development Bank
MJ:	Mega Joule
MMTCDE:	Million Metric Ton of Carbon Dioxide Equivalents
MMTPA:	Million Metric Ton per Annum
MMT:	Million Metric Ton
MOU:	Memorandum of Understanding
NHM:	National Hydrogen Mission
NH3/NH_3:	Ammonia
O&M:	Operations and Maintenance
OEM:	Original Equipment Manufacturers
OPEX:	Operating Expenditure
PEM:	Proton Exchange Membrane
PLI:	Production Linked Incentives
PPA:	Power Purchase Agreement
PPP:	Public Private Partnership
R&D:	Research and Development
SMR:	Steam Methane Reformation
SO:	Solid Oxide
TPA:	Ton per Annum

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Finally, we would like to thank the readers of the report for taking the time to review the findings and conclusions. We hope that this report will provide valuable information and insights to the investors and financing institutions that will be useful in shaping the investment landscape for the green hydrogen sector in India.

Suggested Citation:

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EXECUTIVE SUMMARY

Hydrogen has played a key role in the production of fertilizers and various industrial processes for decades, but has traditionally been produced through a highly polluting process that leads to 9-11 kgs of CO2 for every kg of hydrogen, accounting for 2.2% of global emissions. With improving electrolyzer technologies, declining renewable energy costs and an ever-strengthening decarbonization agenda, there is increasing attention on the production of "green hydrogen" through renewable energy-powered electrolysis as it eliminates all carbon emissions associated with hydrogen. As a result, "green hydrogen" is now being considered at the forefront of global decarbonization efforts for its derivative products as well as through new use cases such as the clean 'fuel of the future'. India is seeing huge traction from both the policy side and from private players, and green hydrogen/ammonia is expected to play a central role in India's decarbonization journey.

This report discusses the global context of the green hydrogen economy followed by a deep dive into the Indian landscape. Various aspects of policy and industrial support are discussed along with key advantages, and challenges that India faces in the path to becoming a global green hydrogen hub. Further analysis is done to showcase the investment opportunity in India from the consumption and value chain perspective followed by the investment supply landscape including key barriers as highlighted by various stakeholders and potential mitigation strategies. As a conclusion, the report presents key recommendations on how stakeholders can support accelerated development of the sector and aid India in becoming a global leader in the sector.

India is well positioned to emerge as a green hydrogen production hub, given its excellent renewable energy resources, including an installed capacity of 62+ GW solar and 42+ GW wind, existing consumption markets for hydrogen and its derivative products, and availability of suitable sites that can be developed into green hydrogen hubs. This will allow producers in India to achieve amongst the lowest levelized costs for green hydrogen and green ammonia, estimated at US$ 3,800-4,800 per ton and US$ 850-1,100 per ton respectively.

The Indian government's proactive approach to helping the country realize this potential by announcing the National Hydrogen Mission (NHM) on the 15th of August 2021 has added further momentum to the growth of the sector. The mission highlights the country's ambition to establish green hydrogen production capacity of at least 5 MMT, leading to an aversion of 50 MMT of carbon emissions annually, and an estimated investment requirement of US$97 billion, by 2030. The mission also highlights India's target to become a key export hub for green hydrogen, with the aim of India capturing 10% of the global import demand in target markets.

In line with government's ambition for the sector, Indian public and private institutions have responded positively by announcing plans for substantial investments throughout the green hydrogen value chain. These include renewable energy developers, electrolyzer manufacturers, oil and gas players, ammonia producers, steel manufacturers, and financial institutions, among others. Although expected to be constrained by demand, primarily due to price disparity between grey and green hydrogen, with the former's average historical prices being 65-75% lower than the latter, stakeholders on the production side of the ecosystem have presented highly optimistic plans.

Till 2030, most of green hydrogen demand is India is expected to emerge from grey hydrogen replacement in oil refining, natural gas distribution and ammonia-based fertilizers, along with exports. The exact market potential and investment demand is expected to be driven by government incentives and disincentives, including potential subsidies to drive production and mandates to drive consumption.

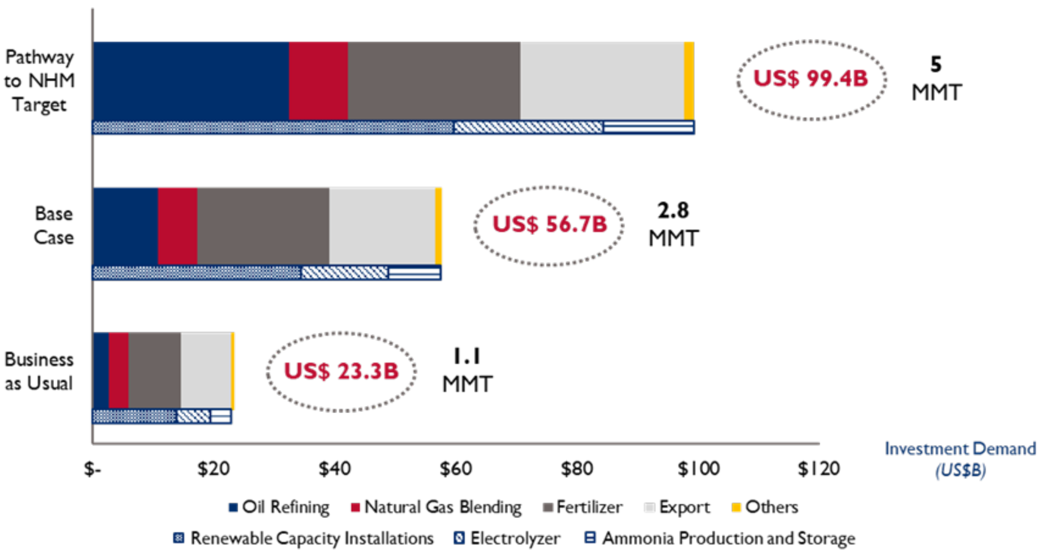
US$ 3.8-4.8 / kg
Estimated Levelized Cost of Green Hydrogen in India

US$ 850-1,100 / MT
Estimated Levelized Cost of Green Ammonia in India

5 Million MT / year
India's Green Hydrogen Production Target by 2030, according to NHM

India is expected to reach annual green hydrogen demand of 2.85 MMT, with an investment demand of US$56.7 billion by 2030 under a 'Base Case' scenario where 10% of India's refineries switch to green hydrogen, existing city gas distribution pipelines are blended with 10% green hydrogen, 50% of ammonia-based fertilizer imports are substituted by domestic green ammonia, and the country achieves 6% of demand from target importing countries. To meet these demand estimates **62 GW of additional renewable energy capacity, 29 GW of electrolyzer capacity, and 11 MMT per annum of ammonia infrastructure will be needed,** representing an estimated investment need of $36B, $15B and $6B respectively, by 2030. The upside scenario is represented by the 'Pathway to NHM Target' graphic and the downside scenario as represented by 'business as usual' assumes green hydrogen is not able to replace existing alternatives and only few announcements materialize.

Figure 1 Investments Required in India's green hydrogen ecosystem by 2030 (USAID SAREP Analysis)



The investment supply market has adequate appetite for large ticket investments in India's green hydrogen sector, considering the strong sustainability and additionality agenda associated with it. However, lack of project bankability remains a key barrier. Project developers face implementation challenges around securing project offtake without price and volume visibility, managing high costs associated with completion risks, and mitigating interface risks due to multiple technologies in green hydrogen projects. Financial institutions are actively pursuing investments but remain conservative in the absence of banked precedents for green hydrogen projects.

Potential Mitigation: Project developers **can be supported from the project development stages onwards, through Project Preparation Facilities or other development support mechanisms.** The government and development-focused financial institutions can play a central role in providing such catalytic support for the development of bankable, investment-ready projects.

Project developers have highlighted an unwillingness of consumers to lock into long-term, fixed price offtake contracts as one of the biggest challenges for project development. This leads to the need for a market demand aggregation body that could enter bankable offtake contracts with developers, in order to supply traders and end consumers of green hydrogen. The presence of this body can also lead to more efficient price discovery through competitive tenders. Currently, green hydrogen pricing is a challenge and even price assessment platforms are less reflective of markets due to low trade volumes.

Potential Mitigation:

Strong policy push can play a major role in creating an initial demand market.

- Introduction of industry wide mandates to push demand by setting green hydrogen purchase obligations for hard to abate sectors can significantly ramp up demand.
- Incentives such as green hydrogen subsidies / contracts for difference can be explored to reduce price disparity between grey and green hydrogen in the short run.
- PLIs to both green hydrogen producers and electrolyzer / balance of plant manufacturers can be considered.

A market facilitation institution could address key gaps in terms of offtake and price structuring.

- Demand aggregation could benefit the entire ecosystem as it would provide developers the option to participate in competitive tenders with potentially long-term offtake from a bankable facilitation institution.

Uncertainty around various implementation considerations such as contractual structures, regulatory requirements and standards for green hydrogen certification has led to slow on-ground implementation. Considering most developers have experience in only a portion of the green hydrogen production, the additional uncertainty around these implementations aspects leads to developers being hesitant to incur significant development costs required to complete comprehensive project preparation work. The government and impact-focused institutions can play a crucial role here, by introducing project preparation facilities and development support dedicated to the green hydrogen sector. The developers would also gain comfort as regulations and standards are introduced, as they have highlighted the need for regulation to be harmonized and standards developed at a global level to ensure ease of compliance, particularly for export-oriented projects.

Potential Mitigation:

Introduction of frameworks for regulation and green certification that are well-harmonized with global equivalents could address some of the ambiguity in the market and allow ease of global compliance for export-oriented projects.

India has an electrolyzer manufacturing capacity of 8 GW per annum in the pipeline till 2025 and significant capacity additions are needed, but developers highlight that the green hydrogen production market is too nascent to push any import disincentives. Domestic electrolyzer producers pointed to the technical challenges for manufacturing and the gaps in India's domestic supply chain for electrolyzer parts while project developers stress on the need to prioritize price reduction, with asks for removal of import duties on renewable energy equipment dedicated for green hydrogen projects.

Potential Mitigation:

Given the nascency of the sector it would be beneficial to prioritize trade policy initiatives aimed at reduction of price disparity between grey and green hydrogen, such as waiver of custom duties on equipment dedicated for green hydrogen production, including solar equipment.

Despite challenges, the sector is expected to demonstrate significant growth in the coming years as regulatory framework solidifies, consumption demand materializes, and the initial few large-scale projects reach operational stages to set precedents for the sector.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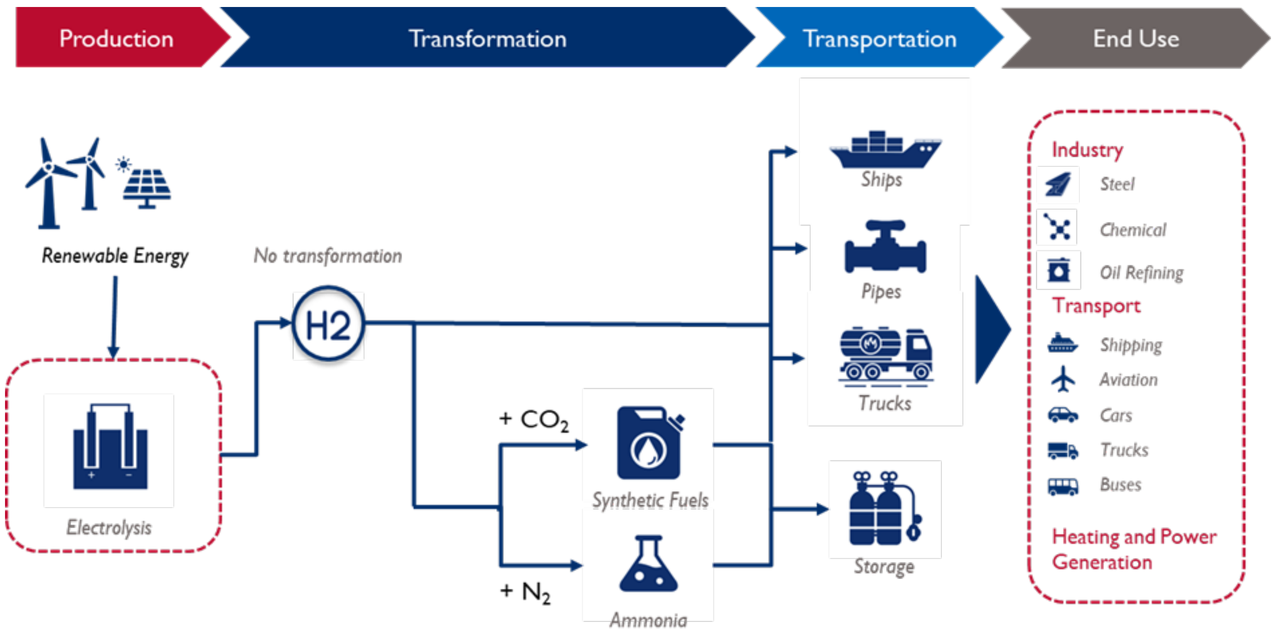
GREEN
HYDROGEN 101

Hydrogen is the simplest chemical element, present naturally as a colorless, odorless, and flammable gas. For decades, it has been a key ingredient in the production of fertilizers and various industrial processes. However, its extraction process is usually highly polluting and leads to significant emissions (IEA, n.d.). With the improved techno-commercial feasibility of alternate production technology of electrolysis utilizing renewable power, it has become viable to produce hydrogen with very low carbon emissions. This has opened the uses of hydrogen to new cases such as energy generation and transportation.

The integration of such hydrogen into the global energy mix would require the development of a robust ecosystem supporting its production, distribution, and consumption. The following section will elaborate on various components of this ecosystem.

Figure 2: Outlook of Green Hydrogen Value Chain (Ouziel, 2021)

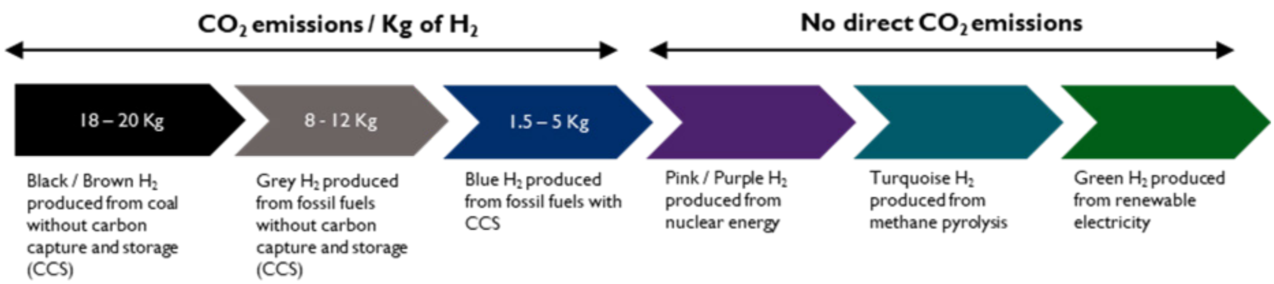


PRODUCTION FUNDAMENTALS

Hydrogen is a readily available element in the environment; however, due to its lightweight and reactive nature, it is found only in limited quantities (1 part per million by volume) in the atmosphere (The Royal Society of Chemistry, n.d.). For it to be utilized in its elemental form, it must be extracted from naturally occurring compounds such as water and methane.

Hydrogen can be extracted through multiple processes using different raw materials and technologies. Each methodology has been accorded a colour to indicate the level of emissions it generates

Figure 3: Different types of hydrogen (H2Bulletin, n.d.), (Moberg & Bartlett, 2022), (Webley, 2022), (RMI, 2020)



At present, the most common method used for the extraction of hydrogen at an industrial scale is a process called 'steam methane reformation (Energy Efficiency & Renewable Office, US, n.d.), which involves the reaction of methane with steam under high-pressure conditions. However, this process is highly polluting and leads to emissions of major pollutants such as carbon monoxide and carbon dioxide. In 2022, the industry accounted for ~2.2% of global annual CO2 emissions (830 MMTCDE per year) (IEA, Fuels and Technologies, 2022).

To reduce these emissions and broaden the scope of hydrogen's applications, cleaner extraction methods for large-scale hydrogen production are starting to gain traction. These processes are becoming increasingly commercially viable due to the declining costs of renewable energy and key production technology, i.e., electrolyzers.

Green hydrogen is considered the most promising form of clean hydrogen for large-scale production (World Economic Forum, 2021). It utilizes clean sources of energy such as solar and wind to produce hydrogen via the electrolysis of water. Electrolysis is a mature technology that has been around for over 125 years (Permanence, n.d.). Its energy efficiency is comparable to that of the steam reformation (60-80%), and the hydrogen produced can reach purities of up to 99.9% (Shivakumar & Himabindu, 2019).

Figure 4: Pollutants released during steam methane reformation

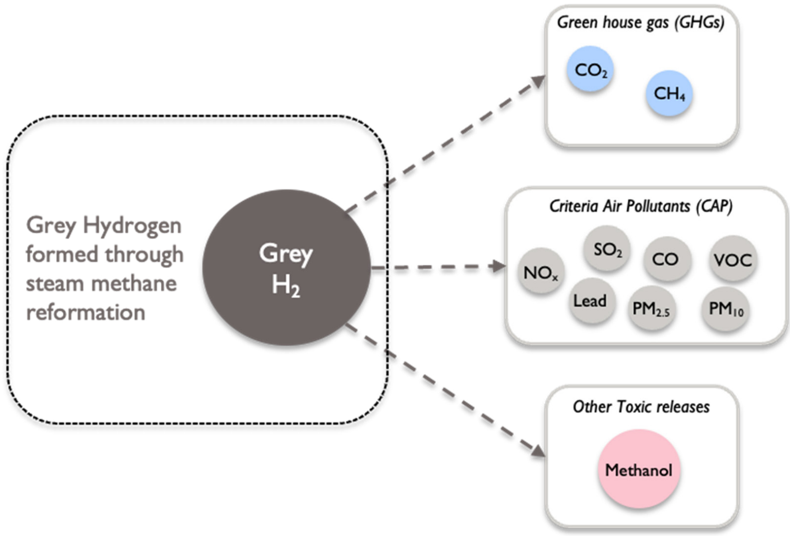


Figure 5: Global declining electrolyzer and renewable costs (Glenk, 2019) (IRENA, 2022)

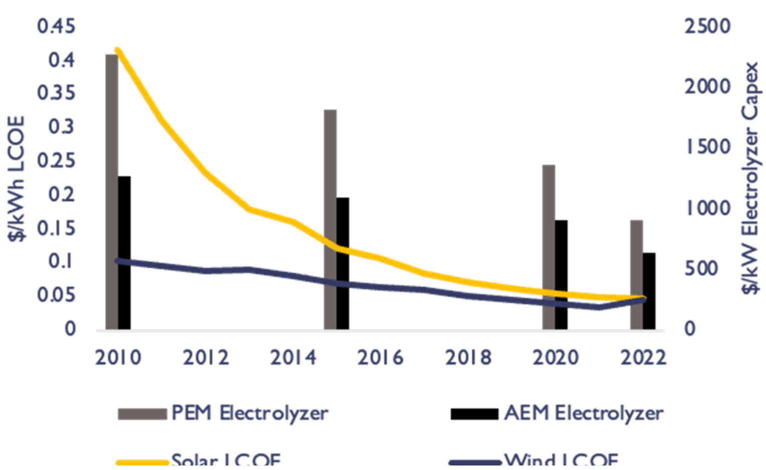
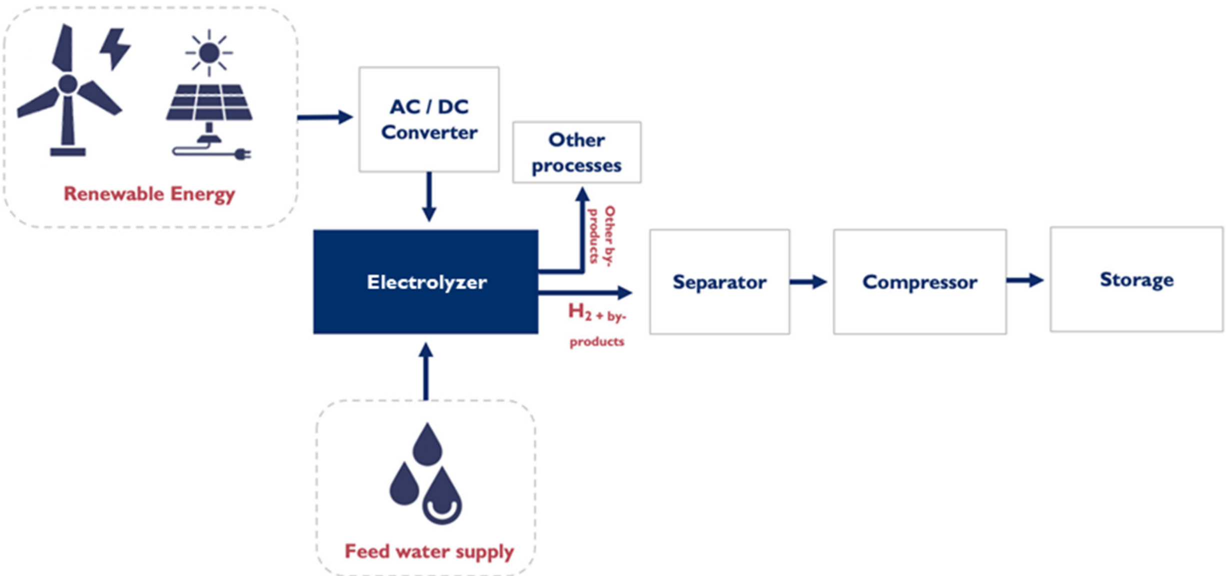


Figure 6: Overview of green hydrogen production process (USAID SAREP Analysis)



KEY PRODUCTION CONSIDERATIONS

The following sections will introduce the two main considerations for a green hydrogen project, i.e., the feed stock required and the type of electrolyzer utilised.

FEEDSTOCK

Feedstock represents the main input required to produce green hydrogen. This is composed of feedwater (pure water), and renewable energy which generally comes from either solar or wind sources (Niti Aayog ; RMI, 2022).

Renewable Energy

Green hydrogen plants typically utilize renewable energy from solar or wind plants on-site or source it externally from a third-party plant located elsewhere. Occasionally other sources such as hydropower may be used.

On average, 50-55 kWh is required to produce 1 kg of hydrogen. (ETEnergyWorld, 2022). The process can also be land intensive given that average land usage is 0.33 sq. km/ MW for solar and 0.2 sq. km/ MW for wind (FinancialExpress, 2020). Depending on geography and availability of the energy resources, the cost of electricity can vary significantly.

Feedwater

Pure water is typically used for electrolysis as it limits the damage to electrodes. Electrolysis is water intensive, as 9L of water is used to produce 1 kg of green hydrogen. This water can either be procured from fresh water sources or produced on site through a desalination or water-purification plant.

For geographies with limited access to freshwater resources, the use of seawater and brackish water for hydrogen production is also being researched and explored (Urquhart, 2021).

ELECTROLYZER

The process of electrolysis is facilitated by the electrolyzer. When supplied with electricity, the device splits water into its components, hydrogen and oxygen, through an electrochemical process. Currently, there are 4 electrolyzer technologies available in the market - alkaline, proton exchange membrane (PEM), solid oxide (SO), and anion exchange membrane (AEM). So far, only alkaline and PEM technologies have been used at an industrial scale while SO and AEM are currently in the research and development phase.

Between the two, alkaline is currently more economical than a PEM electrolyzer, primarily because a PEM electrolyzer uses expensive materials such as platinum and titanium, whereas an alkaline electrolyzer uses readily available materials such as nickel (IEA, 2022). Nonetheless, PEM electrolysers could have slightly lower opex requirements and low maintenance costs due to their significant cost advantages in balance of plant economics (Plugpower, 2022). The two technologies are compared in detail below

Alkaline Electrolyzer

The alkaline electrolyzer is a mature technology that has been well-established since the early 20th century. It uses a liquid electrolyte to conduct electrolysis.

PEM Electrolyzer

The PEM electrolyzer was first introduced in the mid-20th century. It uses a solid membrane to conduct electrolysis, which enables high energy efficiency during production.

Table 1: Key details of a PEM and alkaline electrolyzer (IRENA, 2020)

	Alkaline Electrolyzer	PEM Electrolyzer	Implications
Costs	\$500 - \$1,000/kWel (capex)	\$700 - \$1,400/ kWel (capex)	The current capex requirements for alkaline electrolyzers are relatively lower, even as capex for PEM has declined significantly. However, PEM electrolyzers can have up to 20-30% lower opex requirements over the project life.
Response Time	minutes	seconds	Response time is the time taken to adjust output to adhere to changes in demand and conditions. Renewable energy is often variable thus, a low response time is often preferable. While PEM has a better response time, both technologies are well-equipped to handle fluctuation levels generally seen in RE supply.
Land Usage	140 m2/MW	110 m2/MW	Most PEM electrolyzers have a significantly lesser footprint compared to AEM electrolyzers. However, this is generally not a concern as the electrolyzer footprint is a very small portion of overall project's footprint (if solar / wind is considered as part of the project)
Electrolyzer Life (Hours)	60,000	80,000	PEM electrolyzers can run for a longer period before requiring a stack replacement, which can cost up to 50-60% of electrolyzer's upfront capex.

STORAGE AND DISTRIBUTION FUNDAMENTALS

STORAGE

Hydrogen is a difficult element to store and transport due to its low density and flammability. Under normal conditions (1 bar of atmospheric pressure), 1 unit of gaseous hydrogen occupies nearly 8 times the space of 1 unit of natural gas (Spectra, 2022). Thus, to store and transmit hydrogen, it must be compressed or transformed into different states and compositions. Hydrogen is also highly flammable, thus extra precautions must be taken to reduce the risk of contamination.

Today, hydrogen is stored either in its pure form (in liquid or compressed gas state) or chemically bonded form (chemical compounds or adsorption). The preferred form can vary depending on the end-use case. For example, chemical carriers such as ammonia and methanol may be preferred for long-distance exports due to their high energy density and feasible temperature and pressure requirements. The raw energy density of liquid ammonia is 11.5 MJ/L, which is higher than the 8.491 MJ/L for liquid hydrogen. (Lan R, 2014) Compressed gas hydrogen may be preferred for shorter distances due to the lack of conversion requirements.

The three most common storage units for hydrogen and its derivatives are geological structures, specialized containers, and chemical carriers.

Figure 7: Description of types of storage for Hydrogen

Geological Storage

These are naturally occurring or man-made cavities in the earth's crust. They are created deep within the earth's crust (500 meters to 1,500 meters) to meet the pressure conditions required to maintain the high density of compressed gas. They often include salt caverns, rock caverns and depleted oil fields. Salt caverns are the most popular storage option for large-scale storage due to the high purity maintained. However, their usage is limited by their availability across the globe – these caverns are concentrated in geographies such as Germany, the Netherlands, and Denmark.

Specialized Tanks

These are metal containers specifically made to maintain the gas or liquid at different pressures and temperatures. Depending on their use-case, they can be placed either above or below the ground. These are popular for small-scall storage of hydrogen and can be used for onsite storage in steel refineries or fertilizer manufacturers.

Chemical Storage

Hydrogen can be in its chemically compounded form which most commonly include ammonia, Liquid Organic Hydrogen Carriers (LOHC), and metal hydrides. Ammonia and LOHC are liquid carriers of hydrogen and offer more feasible storage requirements. They are stored in specialized tanks and pipes as they are liquid. Whereas solid metal hydrides are typically stored in warehouses. Ammonia and LOHC are useful for long-distance travel as, supporting storage costs are more feasible.

These storage units are located either on-site or at a warehouse. For some of these storage sites, proximity to ports is essential for ease of export of the product to offtakers in global markets.

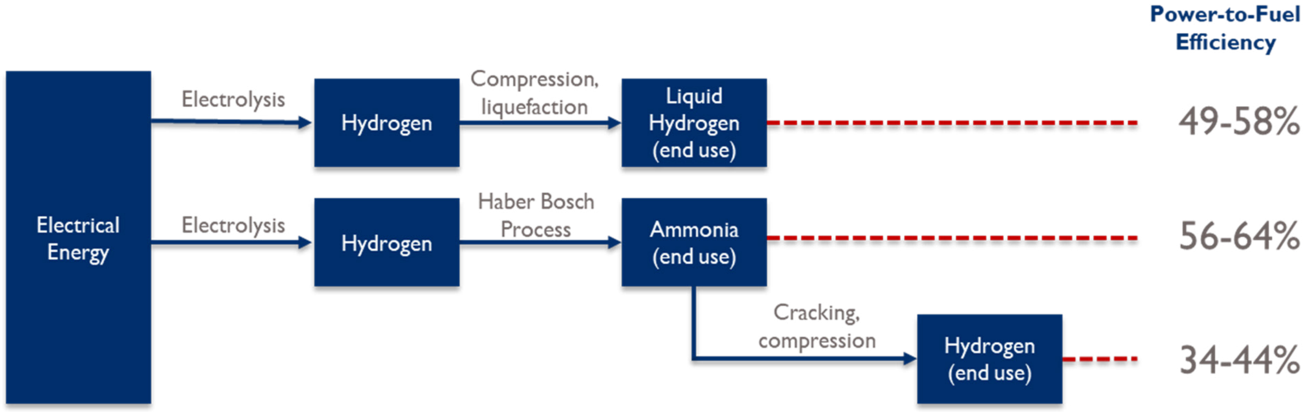
Table 2: Levelised cost of storage per kg (UNECE , 2021)

	Geological Storage					*Chemical Storage*		
	Salt Caverns	**Depleted gas fields**	**Rock Caverns**	**Pressurized containers**	**Liquid Hydrogen**	**Ammonia**	**LOHCs**	**Metal Hydrides**
Volume	Large volumes	Large	Medium volumes	Small volumes	Small – medium volumes	Large volumes	Large volumes	Small volumes
Duration	Weeks - Months	Seasonal	Weeks - Months	Daily	Days - Weeks	Weeks - Months	Weeks - Months	Days - Weeks
LCOS	$0.23	$1.9	$0.71	$0.19	$4.57	$2.83	$4.5	Not evaluated
Technology readiness	TRL 9	TRL 2 - 3	TRL 2 - 3	TRL 9	TRL 7 - 9	TRL 9	TRL 7 - 9	TRL 7 - 9

Gaseous Storage · Gaseous Storage / Liquid Storage · Liquid Storage · Solid Storage

Apart from storage costs for hydrogen, it is important to note the loss of energy during conversion of hydrogen to ammonia, particularly when assessing ammonia as a carrier for hydrogen. The energy losses during conversion can be significant, allowing only 34-44% of energy from the source of electricity to be retained against 49-58% from consuming liquid hydrogen directly. (Sudipta Chatterjee, 2021)

Figure 8: Energy efficiency for hydrogen end use vs conversion to ammonia as a carrier (Sudipta Chatterjee, 2021)



DISTRIBUTION

Hydrogen is envisioned to be a future commodity that can replace fossil fuels. However, the distribution network for the sector is yet to be fully established. Currently, four distribution modes are being explored – pipe, truck, ship, and train. The feasibility of each varies based on their physical properties and operational costs.

Table 3: Hydrogen transportation options (USAID SAREP Analysis)

	Compressed Hydrogen Gas	Liquified Hydrogen	Liquid Organic Hydrogen Carriers (LOHCs)	Ammonia (NH3)
	Can be feasibly transported by existing pipelines, however retrofitting may be required	Cannot be feasibly transported by pipelines, due to its demanding storage requirements	Can be potentially transported by pipelines, however technical barriers such as methanol water contamination and pipe corrosion must be addressed	Can be feasibly transported by existing pipelines, however retrofitting may be required
	Can be feasibly transported by trucks	Can be feasibly transported by trucks	Can be feasibly transported by trucks	Can be feasibly transported by trucks
	Can be potentially transported by ship, however it may be unfeasible due to its high volumetric requirements	Can be feasibly transported by ships	Can be feasibly transported by ships	Can be feasibly transported by ships
	Can be potentially transported by train, however it may be unfeasible due to its high volumetric requirements	Can be feasibly transported by train	Can be feasibly transported by train	Can be feasibly transported by train

Pipes are most feasible for land distribution for medium and large-scale volumes since they utilize less energy than alternatives to transport a larger volume of hydrogen. However, existing pipeline networks for natural gas are expected to have technical challenges for distribution of large-volume transport of pure hydrogen. This is because the hydrogen atoms can potentially infiltrate the interstitial space in the pipe's material, causing localized plasticity which can lead to breakage. Consequently, hydrogen must be blended to a certain extent with another fuel source, such as natural gas, for distribution.

Pipes cannot be utilized for long-distance intercontinental or overseas distribution. For intercontinental distribution, where pipes may not be present, it is more economical to ship hydrogen in the form of chemical carriers such as ammonia and methanol.

Figure 9: Cost of transportation for land-based forms of transport (IRENA, 2021)

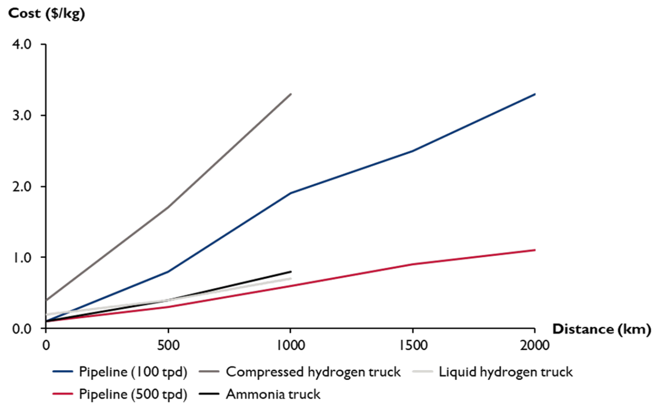
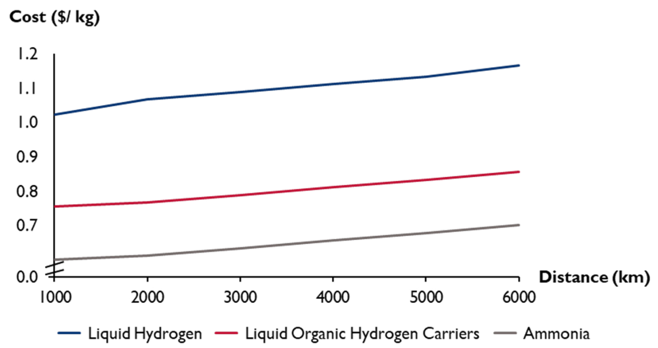


Figure 10: Cost of transportation for shipping (UNECE, 2021)



CONSUMPTION FUNDAMENTALS

Hydrogen is a commonly used chemical with substantial demand globally. As of 2021, annual production was 94 MMT (IEA, 2022), with primary consumption industries including oil refining, ammonia, methanol, and steel industries (Deloitte, 2021).

Figure 11: Hydrogen Use-case Break up (IEA , 2022)

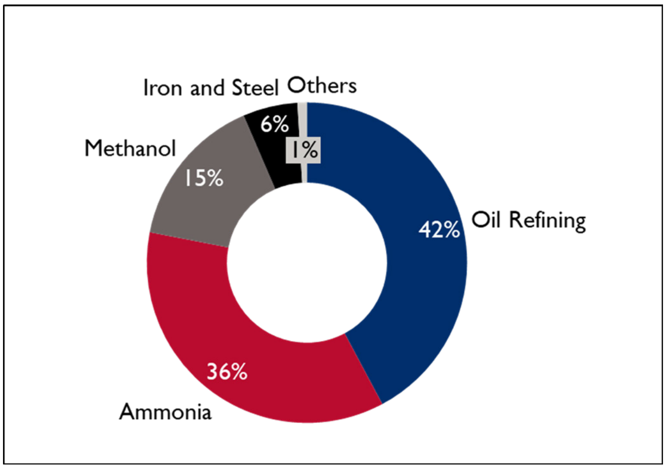


Table 4 : Current hydrogen consumption by industry (Rivarolo & others, 2019), (Aurélien Babarit, May 2019)

Industry	Average H2 Consumption / Ton
Methanol	193 Kgs
Ammonia	177 Kgs
Steel	Variable
Oil Refining	Variable

Chemicals – Ammonia, Methanol and Others

Hydrogen is most commonly used as a feedstock in the chemical industry primarily for the production of ammonia and methanol. Ammonia is used as a fertilizer, an energy carrier, a refrigerant, chemical stabilizer, etc., whereas methanol is used as a feedstock to produce other chemicals compounds and fuels. Ammonia is increasingly being positioned as a future fuel source due to advancements in technology and ability to produce it in a clean manner. It can be considered for marine fuel, as an energy carrier and for power generation. The ammonia industry is thus expected to play a major role in the green hydrogen sector as it not only generates replacement based demand, but also drives demand through new applications.

Oil Refining

Hydrogen is utilized in the oil industry to refine crude oil. Its reactive nature allows it to remove contaminants such as sulfur through a process known as hydrotreating. It is used in hydrocracking to break compounds down into smaller molecules and is also used as a chemical stabilizer.

Steel Industry

Traditionally, natural gas has been utilized as a reducing agent in the steel industry. Due to decarbonization targets, hydrogen is gaining traction as a fuel source in the steel industry, and also as a reducing agent to remove oxygen from iron ore to form sponge iron (a raw material for steel)

Others

Hydrogen also has a number of other uses in industries such as transportation and power as a fuel source, food processing for hydrogenation, and pharmaceuticals as a raw material, among other industries.

In the future, as technology matures and dependence on fossil fuels reduce, significant demand can be expected from the transportation and the energy and heating sector specifically.

Transportation Sector

Hydrogen fuel cell technology and hydrogen internal combustion engine (ICE) technology are seeing significant development. Fuel cells produce electricity through an electrochemical process that combines oxygen and hydrogen, whereas hydrogen ICE is a modified version of mainstream ICE vehicles (with hydrogen as a fuel source). Their application is being actively explored in the road, maritime and aviation-based transportation industries.

Energy and Heating Sector

Hydrogen can be used for domestic heating or industrial heating. On a domestic level, it can replace natural-gas heating systems due to its similar infrastructure requirements. On an industrial scale, it can be used to generate mid-grade (100°C – 400°C) and high-grade heat (400°C+). Hydrogen can also be used to decarbonize existing natural gas grid through blending upto a portion with natural gas (grid injection).

Further, it be used to produce power for the grid as a low-carbon alternative to fossil fuels and hence can be employed as a storage system – Hydrogen produced during excess availability of renewable power can be utilized to produce clean power during lower availability of renewable power.

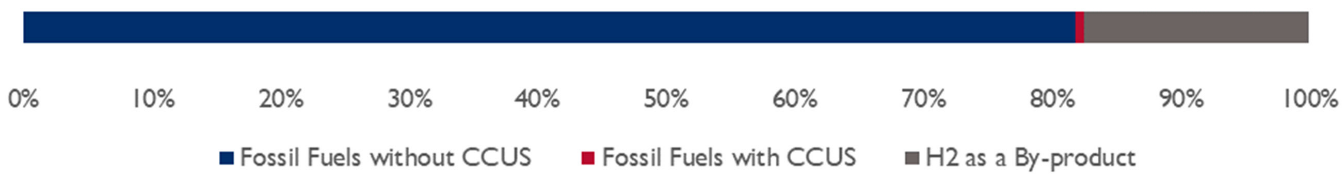
These future uses will further drive demand for hydrogen, creating a robust foundation for a hydrogen-based economy.

The biggest demand centers for hydrogen are China, USA, Russia, and India, representing the potential hotspots for replacement demand of green hydrogen. In 2020, China led the curve consuming 27% of the total 87.2 MMT of hydrogen produced globally. This was followed by the US, India, and Russia with a consumption of 13%, 8% and 7% respectively (Statista, n.d.).

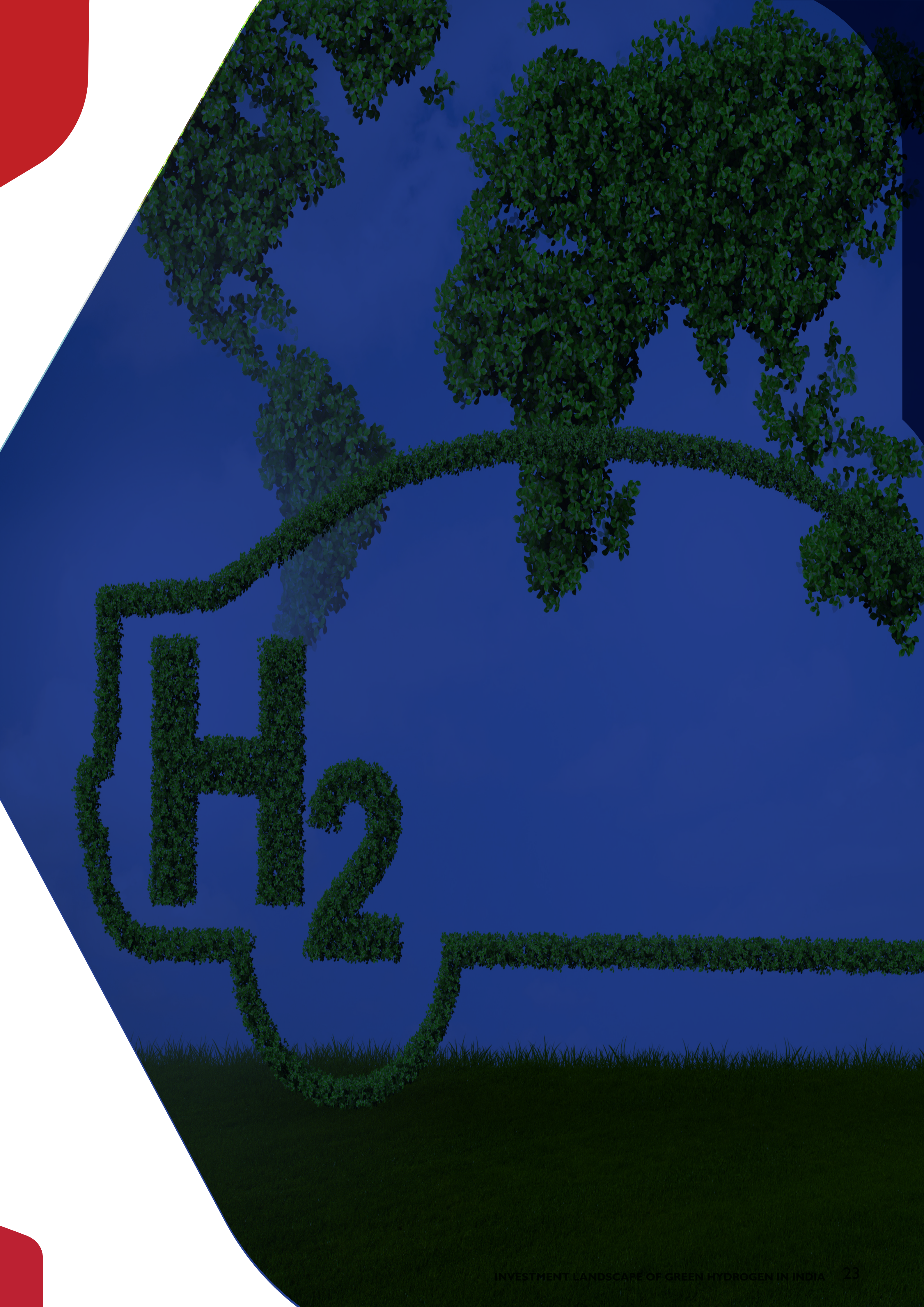
The figure below provides insights into the size of each of the country's steel, chemical and oil refinery industries as of 2020.

Figure 12: Country-wise breakdown of steel, chemical and refinery Industries (World Population Review, 2020), (IEA, Production, consumption and trade of ammonia in selected countries and regions, 2020), (PetroOnline, 2021)

Figure 13: Hydrogen production by technology (IEA, 2021)



At present, most of the hydrogen demand is met by grey hydrogen leading to immense potential for green hydrogen to replace this demand. Hydrogen is also viewed as a valuable energy carrier due to its high energy density (nearly three times the energy density of diesel) complemented by zero emissions in the production process. As such, there is a considerable global push to put green hydrogen at the center of the energy transition.

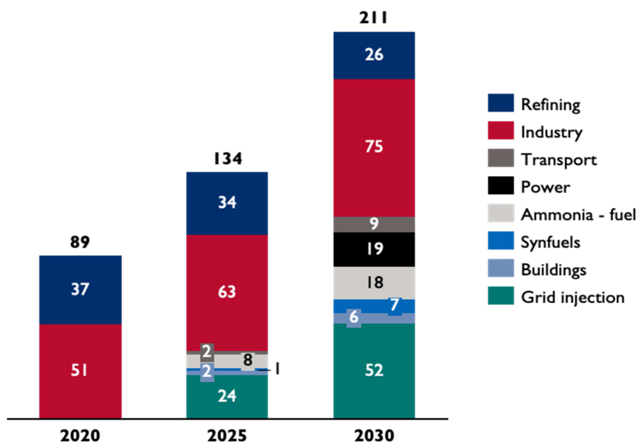

H2

GLOBAL PUSH FOR GREEN HYDROGEN

Countries are seeking low-carbon energy sources and materials to meet the ambitious targets laid out by the Paris Agreement. Hydrogen is placed at the centre of this transition as it will play an instrumental role in achieving the net zero targets set globally. In the International Energy Agency's net zero scenario, low carbon hydrogen and hydrogen-based fuels are expected to reach a production capacity of 528 MMT by 2050, avoiding nearly 60 GT of CO2 by 2050, which accounts for ~6% of global emissions (IEA, n.d.).

If these targets are adhered to, demand for hydrogen can reach as much as 211 MMT by 2030, from 89 MMT in 2020 (IEA, 2022).

Figure 14: Global Demand (MMT) by sector in net zero scenario (IEA, Global hydrogen demand by sector in the Net Zero Scenario, 2020-2030, 2022)



As per other estimates, the hydrogen market size was valued at US$130 billion in 2021 and is projected to reach nearly US$ 231 billion by 2030, a 78% increase from current levels. (GlobalNewswire, 2022). A significant portion of the global hydrogen demand is likely to be met by green hydrogen, given its rapidly improving competitiveness resulting from decreasing electrolyzer costs and renewable energy prices. However, currently, green hydrogen is significantly more expensive than hydrogen produced from natural gas and other fossil fuels.

The competitiveness of green hydrogen is expected to improve as the cost of CO2 emissions increase and this gets added to the price of grey hydrogen. For example, the price of carbon offsets is expected to increase nearly fifty times, from $2.5 / ton of CO2 in 2020 to $120 / ton in 2025 (BloombergNEF, 2022).

Given the market potential of green hydrogen and its role in the decarbonisation of industries, multiple countries have been proactive in announcing policies and targets to foster growth of local green hydrogen ecosystems. Many of them have launched supporting regulations and built roadmaps for the sector's growth. Some of these are highlighted in the Annexure with a high level overview of initiatives in South Asia provided below.

Table 5: Green hydrogen initiatives by South Asia countries

South Asian Countries	Green Hydrogen Initiatives
Bangladesh	• The country does not have a dedicated hydrogen strategy or mission. However, the country has taken active strides to explore alternative energy sources, including hydrogen. In 2021, Bangladesh set up its first pilot green hydrogen plant in Chittagong
Bhutan	• In the 2021 Bhutan Sustainable Hydropower Development Policy, the government placed a special focus on innovation, investment and development of the hydrogen economy • The policy also encourages the adoption of hydrogen as an alternative fuel source and the integration of hydro-power with hydrogen-based storage technologies such as ammonia fuel, and hydrogen fuel • The country will soon launch its Green Hydrogen Road Map
Maldives	• At present no major steps have been taken by the government of Maldives to further the green hydrogen economy. However, ADB did launch a road map for Maldives' energy transition which places a major emphasis on producing hydrogen as well as exploring it as a fuel source
Nepal	• Nepal does not have a dedicated policy / strategy for green hydrogen. However, in 2022, they successfully conducted a Green Hydrogen summit to discuss the potential road map. • As per the Minister of Energy, In the short term, Nepal is looking to utilise its abundant hydro-power resources to produce green hydrogen for energy security, and the fertilizer sector specifically. • In 2022, GreenZo had signed an MOU with API Power to set up a 50 MW Green hydrogen Plant in Nepal by 2025
Sri Lanka	• As per the Ministry of Power and Energy, Sri Lanka is focused on establishing a joint road map for nuclear and hydrogen-based energy to meet its energy needs • The Petroleum Development Authority of Sri Lanka has collaborated with Greenstat hydrogen India to assess the feasibility of establishing a plant in Sri Lanka

The national targets announced by global governments are being supported by incentives of various scale. These are broadly related to technical mandates, carbon pricing, production support schemes, and creation of initial consumption demand. Considering the sector's nascency, these incentives are crucial to push local ecosystems from demonstration stages to achieving commercial scale.

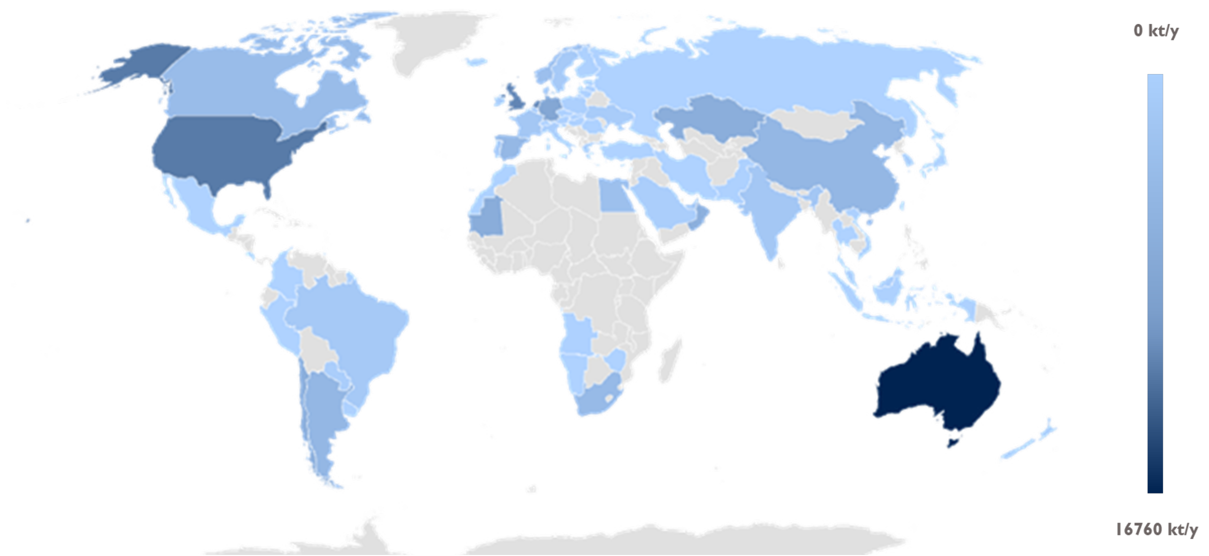
Figure 15: Potential policy interventions (IRENA 2022, Internal Analysis)

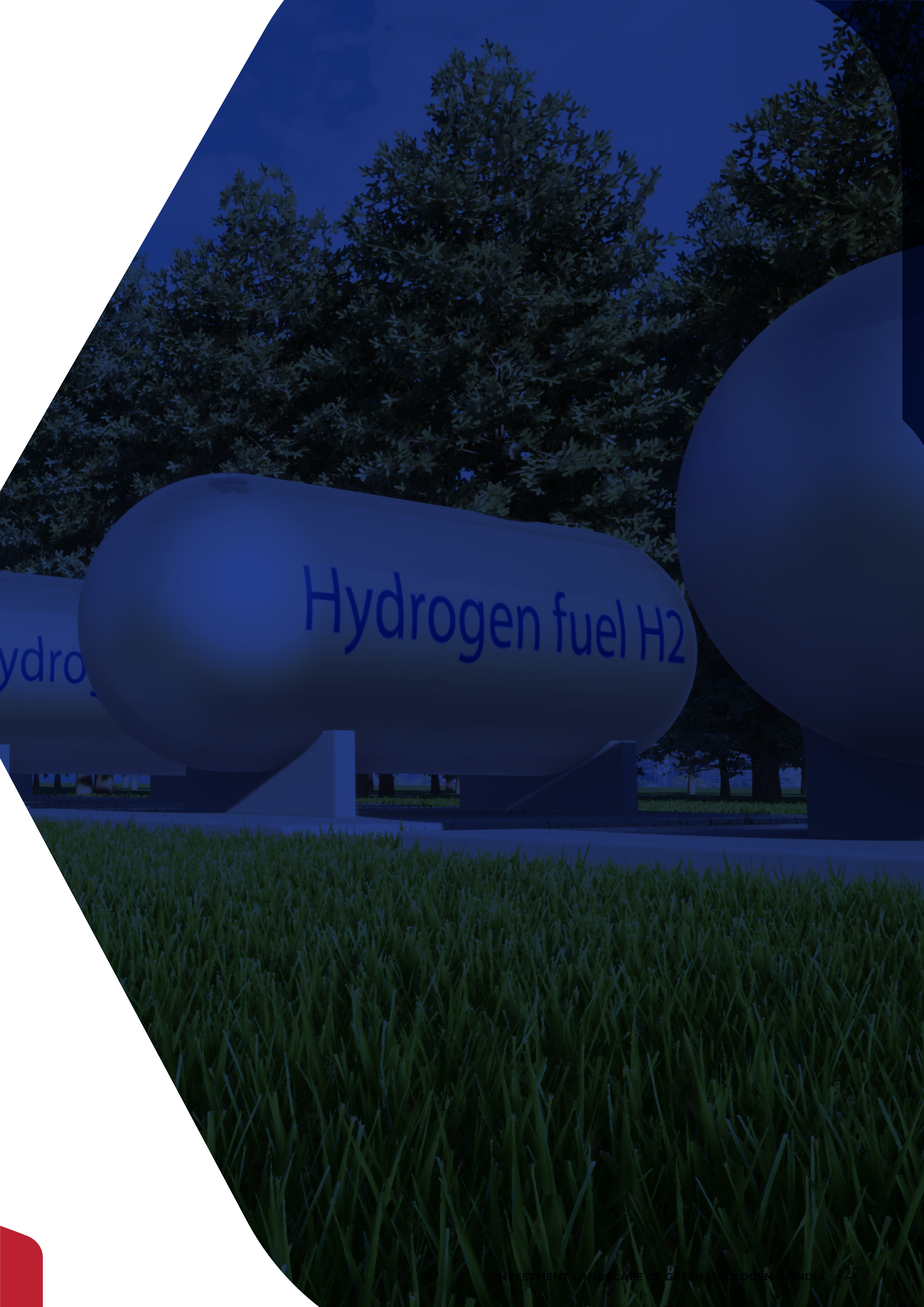
DEMONSTRATION → COMMERCIALISATION → DECARBONIZATION

	Intervention	Examples
	Industrial decarbonisation strategies	UK industrial decarbonization strategy
CARBON PRICING	Carbon taxation	Urguay, New Zealand have levied carbon tax
CARBON PRICING	Emission Trading	Republic of Korea has adopted Korean emissions trading scheme
TECHNICAL MANDATES	Gasmix targets and quotas	Spain and Chile have set targets
TECHNICAL MANDATES	Banned & mandated phase of fossil fuels	France has banned exploration and extraction of fossil fuels
SUPPORT SCHEMES	Bilaterial auctions	Portugal is launching Europe's first auction for piped hydrogen
SUPPORT SCHEMES	Carbon contracts for difference	Germany has taken a leading role in implementing CCfDs, the EU will soon follow
SUPPORT SCHEMES	Tax rebates	US Government has floated a clean hydrogen production tax credit of up to $3.00/kilogram
SUPPORT SCHEMES	Funding grants	EU established the innovationfund, estimated to provide $38 billion
MARKET CREATION	Product-specific instruments	Tax differentiating and capital allowances have been implemented in UK
MARKET CREATION	Quotas for green products	German Hydrogen strategy discusses a green-certification scheme
MARKET CREATION	Sustainable public procurement	Government of India pledged to buy low-carbon construction material
MARKET CREATION	Ecolabelling	Japanese government has taken strides via ecoleaf an eco-labeling company
	Research and development	Australia renewable energy agency allocated USD 40 million for the sector
	Guarantees of origin	Netherlands is amongst the first to issue guarantees of origin

The roadmaps and policy support by various governments have also been complemented by various industry initiatives. As per International Energy Agency's 'Hydrogen Projects Database', over 480 GW electrolyzer capacity was announced or under advanced stages of development as of October 2022. This includes around 4.6 GW under construction as well.

Figure 16: Capacity of projects announced - in kt per year hydrogen (IEA)




Hydrogen fuel H2

GREEN HYDROGEN IN INDIA

Green hydrogen and ammonia are expected to play an important role in India's decarbonization journey. The country has a target for 45% reduction in emissions intensity of GDP by 2030, from 2005 levels. Renewable energy has played a critical role in this by significantly decarbonizing India's power sector. For context, non-fossil energy sources comprise over 41% of India's installed capacity today (Invest India, 2023). With green hydrogen and ammonia, renewable energy's role is extended to decarbonization of sectors beyond power generation. Green hydrogen and ammonia would also be critical for achieving energy security and reducing India's reliance on fossil fuel imports, which currently account for over 40% of India's energy requirements (MNRE, 2023). As such, the sector has seen a lot of traction from both Government and industries to accelerate the growth of the entire ecosystem.

INDIA'S GREEN HYDROGEN TARGETS – THE POLICY PUSH

The National Hydrogen Mission was launched on August 15, 2021, with a view to cutting down carbon emissions and increasing the use of renewable sources of energy. In January 2023, India's Union Cabinet approved the 'National Green Hydrogen Mission', the sector's flagship program aimed at making the country a global hub for production, utilization, and export of green hydrogen and its derivatives. The mission outlines national objectives and the roadmap for government initiatives for the sector till 2030.

> 5MMT	125 GW	50MMT	~$97B
Annual Green Hydrogen Production Capacity by 2030	Associated Renewable Energy Capacity Addition by 2030	Annual CO_2 emissions averted by 2030	Estimated total investments by 2030

Phase 1 (2022-2026)

- Creating demand while enabling adequate supply through domestic electrolyzer manufacturing capacity
- R&D, pilot projects for future energy transition in hard-to-abate sectors (steel, heavy-duty mobility, shipping)
- Incentives aimed at indigenization of the value chain

Phase 2 (2026-2030)

- Green hydrogen production costs to be competitive with alternatives in refining and fertilizers
- Depending on maturity, potential for commercial scale projects in steel, mobility, and shipping
- R&D, pilot projects for other potential sectors like railways, aviation etc.

To support the mission's key objective of at least 5 MMT/ annum green hydrogen capacity, a domestic electrolyzer manufacturing target of **60-100 GW capacity by 2030** has been announced. This is 7.5-12.5 times more than even the global electrolyzer manufacturing capacity of ~8 GW in 2021 (IEA, 2022). The mission also aims to achieve cumulative reduction in fossil fuel imports over USD 12 BN, abatement of nearly 50 MMT of annual greenhouse gas emissions and creation of over 600,000 jobs.

Apart from targets highlighted in the National Hydrogen Mission, the government has also announced a target for reduction of green hydrogen production costs – less than **US$2.5/kg by 2025** and **US$1/kg by 2030** (ETEnergyWorld, 2022).

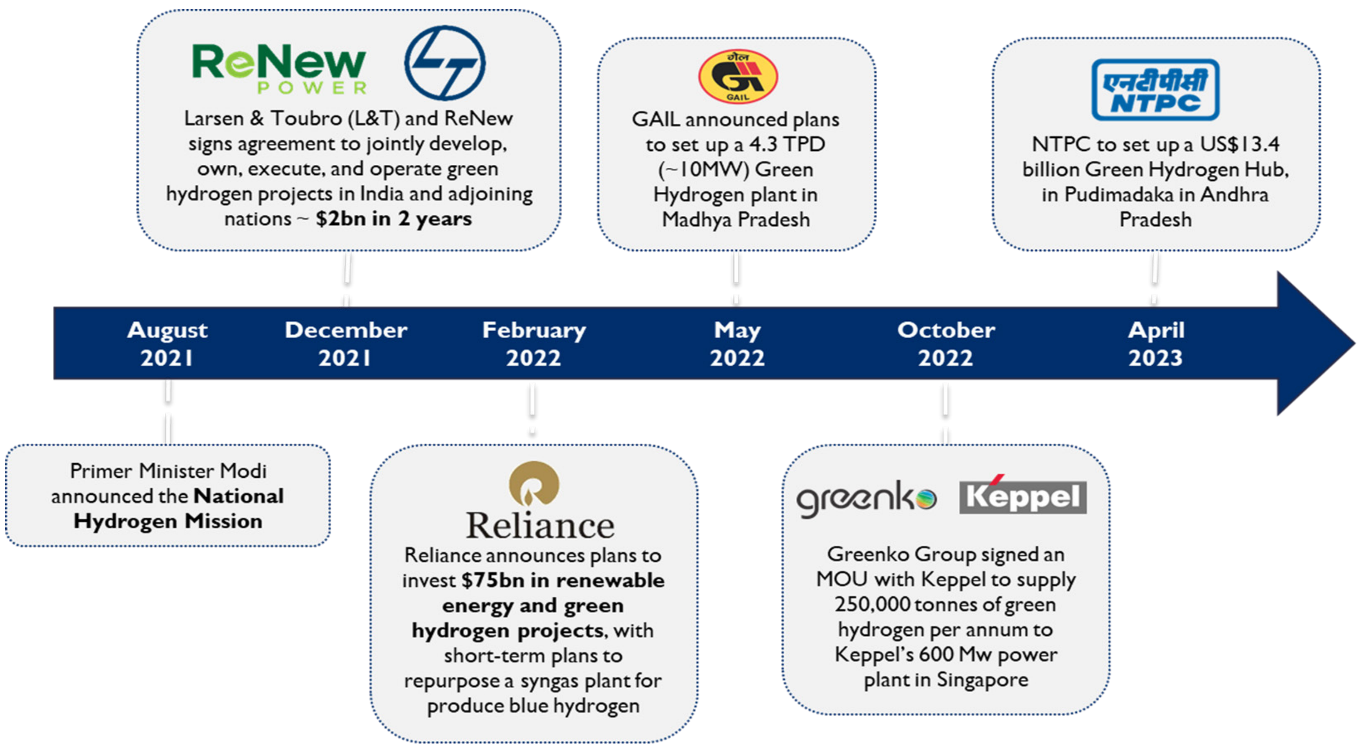
The National hydrogen mission has seen an extremely positive response from various stakeholders and although some have highlighted that further clarity is required around few key items including incentives, they have stated that this is the much-needed step from a policy perspective towards growing the ecosystem.

INDIA'S GREEN HYDROGEN ANNOUNCEMENTS - THE INDUSTRIAL RESPONSE

The Indian industry has come up with myriad of announcements (see Annexure) to develop the green hydrogen ecosystem and has also highlighted ambitious targets. For example, in 2021, Reliance Industries Limited announced plans aimed at lowering green hydrogen production cost to less than $1/kg over a decade (TOI, 2021). This is detailed further in the investment landscape section.

These announcements are indicative of a significant boost in the supply side. However, for all these announcements to materialize into commercially feasible projects and business models, there needs to be further push from the policy side to grow domestic demand as well as incentives and support across the value chain to make the final cost of product competitive. Several stakeholders interviewed during the development of this report highlighted that this also needs to be topped with incentives for the ecosystem players and disincentives for existing grey hydrogen users to tackle the issue from a demand and supply perspective.

Figure 17: Some major announcements in the sector (USAID SAREP Analysis)



India is well positioned to be global hub for green hydrogen production, particularly as announced initiatives are implemented over the upcoming years

62 GW
India's solar capacity (2022)
42 GW
India's wind capacity (2022)

India has competitive energy costs driven by abundant renewable energy resources and government policies

60-100 GW by 2030
Electrolyzer capacity as per National Hydrogen Mission's Target

There is strong push to ramp up electrolyzer supply through local manufacturing

India's Position in Global Markets (2021)
3rd Ammonia Consumption
4th Oil Refining Capacity
2nd Steel Production

Presence of one of the largest domestic market for hydrogen, though with limited ability to pay a significant green premium

10 states
Identified by GOI to become key hydrogen manufacturing enablers

Availability of complementary support infrastructure with initiative for development of dedicated production hubs

India has considerable advantages including having a good mix of right resources and proactive steps from government and industry to foster a domestic green hydrogen and ammonia ecosystem. However, there are certain challenges which need to be adequately addressed to ensure growth of the sector. The following section highlights some of these key advantages and challenges.

ADVANTAGES

ABUNDANCE OF RENEWABLE ENERGY

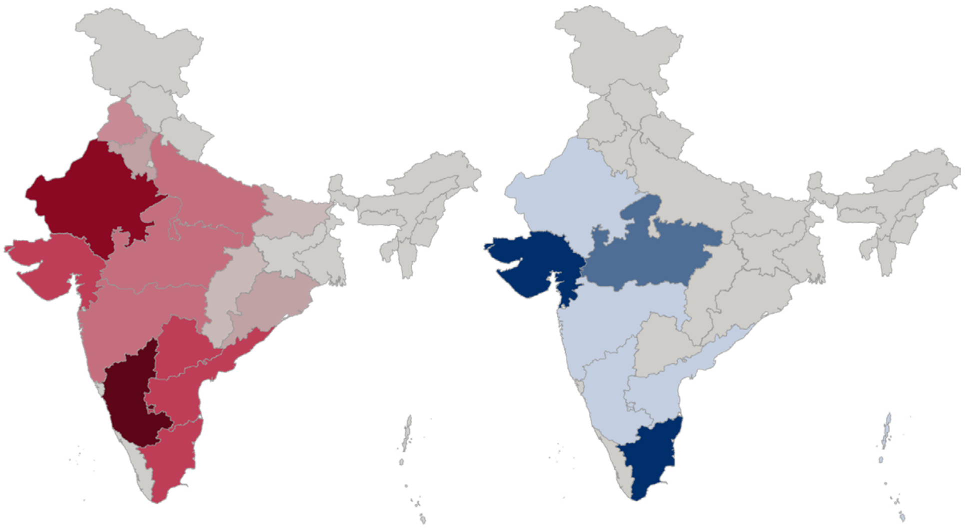
With renewable energy production or procurement typically comprising an estimated 50-60% of hydrogen production costs (Koundal, 2022), a high renewable energy availability at a low cost becomes the foremost requirement for a green hydrogen production destination.

India has an abundance of renewable energy potential with estimated solar energy potential of about 750 GW and wind energy potential of 695 GW at hub height over 120 meters. (PIB, 2020) The country already has installed generation capacities of 62 GW and 42 GW (Nov 2022) respectively (MNRE, 2022), and has achieved globally competitive prices going as low as US$ 0.027/kWh for solar (PV Magazine, 2022), US$ 0.03/kWh for wind power (JMK Research, 2021) and US$ 0.044/ kWh for round-the-clock power with annual CUF at 80%. (CEEW-CEF, 2020) Hydropower remains less competitive and mostly restricted to the public sector, with private sector accounting less than 10% of the total capacity (ORF, 2022).

Considering green hydrogen projects usually need to rely on a mix of renewable energy sources to achieve round-the-clock renewable energy, India benefits from the fact that its key renewable energy producing states such as Gujarat, Rajasthan, Karnataka, Maharashtra, among others, have excellent solar as well as wind resources. This offers the potential to develop single-site hybrid assets for powering electrolyzers which in turn helps to bring down transmission costs for projects

Further, renewable energy procurement is eased by India's policies outlined in the Green Hydrogen Policy (launched in February 2022).

Figure 18: India's solar (left) and wind (right) capacity concentration (MNRE, 2021)



Flexibility to procure renewable energy from self-developed plants, third-party plants or the Power Exchange

Waiver on inter-state transmission charges for a period of 25 years, for projects coming up till 2025

Availability of grid banking for surplus renewable energy, up to a period of 30 days

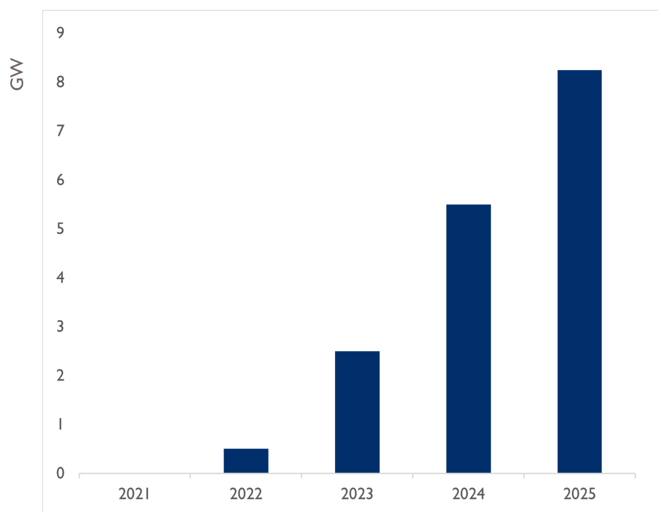
The incentives highlighted in the policy provide developers with the potential for significant energy cost optimizations. For example, the waiver of transmission charges can allow developers to select remote sites with better renewables potential at no additional costs for transmission. Availability of banking can reduce dependence on expensive alternate energy sources such as battery installations which is otherwise required for powering electrolyzers during non-sunshine hours and periods of generation losses. This will allow reduction in energy costs, making the green hydrogen costs more competitive.

SIGNIFICANT PUSH TO OPTIMISE EQUIPMENT SUPPLY CHAIN THROUGH RAMPING UP LOCAL MANUFACTURING CAPABILITIES

Development of large-scale green hydrogen production capacity would require a strong upstream market that ensures supply of high quality, low-cost electrolyzers in large volumes. While electrolyzers can be imported, development of local manufacturing capabilities would be instrumental in optimizing cost and ensuring a streamlined supply chain. This is particularly critical in the current scenario where increasing demand has led to a global electrolyzer supply crunch, with order books of key global players "booked and overflowing till 2025" (ET, 2022).

India has planned a significant ramp-up of local electrolyzer manufacturing capacity, with a target of 60-100 GW capacity by 2030 under the National

Figure 19: Electrolyzer manufacturing capacity in India (Rystad)



Hydrogen Mission. The industry has also backed these with announcements of investments in gigawatt-scale electrolyzer manufacturing facilities, mostly in partnership with international manufacturers. At present, manufacturing facilities for 8 GW electrolyzers have already been announced till 2025 (PV Magazine, 2022). These developments are expected to enable a robust local supply market and bring down electrolyzer costs for developers in India (Business Standard, 2022).

SUITABILITY OF PROJECT SITES AND SUPPORT INFRASTRUCTURE

Green hydrogen production can be land-intensive particularly if the area utilized for renewable energy production is also accounted for as part of the project. This is a key reason why land scarce countries such as Japan and South Korea find it more practical to import green hydrogen than to produce it domestically (PV Magazine, 2021).

Further, production sites need to have good connectivity with consumption destinations. For export-oriented projects, this means access to ports with supporting infrastructure such as storage facilities, jetty-less terminals for onloading on ships, among others. Projects aimed at domestic consumption can either be co-located at demand centers or can utilize existing pipeline infrastructure to save on high transportation costs. India already trades and consumes large volumes of LNG, providing scope for significant infrastructural synergies with green hydrogen and ammonia (Menon, 2022).

To support site availability, the Indian government has requested states to create land banks for renewable energy and green hydrogen deployment. Further, they have also identified 10 states that could be key enablers in manufacturing of green hydrogen, based on presence of use-case industries, availability of ports, and renewable energy resources, among others. These are expected to have zones and clusters dedicated to the production of green hydrogen and ammonia, providing appropriate sites and dedicated infrastructure to support large scale production capacity (Moneycontrol, 2022).

Major energy agencies and ecosystem players have highlighted that a cluster-based approach or hydrogen hubs will play an important role in developing the ecosystem. These industrial locales, in which electrolysis facilities may be located in close proximity to industrial users, shipping and transport infrastructure, are expected to achieve economies of scale. Various plans to achieve such concentrations are now emerging in India. The National Hydrogen Mission has highlighted a 'cluster-based production and utilization model' to improve viability of hydrogen projects during initial years.

Figure 20: States identified as enablers in manufacturing green hydrogen by Govt. of India (Moneycontrol, 2022)

Potential Benefits of a cluster-based approach in developing Green H2 ecosystem

- Co-ordinated and optimal planning of projects resulting in pooling of resources and developing common infrastructure for projects to achieve economies of scale. This is particularly helpful to optimize:
  - » Storage and distribution infrastructure (storage facilities, pipeline network, fueling stations etc.)
  - » Utilities infrastructure (desalination plants, power transmission network etc.)
  - » Access to ports and supporting infrastructure for export-oriented projects
  - » Access to major demand centers in cases where hubs are developed close to demand clusters for example refineries/ fertilizer production plants which in turn will help reduce challenges around transport
  - » Pilot projects in newer applications, for example, mobility and steel, which can be supported easily in these hubs taking advantage of existing ecosystem
- Production clusters may benefit from exclusive incentives that could be provided by the government such as capex or opex subsidies for hydrogen production, purchase premiums and tax incentives
- Cluster approach can help to develop dedicated knowledge and skill centers that can further aid development of the ecosystem

The concept of hydrogen clusters is also seeing traction from industry bodies and sub-sovereign entities. For example, the Indian Hydrogen Alliance (IH2A) and Govt. of Kerala will be setting up a large Green Hydrogen Hub in Kochi (IH2A, 2022). This is expected to include several incentives for project development, including deployment of large-scale common storage and distribution infrastructure at the envisaged hub.

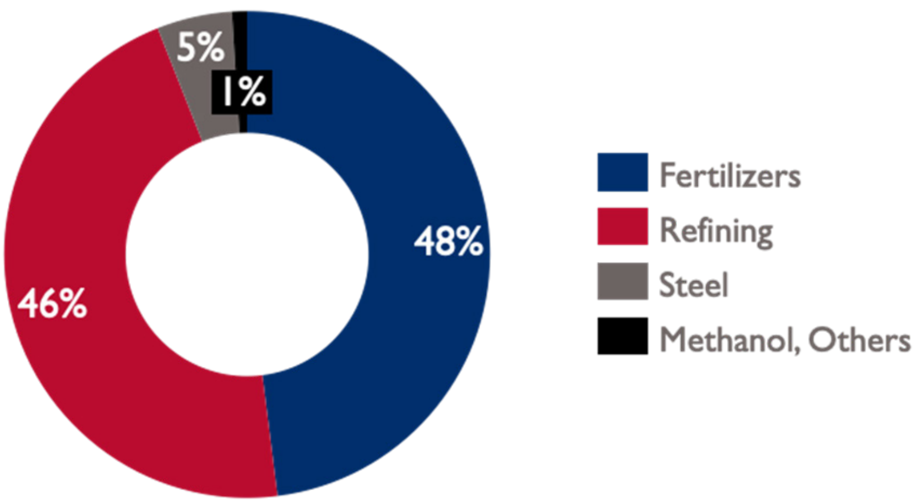
Table 6: Overview of green hydrogen announcements in India

Proposed Green Hydrogen Hubs in India	
NTPC announced a Green Energy Park Project at Pudimadaka in Anakapalle *(Proposed)*	The proposed hub will have a production capacity of 1500 TPD and the estimated cost is US$13.4 billion
Government of Kerala announced plans to set up multiple Hydrogen Hubs in partnership with IH2A *(Proposed)*	The government has announced a US$ 24 million budget to set up Hubs in Kochi and Trivandrum. As per state's draft GH2 policy, government hopes to provide incentives to reduce cost to $2/kg and later to $1/kg
IH2A *(Proposed plants)* • Ankleshwar-Vadodara in Gujarat as National Green Chemicals and Ammonia Fertilizer Hub • Bellary-Nellore (Karnataka-Andhra Pradesh) as National Green Steel and Chemicals Hub • Pune-Mumbai (Maharashtra) as National Green Steel and Transport Hub	• The park will have a 40 MW electrolyser plant, producing 8000 tonnes Green H2 per annum • The park will have a 30 MW electrolyser plant, producing 5000 tonnes Green H2 per annum • The park will have a 30 MW electrolyser capacity plant, producing 5000 tonnes Green H2 per annum

PRESENCE OF CONSUMPTION MARKET

India is one of the largest consumers of hydrogen globally, with consumption of ~6 million tons in 2022 (TERI, 2022). Most of the consumption is seen in the production of ammonia fertilizer (48%) and oil refining (46%), while the remaining is utilized in steel production (5%), methanol production and other industrial production processes (1%).

Figure 21: Hydrogen Consumption in India (MEC+, IEA, WorldSteel)



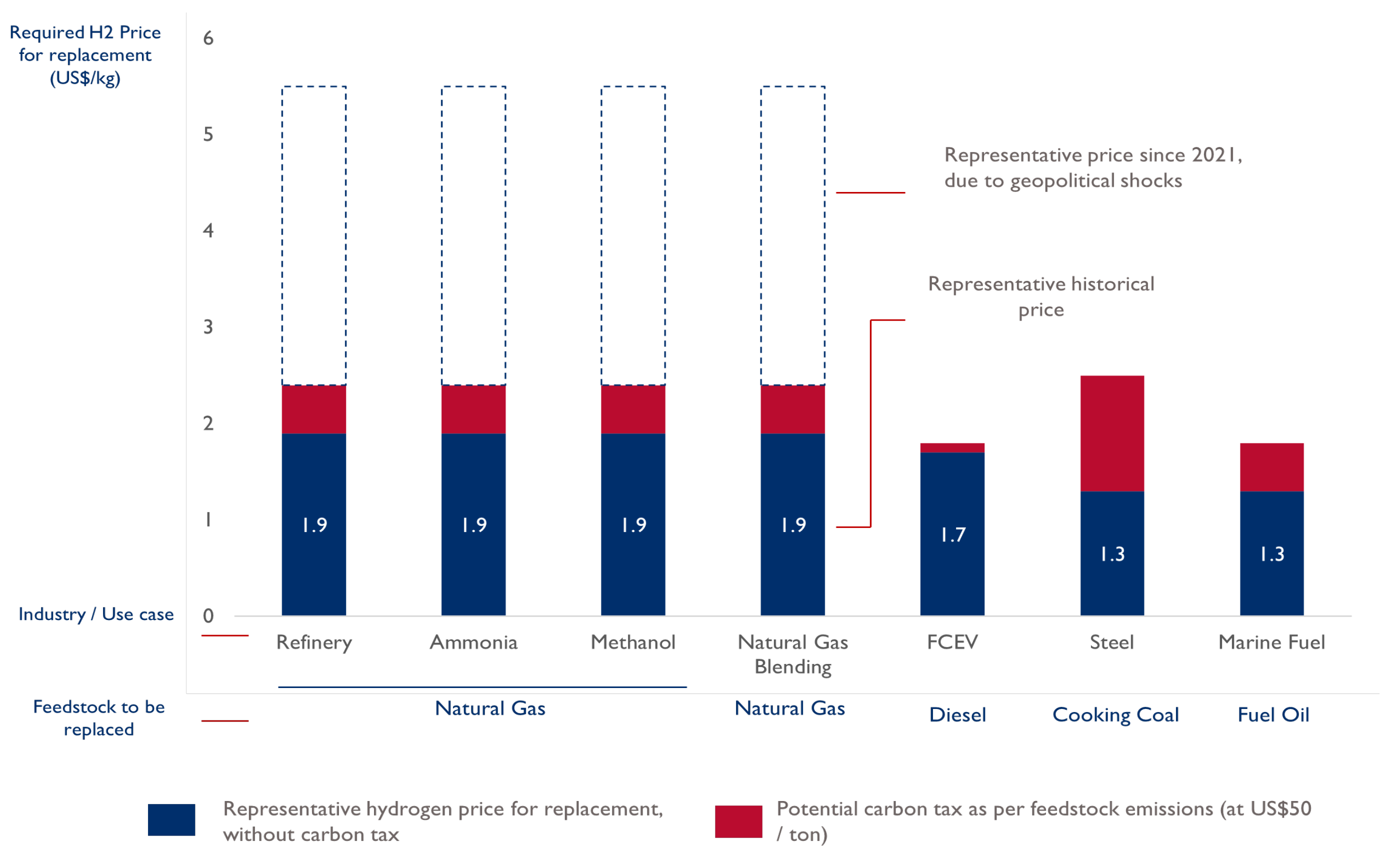
Considering that replacing existing demand of grey hydrogen is expected to drive green hydrogen market before new use cases mature, existence of a large domestic consumption market can be instrumental to spur production of green hydrogen in India. However, it should be noted that any large-scale replacement demand will require some parity between grey and green hydrogen prices, particularly in the fertilizer market, which is run on massive subsidies leaving limited scope for any green premiums (Outlook, 2022). Pricing challenges are discussed in the subsequent section.

CHALLENGES

THE COST CHALLENGE

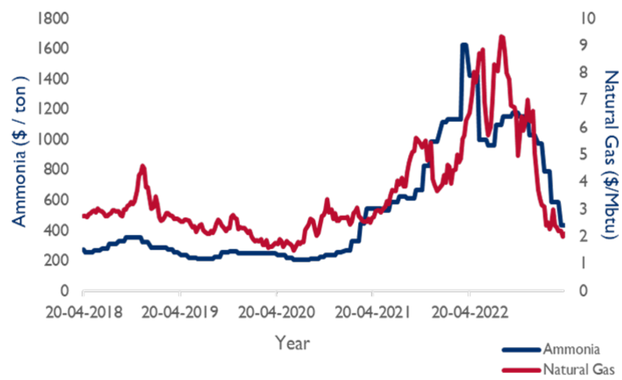
Green hydrogen is expected to decarbonize multiple industries by replacing carbon-based fuels like natural gas, diesel, coal, marine fuel oil, among others. Large scale demand-driven adoption of hydrogen will only occur when the industries relying on carbon-based fuels can commercially justify the switch to green hydrogen. For India, the price parity with green hydrogen alternatives would be achieved at ~US$1.9/kg for industries using grey hydrogen directly, ~US$1.7/kg for diesel in vehicles, and ~US$1.3/kg for coal and marine fuel oil in steel and shipping respectively (Mckinsey, 2022).

Figure 22: Cost of replacing conventional energy sources with Green Hydrogen in India. (Mckinsey, 2022)



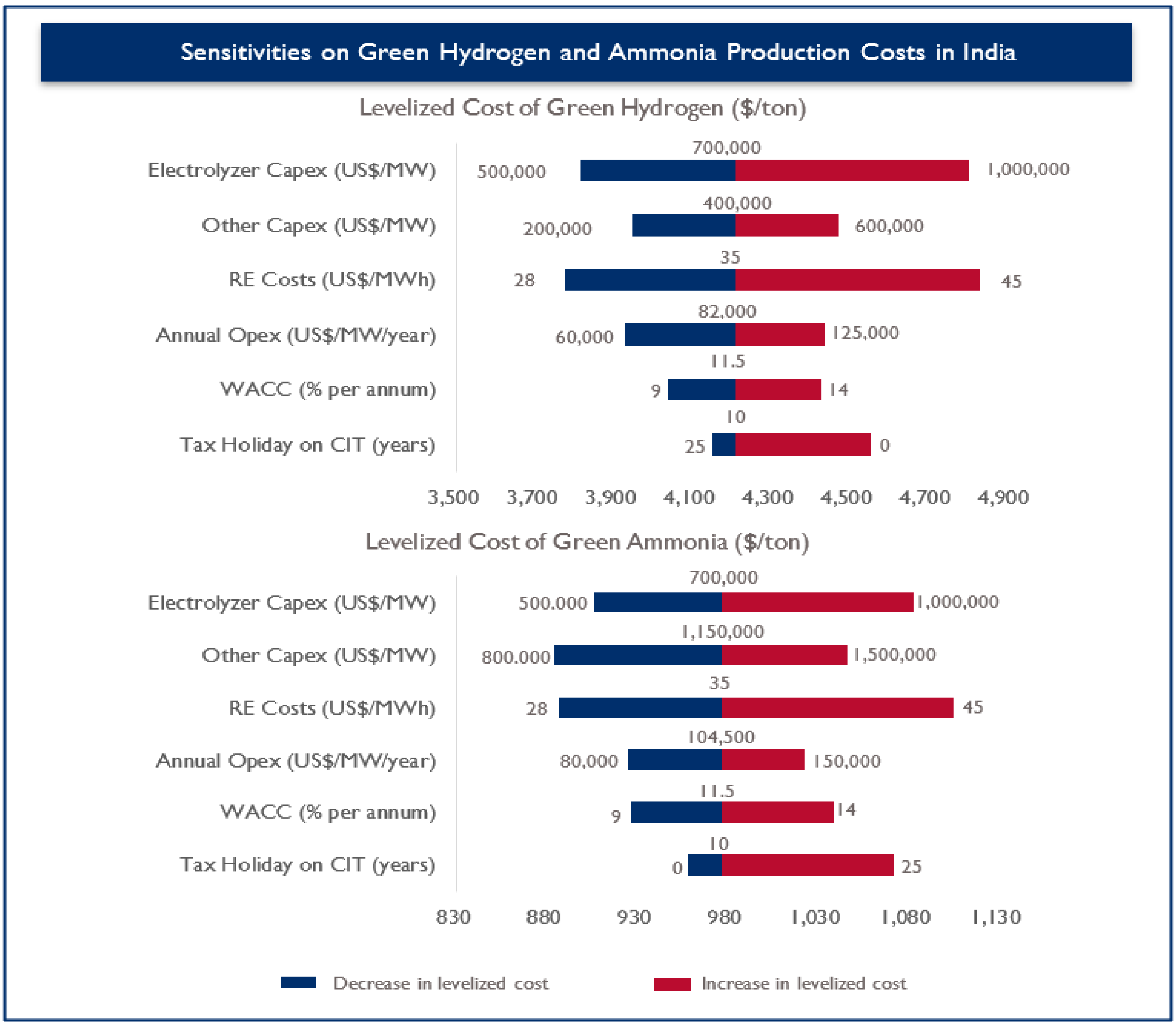
Although achieving price parity is a challenge, green hydrogen still has some advantage over its grey alternative. Grey hydrogen has historically been priced below an average of less than US$ 2 per kg but its prices increased sharply when natural gas supplies declined due to the onset of Ukraine war in 2021. Prices increased to over US$ 5 per kg in most markets, effectively bringing grey hydrogen prices on par with green hydrogen prices. (Euronews, 2022) This is, however, expected to change as natural gas prices normalize. As such, green hydrogen has a natural advantage given its prices are not correlated with a highly volatile commodity such as natural gas and pricing is generally expected to remain stable.

Figure 23: Natural Gas and Grey Ammonia Historical Prices (Bloomberg)



Green hydrogen (and ammonia) primarily uses renewable energy as feedstock, the costs of which mostly depend on the upfront capex being levelized over project duration, thus allowing high visibility on future production costs. Since green hydrogen and ammonia costs are also a function of their high upfront capex, along with largely predictable operating costs, they are calculated as levelized cost of hydrogen (LCOH) or ammonia (LCOA). **The current LCOH and LCOA for green hydrogen and ammonia production in India is estimated to be US$ 3,800-4,800 and US$ 850-1,100 per ton respectively, depending on various input parameters.**

Figure 24: Levelized cost of green hydrogen and ammonia in India (USAID SAREP Analysis)



Key Benchmarks and Assumptions

Electrolyzers (Stack and BOP)
CAPEX: USD 500-800k / MW (AEM); 700-1200k / MW (PEM)

Ammonia Synloop
CAPEX: USD 120-200k / tpd
OPEX: 1-2.5% of EPC

Air Separation Unit
CAPEX: USD 90-120k / tpd N2
OPEX: 1-3% of EPC

Hydrogen Storage
CAPEX: USD 700-900k / ton H2
OPEX: 0.1-0.4% of EPC

Ammonia Storage
CAPEX: USD 1-3k / ton NH3

Other Costs
Include transmission infrastructure, pipelines / port infra, and other components

Conversion Factors

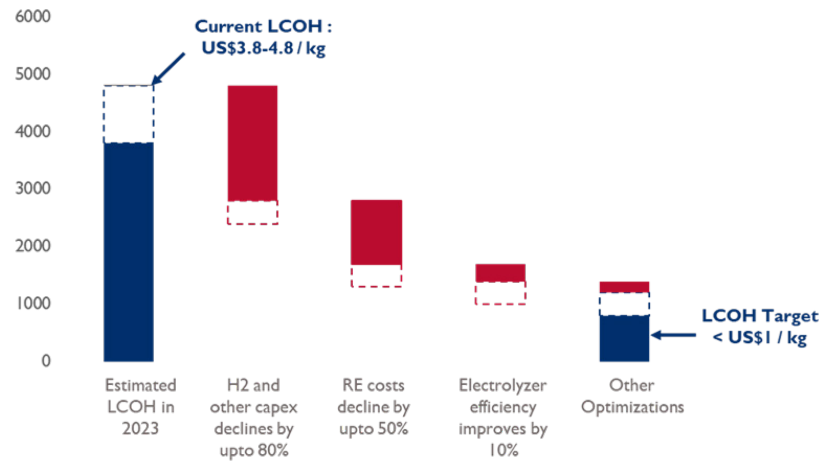
Energy to H2: 50-55 MWh energy / ton H2
Water to H2: 9-10 m3 / ton H2
H2 to NH3: 5.5 tons NH3 / ton H2
H2 generation per MW electrolyzer: ~100-150 TPA

Assumptions and Benchmarks based on internal analysis of data sourced from multiple primary and secondary sources and are indicative only.

For context, the target of lowering green hydrogen production cost to less than $1/kg over a decade is significantly lower than this estimated LCOH. Also, if we compare this to the target costs to achieve commercial parity for alternative feedstock, as highlighted above, this is US$2.5-3.5/kg (65-75%) higher. To achieve the necessary price parity with grey hydrogen, various levels of optimization across key parameters impacting LCOH can be explored. For example, cheaper renewable energy sources and electrolyzers can play a big role in achieving this parity.

Figure 25 Pathway to LCOH of US$1/kg (USAID SAREP Analysis)

The pathway to envisaged LCOH of US$1/kg is expected to involve significant reductions in electrolyzer and support infrastructure's capex, renewable energy costs and improvements in electrolyzer efficiency, among other optimizations.



THE RESOURCE CHALLENGE - AVAILABILITY OF WATER

Water is a critical input for producing green hydrogen. To produce 1 ton of green hydrogen, electrolyzers require around 9-10 m3 of demineralized water while the rest of plant can utilize around 60-95 m3 of raw water for cooling and other operational purposes (Shah, 2023).

This can be a challenge for large projects coming up in dry regions, where water desalination becomes the preferred procurement option adding up to 4% to green hydrogen costs (RECHARGE, 2021). Further, there can be environmental concerns leading to non-feasibility of projects - for example, a 6 GW project in South Australia was discontinued due to risks associated with water supply and desalination (PV Magazine, 2022).

Although estimated freshwater requirement for India's green hydrogen targets represent less than 0.1% of India's annual freshwater withdrawals (Knoema, 2019), large-scale projects may be required to source water from seawater desalination, particularly in states with freshwater challenges. These include states such as Rajasthan, Gujarat, Tamil Nadu, and Madhya Pradesh, among others. (Scroll, 2023) India is yet to outline a clear policy on water consumption for green hydrogen projects.

Potential mitigation strategies:

- Improving desalination techniques to make the process more efficient and cost effective can help address this problem. For example, BP and Yara International are considering using treated seawater in their plants in Western Australia
- Improving R&D in wastewater usage can also address this problem. The National hydrogen mission already talks about optimizing water utilization through "the use of industrial or municipal wastewater for hydrogen production, wherever feasible"

Pilot projects for both the technologies can be supported through added policy incentives.

688B m3 / annum
India's agricultural water withdrawal

56B m3 / annum
India's municipal water withdrawal

0.05B m3 / annum
Estimated DM water for 5M MT Green Hydrogen production

Figure 26: Overview of Transportation and Distribution Infrastructure in India

~17,000 Kms in length	Trackage of ~127,000 Kms	~220 Ports	6,300,000 Kms road network

Please note: The pipeline length above represents the length of the natural gas pipeline

STORAGE, TRANSPORTATION AND DISTRIBUTION IN INDIA

TRANSPORTATION

India presently lacks a dedicated hydrogen transportation infrastructure, as a majority of the hydrogen is produced for captive usage. Nevertheless, as the hydrogen economy continues to grow, India has the potential to utilize its existing distribution infrastructure, which comprises extensive pipeline coverage, a vast road and railway network, and shipping infrastructure, to accommodate the growing need.

Constructing a dedicated pipeline network for hydrogen is expensive. Therefore, India will most-likely focus on retrofitting its existing natural gas pipelines to accommodate hydrogen in the short term. Presently, India has a natural gas pipeline network spanning over 17,000 kilometers, with an additional 15,000 kilometers under development (Ministry of Petroleum and Natural Gas, n.d.). However, the existing pipeline can only blend a low percentage of hydrogen, the exact percentage is still under evaluation. But a rough estimate of 5-20% can be taken if the existing pipeline infrastructure is comparable to that of Europe (European Comission, 2022). Another limitation of the pipeline includes its sparse coverage in certain regions – including northeastern states, and some of India's islands due to terrain. In this case, other modes of transport such as trains, ships and trucks can be explored.

Trucks and trains are useful for last mile and inland delivery of hydrogen; however, they are less cost-effective as hydrogen must primarily be transported in its liquid or chemical carriers. If railway transport were to be explored, Indian railways, which operates the fourth-largest network in the world, covering almost 126,000 kilometers, could offer a feasible option for consumers whose facilities are located far from production units or ports (Indian Railways, n.d.). There are various advantages for this mode of transport including the ability to precisely plan transport times, the high level of reliability and safety, and the possibility of transporting large quantities inland. While rail transport has not been utilized for hydrogen in India thus far, its use case is being explored in Germany and experts have determined that, "there is nothing from a technical point of view against transport by rail". The only roadblock that remains is to develop a container that has been approved for freight (PV magazine, 2020). However, this can be overcome as, rail and road transport are similar and the Indian railway sector, on occasion, has transported oil and natural gas as well, opening the avenue for replicability.

STORAGE

In India, the most common method of hydrogen storage is through pressurized cylinders or storage tanks, which are mostly used for on-site storage and transportation. Cylinders come in four different forms, with lighter varieties, which are typically utilized for non-stationary applications, being import dependent (Ministry of New and Renewable Energy, Goverment of India, 2007). Although most storage tanks are expected to be onsite, large scale storage facilities near potential hydrogen clusters can be explored. The National Hydrogen Mission has referenced exploring pilot projects in that space although details are not available at this point.

During stakeholder interactions, a leading midstream player in the country suggested that "there is significant gap in midstream infrastructure development even in grey ammonia market" and as such highlighted the need for a focused approach for midstream infrastructure development for promoting the green ammonia ecosystem especially when targeting export markets.

For potential export facilities, the national green hydrogen and green ammonia policy also highlights that "manufacturers of Green Hydrogen / Green Ammonia shall be allowed to set up bunkers near Ports for storage of Green Ammonia for export / use by shipping. The land for the storage for this purpose shall be provided by the respective Port Authorities at applicable charges."

For bulk-storage applications, India has access to significant geological storage capacity in the form of deep saline aquifers, sedimentary basins, and potential salt structures. A recent study found that deep saline aquifers alone have an estimated capacity of around 22,600 TWh, while major sedimentary basins like the Krishna-Godavari, Rajasthan, Cauvery, and Cambay basins have capacities of over 7,100 TWh (Vishal, Verma, Sulekh, Singh, & Dutta, 2023). The combined capacity of these two storage options alone is equivalent to approximately 35% of Europe's onshore and offshore storage capacity (Caglayan, et al., 2020).

Although other forms of hydrogen storage such as solid-state storage facilities using metal and complex hydrides and liquid hydrides exist, they are yet to be commercially deployed in India.


H2 ENERGY STORAGE
H2
HYDROGEN
ENERGY

INVESTMENT LANDSCAPE IN INDIA

The green hydrogen sector is still in its early stages in India, and widespread adoption of the technology will require a comprehensive push towards sustainability, accompanied by a significant reduction in production costs. Production costs are expected to be reduced as technology matures and production capacity scales.

Such scaling of capacity will require large-scale patient capital to support development of a robust ecosystem. The cost of capital will need to be highly competitive to achieve the lowest prices acceptable to buyers. This would be a challenge as financiers tackle uncertainty about various technical, commercial, legal, and other aspects, in the absence of banked precedents and established models for green hydrogen.

MARKET LANDSCAPE IN INDIA

As discussed in earlier sections, the green hydrogen sector has received significant attention from the Indian industry, which has further accelerated after the launch of the National Hydrogen Mission. However, most of the current announcements have been on the production side of the value chain, with large-scale projects relying on potential offtake from third-party domestic or international consumers. The consumption side is yet to see similar interest, with limited announcements for large-scale green hydrogen offtake or captive production.

Some of the key stakeholders, based on announced or ongoing initiatives in the sector, are highlighted in the infographic below. Details on individual announcements in the Annexure.

Figure 27: Key Stakeholders in India's Green H2 Ecosystem - non-exhaustive (USAID SAREP Analysis)

PRODUCTION-SIDE MARKET

- **India's public and private sector entities have both come forward to announce targets for large scale production of green hydrogen and ammonia.**

These primarily include large conglomerates, renewable energy developers, oil refiners, and steel manufacturers. A representative from a large electrolyzer manufacturing company pointed out that renewable energy players are looking at the sector with greatest enthusiasm, as it offers them an alternative market for building their renewable energy capacity in addition to public tenders.

- **Public Sector Undertakings have been actively setting up pilot projects in the country**, focusing on the objective of local capacity building for hydrogen technologies. Private players have been focused on developing large scale projects and have entered into MOUs with multiple state governments to secure land sites and other government support for export-oriented projects.

Case Study: NTPC's Green H2 refueling station in Leh

NTPC is setting up a Green Hydrogen fueling station at a project site that is 36,000 meters above sea level in Leh. The pilot project will have a capacity of 80 kg per day Green Hydrogen and will be powered by a dedicated 1.25 MW solar power plant. The project is being executed by Amara Raja Power Systems.

During stakeholder interactions, a company representative highlighted that an important consideration for setting up the project in a location like Leh was **to demonstrate and test the deployment of Green H2 infrastructure in challenging conditions.**

- While a significant production capacity has been announced, its realization is contingent upon the developers' ability to secure offtake for these projects.

As of April 2023, very few projects have been able to secure long-term offtake contracts for their planned output. Production for captive use has also been mostly restricted to pilot or small-scale projects.

Case Studies: Projects with advanced stage offtake negotiations

In August 2022, Jindal Stainless (Hisar) Ltd. signed an offtake agreement with Hygenco India Pvt. Ltd. to build, own and operate a multi-MW Green Hydrogen facility for 20 years. The project will house an alkaline electrolyser with up to 75 TPA in initial phase, expandable to 250 TPA (Jindal Stainless, 2022) (Argus Media, 2022)

In February 2023, Uniper and Greenko signed exclusivity for offtake in the upcoming Green Ammonia Project in Kakinada. Under the agreement, the entities will negotiate a purchase agreement for 250,000 TPA Green Ammonia for export to Europe. (Uniper, 2023)

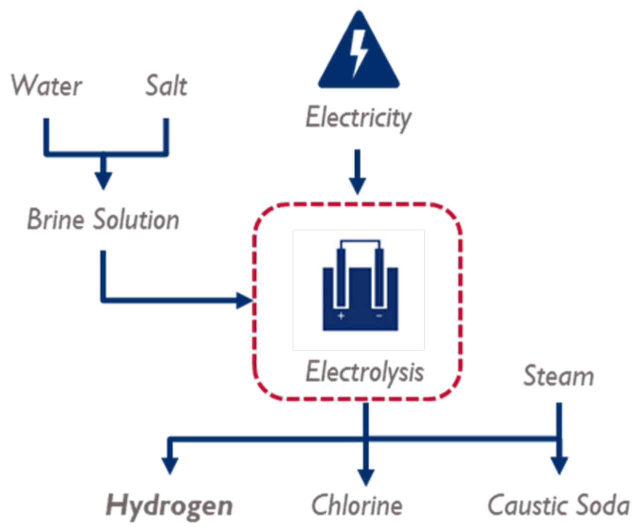
- **At the end of 2022, India's electrolyzer manufacturing capacity was less than 1 GW, with Ohmium as the largest local manufacturer**

Ohmium has an operational 500 MW (expandable to 2 GW) per annum facility for PEM electrolyzers in Bengaluru (Ohmium, 2021). A major portion of electrolyzer capacity has been traditionally used to cater to demand from the chlor-alkali industry in India (EY, 2023).

- **India is expected to witness a significant ramp up in electrolyzer manufacturing capacity with a target pipeline exceeding 8 GW by 2025 (PV Magazine, 2022).**

Multiple players in the green hydrogen value chain have strategically partnered with foreign electrolyzer manufacturers for joint development of electrolyzer gigafactories in India. These include partnerships between Reliance-Stiesdal, Greenko-John Cockerill, Adani-CRT, among several others.

Case Study: Hydrogen in the Chlor-Alkali Industry



- The chlor-alkali industry, which produces chlorine, caustic soda and other such chemicals, relies on specialized electrolyzers (mercury cell, membrane or diaphragm), and generates hydrogen as a byproduct.
- A representative from a top 3 caustic soda manufacturers in India highlighted that India produces 5 Mn TPA caustic soda, which leads to 125,000 TPA hydrogen as a byproduct.
- Converting chlor-alkali industry's power consumption to renewable energy can be a critical step towards replacement of grey hydrogen (here, as a byproduct).

Despite significant techno-commercial challenges, the Indian industry has shown a strong and aggressive intent towards production of green hydrogen. However, multiple stakeholders have expressed that this intent is primarily constrained by the limited consumption demand, which will ultimately determine whether these initial announcements will advance to later stages. A few developers also pointed out that the "non-urgent target of achieving net zero emissions" has limited the growth of local demand for various commercial and industrial applications.

CONSUMPTION-SIDE MARKET

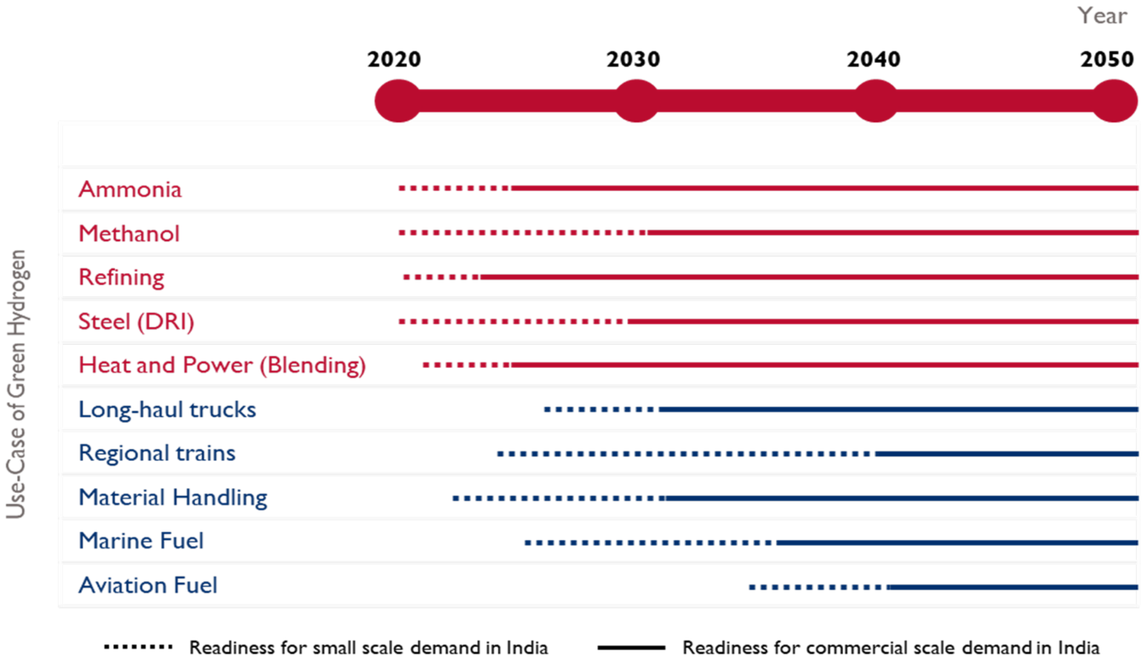
As India gears up to achieve its decarbonization targets over the next few years, it is expected that there will be a significant uptake in consumption demand of green hydrogen and its derivatives with improved commercial viability due to technology improvements and government incentives. This demand is expected to be driven largely by replacement of grey hydrogen in industries such as oil refining, ammonia, gas distribution, steel, and mobility among others. Since some of these sectors are 'hard-to-abate' sectors, government can also consider an external push to consumption demand through sector-focused mandates. The next section deep dives into the consumption side in further detail and how it can be expected to evolve in the coming years.

Industries with the least green premium or switch - over cost in terms of overall impact of hydrogen price in final product prices will be the early transitioners. This includes refining and natural gas distribution sectors. For example, some research suggests that usage of 20% green hydrogen in a refinery will only increase the cost of the final product by 1-5% (VS, 2021) and as such will probably have the easiest transition. Petroleum refining will also have reliable H2 demand which may also increase in the near term due to tighter sulphur regulations all around the globe (for example IMO 2020).

Sectors such as the fertilizer, steel and mobility industry with technological challenges or lower capacity to absorb such a premium are expected to transition at a slower stage. For example, while the use case of ammonia fertilizers has advanced technological readiness, it unfortunately has low commercial readiness in India. This is because of hydrogen's high proportion in the cost of output ammonia fertilizer, and the market's inability to absorb a green premium, with existing pressure on subsidies.

Other than domestic-based demand, India is also expected to become a key export hub for green hydrogen, as it can cater to import demand from regions such as Japan, European Union, South Korea, Singapore, and others. These regions are expected to be key demand centers but are not ideal for large-scale production.

Figure 28: Industry-opinion on consumption demand by different sectors in India. (USAID SAREP Analysis)



INVESTMENT POTENTIAL BY CONSUMPTION SECTORS

The sections below highlight sector-wise market and investment potential for green hydrogen in India under three different scenarios till 2030.

The **'Base Case'** has an underlying assumption that existing public and private sector momentum for green hydrogen would continue and announced projects will be implemented over the next few years.

The **'Pathway to NHM'** assumes that government will introduce significant mandates, subsidies and other incentives to drive demand in green hydrogen sub-sectors to push production capacity to at least 5 MMT by 2030, in line with the NHM target.

The **'Business as Usual'** assumes a downside scenario where green hydrogen is not able to replace existing alternatives and only few announcements materialize.

POTENTIAL FROM DOMESTIC CONSUMPTION

Domestic demand for green hydrogen is expected to be largely driven by oil refining, natural gas blending and fertilizer industries until 2030. Other use cases such as steel, transportation, methanol, among others are expected to move beyond pilot and small-scale projects post this period, when techno-commercial feasibility for these improve.

OIL REFINING INDUSTRY

Industry Growth and Opportunity

India's refinery industry is one of the largest in the world, producing approximately 240 million tons in FY 2022. (Ministry of Petroleum and Natural Gas Economics & Statistics Division, 2022). The industry is poised to grow rapidly, with domestic demand for oil expected to increase from 4.7 million barrels in 2021 to 6.7 million barrels in 2030. To accommodate this demand, the government aims to double the industry's capacity to 500 million by 2030 (Economic Times, 2020).

Refineries rely on vast quantities of hydrogen in 'de-sulfurization' of crude oil to make petrol, diesel, and other chemicals. The Indian refineries consume approximately 3 million tons of hydrogen annually, nearly all of which is grey hydrogen and produced using the SMR process.

Green Hydrogen Investment Potential

Total demand for hydrogen in India's oil refining industry is projected to reach ~6 million tons by 2030. The sector is expected to be among the first to transition to green hydrogen, considering a non-significant impact on output economics - hydrogen only accounts for 2-4% of total costs (RMI ; Niti Aayog, 2022).

Key Considerations

The industry's adoption of green hydrogen is expected to begin as early as 2023. While the government has not announced any explicit targets for the sector, multiple oil public sector undertakings (PSUs) have announced internal targets for adoption of green hydrogen. These targets have significant heterogeneity in terms of consumption volumes and timelines.

Three scenarios have been highlighted to model the Indian refineries' transition to green hydrogen with the base case assumption of 10% hydrogen demand being met by green hydrogen in 2030, considering similar internal targets from leading oil PSUs such as Indian Oil (Business Standard, 2022).

The sector's demand potential will require significant investments in setting up additional renewable energy capacity, electrolyzer capacity and other support infrastructure for green hydrogen production. Under a standard configuration for large scale plants (assumptions in Annexure), investment requirements from oil refining industry are estimated at $10.8B to achieve 10% demand from green hydrogen (under the base case) and $32.5B to achieve 30% demand from green hydrogen (under the Pathway to NHM case).

Business as Usual

Green H2 will replace 2.5% of the total demand by 2030

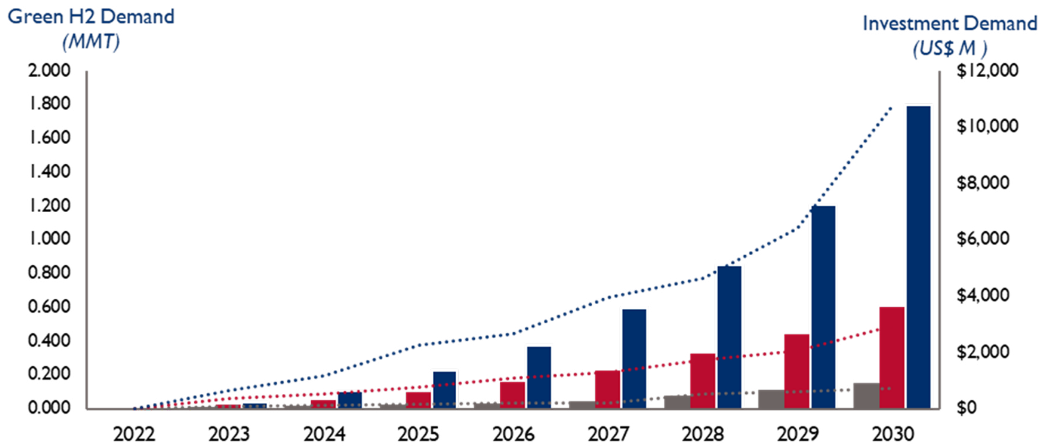
Base Case

Green H2 will replace 10% of the total demand by 2030

Pathway to NHM Target

Green H2 will replace 30% of the total demand by 2030

Figure 29: Green hydrogen demand and corresponding investment demand for the Oil refinery sector in India till 2030



Green Hydrogen Investment Demand for Oil Refineries till 2030

Green Hydrogen in Oil Refinery - 2030				
	Business as Usual	Base Case	Pathway to NHM Target	CO2 emissions avoided by 2030
Hydrogen demand	0.15 MMT	0.6 MMT	1.8 MMT	4.2 – 48 MMT
Investment demand	$ 2.6 Billion	$ 10.8 Billion	$ 32.5 Billion	

NATURAL GAS INDUSTRY

Industry Growth and Opportunity

India has an annual natural gas consumption ~63 billion cubic meters as of 2022 – 30% by the fertilizer sector, 20% by the city gas distribution (CGD) sector, and 15% by the power sector, among others. With a strong government push for replacing more polluting fossil fuels with natural gas consumption, India's natural gas consumption is expected increase to 200.75 billion cubic meters by 2030, representing a CAGR of 15% (IBEF, 2022).

Considering the significantly cleaner footprint of green hydrogen, the government is planning to blend portions of green hydrogen in existing CGD pipelines for natural gas. At present, multiple pilot projects are being carried out to assess the technical considerations of such blending. For example, GAIL has successfully blended up to 2% hydrogen in the Avantika gas pipeline, with plans to expand this to 15% in a phased manner (Economic Times, 2022).

Green Hydrogen Potential

As per current assessments, it is technically feasible and safe to blend up to 20% hydrogen by volume, without significant changes to current natural gas pipelines. If proven scalable, the industry is poised to adopt significant volumes of hydrogen, due to limited upfront investments and demonstrable impact on sector's carbon footprint. While blending increases the overall cost of gas supply (since green hydrogen is more expensive than natural gas), stakeholders in the industry have suggested these can be absorbed by the natural gas sector's balance sheet or passed on minimally to customers.

Key Considerations

Considering the additional safety concerns with hydrogen distribution, its compatibility with existing gas pipeline infrastructure needs to be assessed comprehensively. As per research conducted in the EU and US, hydrogen can be blended anywhere between 5% and 20% of the total volume depending on the piped gas infrastructure.

This report presents an analysis of three scenarios where green hydrogen replaces 10% natural gas in CGD pipelines by 2030, with consideration to government's target of reaching up to 15% by 2035. There is also an analysis of alternate scenarios where 5% and 15% green hydrogen is achieved by 2030 (DownToEarth, 2023).

The sector's demand potential will require investments in setting up additional renewable energy capacity, electrolyzer capacity and other support infrastructure for green hydrogen production. Under standard assumptions, these are estimated at $6.4B to achieve 10% green hydrogen blending in city gas pipelines (under the base case) and $9.7B to achieve 15% green hydrogen blending (under the Pathway to NHM case) by 2030.

Business as Usual

5% Green H2 will be blended into city gas pipelines by 2030

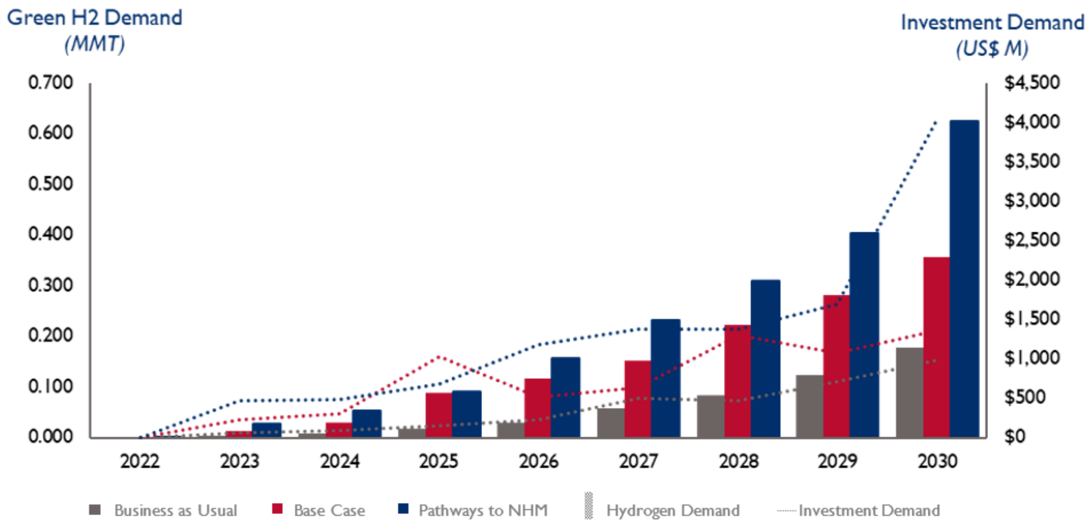
Base Case

10% Green H2 will be blended into city gas pipelines by 2030

Pathway to NHM Target

15% Green H2 will be blended into city gas pipelines by 2030

Figure 30: Green hydrogen demand and corresponding investment demand for the natural gas blending in India till 2030



Green Hydrogen Investment Demand for the Natural Gas blending Sector till 2030

Green Hydrogen in Natural Gas - 2030				
	Business as Usual	Base Case	Pathway to NHM Target	CO2 emissions avoided by 2030
Hydrogen demand	0.18 MMT	0.36 MMT	0.54 MMT	1.4 – 4.3 MMT
Investment demand	$ 3.2 Billion	$ 6.4 Billion	$ 9.7 Billion	

GREEN AMMONIA AND FERTILIZERS

Industry Growth and Opportunity

Since the green revolution in the 1960s, India has been heavily reliant on inorganic fertilizers to support agricultural output. This has resulted in India becoming the second-largest consumer of fertilizers worldwide, with ~63.94 million metric tons consumed in 2021-2022 (The Fertiliser Association of India, 2022).

Around 75% of these fertilizers are nitrate-based and require ammonia as a raw material for production. Hence, fertilizer sector has emerged as one of the biggest hydrogen consumers in India, accounting for nearly 48% of the country's hydrogen demand in 2020 (Nallapaneni & Sood, 2022).

India's limited domestic natural gas availability leads to large-volume imports of ammonia, along with direct fertilizers such as urea, DAP, among others. India currently imports ~3 million tons of ammonia annually (World Bank, 2022). It also directly imports ~26% of its urea needs and ~55% of its DAP needs, along with domestic production from ammonia.

The fertilizer industry is heavily subsidized by the government to keep prices stable and affordable for end consumers (The Fertilizer Association of India, 2022). This led to the government spending over $9 billion on urea subsidies alone, in 2021 (PRS Legislative Research, 2022). Aimed at self-reliance for fertilizers, the Indian government has set the objective to add the maximum urea capacity worldwide over the next 10 years.

Green Hydrogen Potential

The fertilizer industry relies heavily on imported ammonia, urea and DAP, making it vulnerable to fluctuations in highly volatile natural gas prices. The green hydrogen market provides a potential solution by reducing dependence on imported fertilizers and eliminating exposure to these price fluctuations.

In the National Hydrogen Mission, the government of India outlines the target to replace all nitrogenous fertilizer imports with green alternatives by 2035. Considering this, green hydrogen demand between 2023 and 2030 is expected to be largely driven by replacement of imported ammonia, urea and DAP with their green counterparts.

Green ammonia is also expected to have an important role as a green hydrogen carrier and clean fuel. Its demand for the former is excluded here to avoid double counting with hydrogen use cases. Further, its use as a clean fuel is expected to have limited volumes until ammonia-ready transport infrastructure scales. Hence, these newer applications of ammonia are anticipated to contribute to ammonia demand significantly only post 2030.

Key Considerations

The government's focus on substituting fertilizer imports with domestic production is expected to drive the rate of adoption of green hydrogen in the sector, through mandates or subsidies in the sector.

As per numerous developers, adoption of green hydrogen in existing plants would be inconvenient as they would now need to purchase CO2, which was earlier a readily available by-product. Further, there will be an increase in production prices of urea, which without subsidies or incentives could result in inflation.

Three scenarios have been analyzed, with a base case scenario where India replaces 50% of its ammonia, DAP and urea imports by 2030.

Replacement of ammonia and fertilizer imports with green hydrogen-based derivatives would require investments not only in additional green hydrogen production capacity but also ammonia production infrastructure at a minimum. Under standard assumptions for integrated green hydrogen and ammonia production, the sector's investment demand is estimated at $21.9 billion if Indian can replace up to 50% of ammonia, urea, and DAP imports (under the base case) and $28.5 billion if 65% replacement is achieved (under the Pathway to NHM case) by 2033.

Business as Usual

20% of Urea, DAP and Ammonia imports will be substituted by 2030

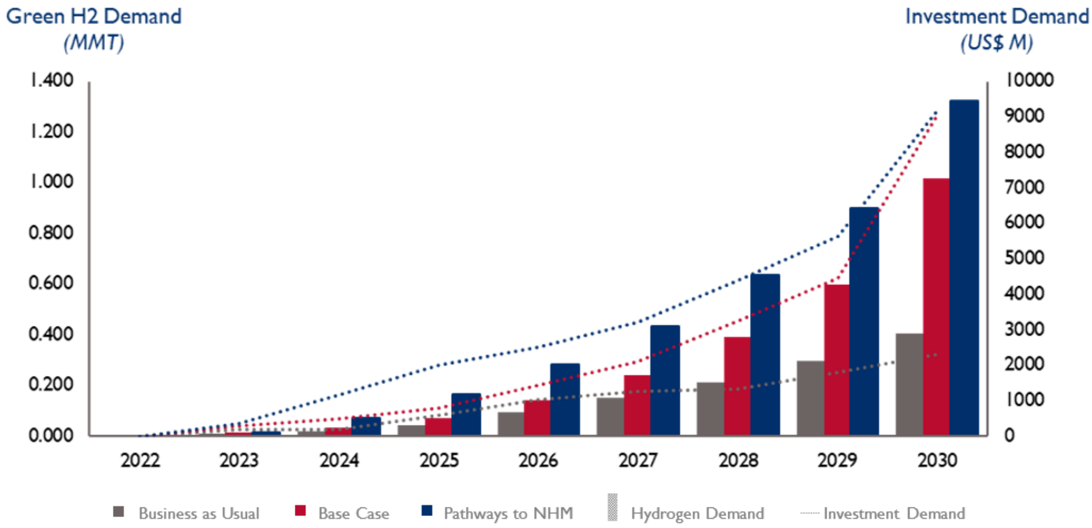
Base Case

50% of Urea, DAP and Ammonia imports will be substituted by 2030

Pathway to NHM Target

65% of Urea, DAP and Ammonia imports will be substituted by 2030

Figure 31: Green hydrogen demand and corresponding investment demand for the fertilizer sector in India till 2030



Green Hydrogen Investment Demand for the Fertilizer Sector till 2030

Green Hydrogen in Fertilizer - 2030				
	Business as Usual	Base Case	Pathway to NHM Target	CO2 emissions avoided by 2030
Hydrogen demand	0.41 MMT	1.02 MMT	1.32 MMT	
Investment demand	$ 8.7 Billion	$ 21.9 Billion	$ 28.5 Billion	11.4 – 35 MMT

OTHERS

Some of the other key consumption sectors for India include steel, transportation, methanol, among others. There are multiple pilot and small-scale projects announced for green hydrogen deployment in these industries. However, these contribute a small portion of total green hydrogen demand in India and their large-scale demand is expected post 2030.

STEEL

Industry Growth and Opportunity

India's steel industry is the second largest producer of crude steel globally, boasting a production of over 130 million tons in 2021-2022. The industry's growth has been fueled by the availability of raw materials such as iron and a cost-effective labor force. India aims to add significant production capacity with a target of 300 million tons per annum by 2030-2031 (IBEF, 2022).

Due to its heavy reliance on fossil fuels, steel production leads to 1.8 tons of CO_2 per ton of steel produced. Consequently, the industry is a major contributor of greenhouse gas emissions, accounting for 7% of the country's total. It is a significantly 'hard to abate' sector, underpinning the potential role of green hydrogen as a viable green solution.

Green Hydrogen Potential

In India, steel production relies on four methods: basic oxygen furnace (BOF), electric arc furnace (EAF), induction furnace (IF), and direct reduced iron (DRI). Around 90% steel production in India is accomplished through Blast Furnace (BF) or coal-based Direct Reduced Iron (DRI), with both methods contributing equally (Ministry of Steel, Goverment of India, 2022).

Presently, hydrogen is not actively utilized in steel production, making it challenging to integrate it into the value chain. The direct carbon emissions in this process come from direct reduced iron (DRI) production, which currently utilizes fossil fuels like coal and natural gas as a reducing agent. However, the use of green hydrogen, produced through renewable energy sources, can replace natural gas and create a clean DRI production process.

Further, hydrogen can be incorporated in the EAF and BOF processes in the near term. For instance, the EAF process can be used to produce "green steel," as it relies entirely on electricity.

Similarly, hydrogen can be introduced through fuel injection into the BOF process, although it cannot serve as the sole fuel source due to incompatibilities with current blast furnaces. This injection process reduces CO_2 emissions significantly, but its feasibility requires further research and analysis, according to the Ministry of Steel.

Key Considerations

Till 2030, it would be unexpected to see significant commercial-scale green hydrogen demand from domestic steel industry, considering the techno-commercial feasibility for the transition is yet to be established. Further, steel is a highly competitive commodity market and is unlikely to absorb the green hydrogen premium without a strong impact on market dynamics. Stakeholders have also reported reluctance amongst steel manufactures as the industry has significant inertia to alter existing infrastructure substantially for incorporating green hydrogen (Ministry of Steel, Goverment of India, 2022).

METHANOL

Industry Growth and Opportunity

India is the third largest consumer of methanol, with an approximate demand of 2.26 million tons as of 2021. However, most of the methanol demand is met by imports and only 20% is produced domestically, primarily using imported natural gas as a feedstock. India's methanol demand is expected to rise to 4.4 million tons by 2030.

Thus, in its effort to reduce this import dependence on both natural gas and methanol, the government is currently focused on increasing domestic methanol production capacity and replacing natural gas-based plants with coal-to-methanol plants (Niti Aayog, n.d.).

Green Hydrogen Transition

Methanol from green hydrogen (green methanol or e-methanol) is being seen as a promising low-carbon liquid fuel and can emerge as a promising alternative in areas such as maritime transport (Iberdola, n.d.). However, the use cases based on e-methanol as a replacement fuel will take a few years to reach scales requiring large scale demand, since methanol-ready transportation infrastructure is limited and will need to be scaled (The Pioneer, 2018).

In the meantime, replacement demand for existing methanol consumption is also unlikely to reach large volumes, given that the methanol industry is currently transitioning to coal-powered plants. Without an external push, green hydrogen consumption is expected to scale with improvements in commercial competitiveness, likely beyond 2030. However, India is expected to see development of export-oriented projects for e-methanol, some of which can come up prior to 2030 (TOI, 2023).

At that point, demand is likely to arise from replacement of methanol imports with methanol produced from green hydrogen.

Key Considerations

Until 2030, it would be unexpected to see significant commercial-scale green hydrogen demand from India's e-methanol industry.

TRANSPORTATION

Industry Growth and Opportunity

India's transportation sector is growing at a CAGR of 5.9% and is among the fastest growing areas in the infrastructure space (FICCI, 2023). It is currently responsible for 14% of India's energy-related CO2 emissions, with projected emissions expected to double by 2030. Decarbonization of transportation is among India's Nationally Determined Contributions under the Paris Agreement, and the government has taken multiple initiatives for its transition to cleaner energy sources, particularly for road transport which accounts for 90% in transportation's CO2 emissions (Roy, 2023).

Promotion of electric mobility has been among the top priorities for the sector. However, there exist multiple environmental and demand-side concerns associated with EVs, with long charging times as a key barrier. Further, EVs are not an efficient option for larger land transport vehicles such as buses, trucks and trains, and long-distance mobility remains a hard-to-abate sub-sector within transportation (News18, 2022).

Green Hydrogen Transition

Green hydrogen and green ammonia are 'clean fuels' and expected to drive medium to long term decarbonization across road, railways, marine, and aviation sectors.

Hydrogen Fuel Cell Vehicles (FCEVs) are being considered a better solution for road transport. Green hydrogen's fueling infrastructure and process is similar conventional petrol/diesel (a key challenge in electric vehicles) and it has three times the energy efficiency of these fuels (RMI, 2019). While India has kickstarted development of FCEV and hydrogen-fuel based cars, buses, trains and ships, the sector is quite nascent and still a few years away from large-scale commercial production (ET, 2022) (Times Now, 2022) (ET, 2022).

Key Considerations

Till 2030, it would be unexpected to see large scale green hydrogen demand from India's transportation sector, considering it will require commercialization of hydrogen-ready transport vehicles and refueling infrastructure.

Indian Railways' Transition Towards Green Hydrogen

The Indian Railways is expected to participate as a key stakeholder in the green hydrogen ecosystem, considering its potential to decarbonize India's trains. To kickstart the transition, the Indian Railways announced plans to issue a tender of **35 hydrogen-powered trains**, initially to be run on heritage and hill routes. (ET, 2023)

The total acquisition cost of the trains is expected to be **~$ 350M**.

Estimated investment in hydrogen-powered train

$ 10M / train

Estimated investment in ground infrastructure per route

$ 8.6M / route

Research highlights that hydrogen fuel consumption for a green hydrogen–based engine with similar energy output as a diesel engine can be **0.66 kg per km** and can be 27% higher costlier than fuel cost for diesel at currently estimated prices. Additionally, the capital cost of fuel cells for a single passenger train can be **$1.46 M**, along with requirements of ancillary equipment. (ETEnergyWorld, 2022)

The capital investment for fuel cell installations can be justified with CO_2 savings from using green hydrogen, which are estimated at **1400g CO_{2e} per diesel vehicle km**. (ORR, UK, 2022)

Estimated hydrogen consumption for a train operating 1000 km / day for 300 days

200 tons

Estimated carbon emission savings for a train operating 1000 km / day for 300 days

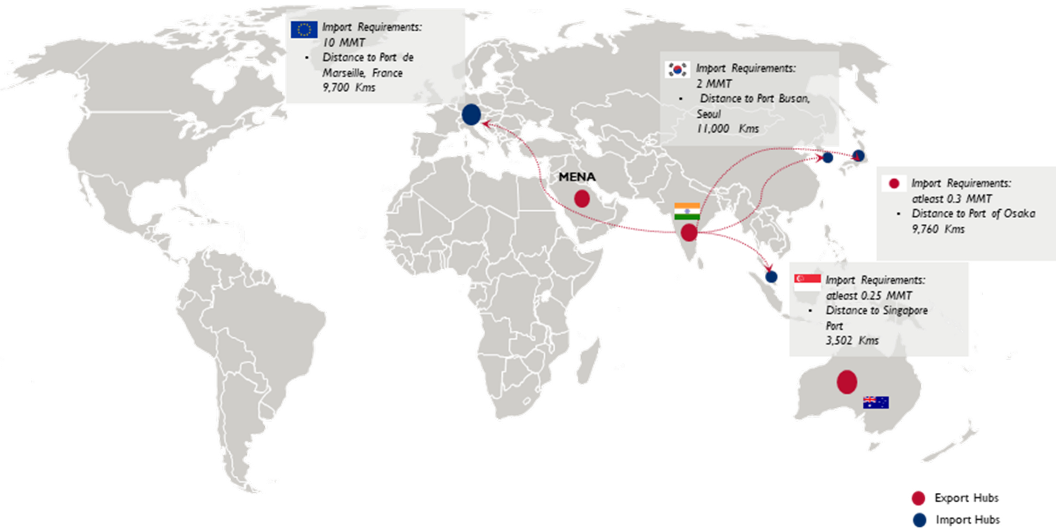
420 tons

POTENTIAL FROM EXPORTS

Hydrogen is assuming a progressively important role in the global energy transition, as nations across the world intensify their efforts to achieve net-zero targets. Most large countries have already announced green hydrogen production and consumption targets for the next few decades (highlighted in Annexure). Countries with more favorable renewable energy generation conditions are focused on intensifying efforts to ramp up production, to cater to domestic as well as export demand from countries having less favorable renewable energy conditions but strong decarbonation agendas. While regions like the Middle East, Australia, India, and others are key net exporters of hydrogen, regions like the European Union, Japan, and US, among others, are net importers due to production side constraints (KPMG, n.d.).

India's National Hydrogen Mission aims to leverage India's abundant renewable energy resources to position the country as a key export hub, with a **target of achieving at least 10% of the world's green hydrogen export market by 2030** (MNRE, 2023).

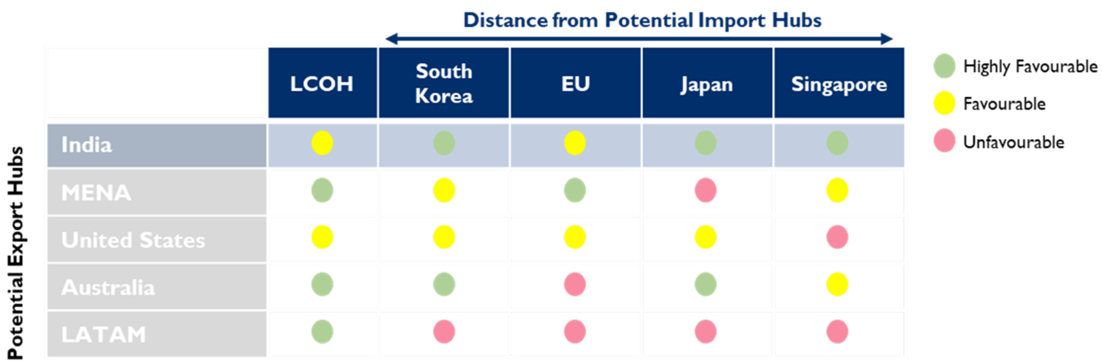
Figure 32: Potential Export Destinations and Distance from India (2030), (International Trade Administration, 2021), (S&P Global Commodity Insights, 2021), (European Comission, n.d.), (Bandhu, 2022)



Japan, Korea, Singapore, and Europe can be the main export hubs for India, based on their import potential, proximity to India, and purchasing power. Other countries such as Bangladesh and Sri Lanka could become potential export destinations in the future, but their hydrogen transition plans are yet to be determined.

Capturing these four markets may be challenging as India faces stiff competition from large exporters such as the Middle East and Australia. While the EU market penetration could be limited given its proximity to the Middle East, the South Korean, Singaporean, and Japanese markets could still present significant import opportunities for the country. The figure below presents a comparative analysis of how India is positioned in terms of LCOH (2030) and shipping distance from most important import hubs as compared to other export geographies.

Figure 33: India Export Potential Assessment (RMI ; Niti Aayog, 2022), (USAID SAREP Analysis)



Please note: Colour grading is based on relativity, and LCOH is based on 2030 estimations

Key Considerations

As per government and stakeholder announcements, aggregate import demand for Singapore, Japan, Korea and the European Union is ~12.5 million tons by 2030. Taking into consideration that some of these countries have already formed strategic partnerships to satisfy their import needs, this report highlights three scenarios for exports of green hydrogen with the base case assumption that 15% of Japan's and Korea's import demands, 5% of EU's import demands and 50% of Singapore's import demands are met by India by 2030.

Considering green hydrogen can be non-economical to ship for exports, it is assumed that export demand would be met primarily by green ammonia exports instead. Based on standard assumptions for such integrated green hydrogen and ammonia projects, export-oriented projects are estimated to require investments of $17.5 billion to achieve 6% of the overall import market of these target destinations (under the base case) and $26.9 billion to achieve 10% of the overall import market from these (under the Pathway to NHM case) by 2030.

Business as Usual

India will meet 3% of the import demand from target markets by 2030

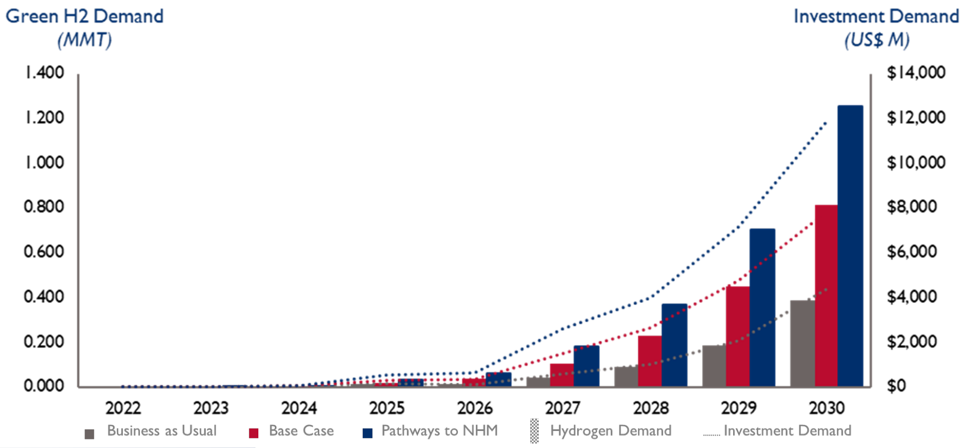
Base Case

India will meet 6% of the import demand from target markets by 2030

Pathway to NHM Target

India will meet 10% of the import demand from target markets by 2030

Figure 34: Green hydrogen demand and corresponding investment demand for India to satisfy export requirement till 2030



Green Hydrogen Investment Demand for the export sector till 2030

Green Hydrogen in Exports - 2030	Business as Usual	Base Case	Pathway to NHM Target	CO_2 emissions avoided by 2030
Hydrogen demand	0.39 MMT	0.81 MMT	1.25 MMT	6.8 – 23.9 MMT
Investment demand	$ 8.3 Billion	$ 17.5 Billion	$ 26.9 Billion	

INVESTMENT POTENTIAL BY VALUE CHAIN

The consumption demand from various sectors is expected to be met by green hydrogen projects being set up as captive plants at consumption sites, or third-party plants supplying to end users or export destinations. These projects will access renewable energy from co-located or remotely located energy projects, with the objective of optimizing energy costs and electrolyzer utilization.

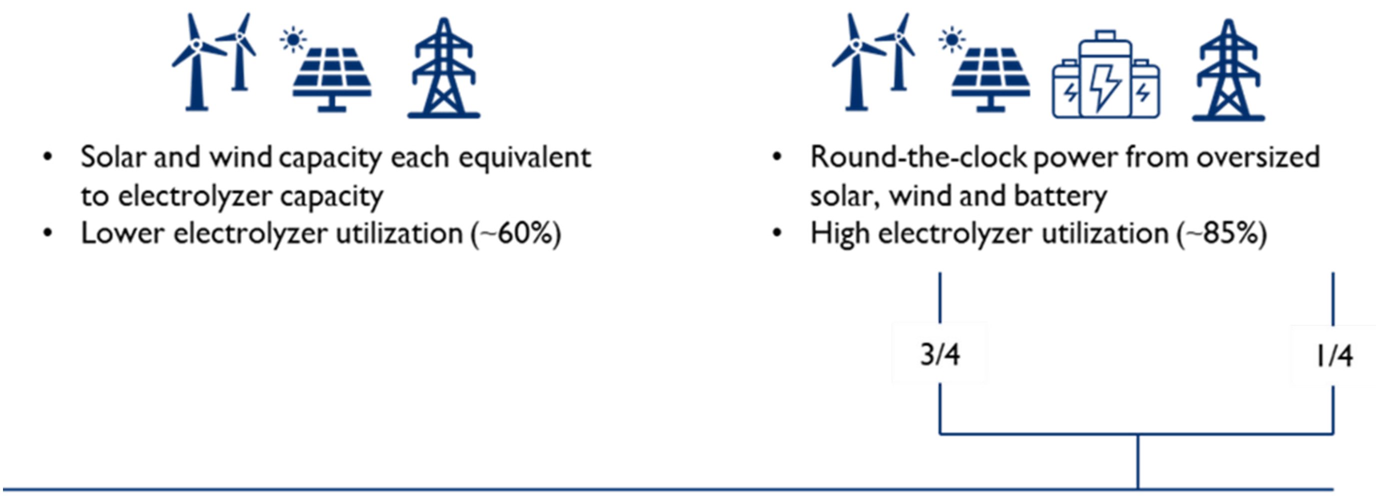
Renewable Energy Capacity Additions

To improve electrolyzer utilization, most developers will need to rely on a hybrid energy mix to mitigate risks of low-capacity utilization factor and high temporal variation associated with using a single source of primary renewable energy such as solar and wind. These variations can lead to low and inconsistent electrolyzer utilization when the main renewable energy source is not supported by alternative sources.

Green hydrogen projects will require development of oversized renewable energy capacity, supplemented by battery storage, to source round-the-clock (RTC) energy to target higher utilization levels (ETEnergyWorld, 2023). These would be particularly desirable in use cases such as ammonia production, where a continuous hydrogen supply is required.

Green hydrogen projects are expected to lead to large capacity additions to India's renewable energy capacity. In a scenario where a quarter of upcoming green hydrogen projects rely on RTC power from oversized solar and wind assets and supplemented by battery, to achieve electrolyzer utilization up to 90%, and others rely normal-sized solar and wind assets to achieve up to 60% utilization, India is expected to add around 61 GW solar and wind capacity till 2030 in the base case. Under the same assumptions, the country is expected add 109 GW and 25 GW for green hydrogen production, to achieve production capacities highlighted in the Pathway to NHM Target and Business-as-Usual scenarios, respectively.

Figure 35: Capacity additions and investment demand from renewable energy



	Business as Usual	Base Case	Pathway to NHM Target
Capacity Addition	25 GW	61 GW	109 GW
Investment demand	$ 14.5 Billion	$ 36 Billion	$ 63.5 Billion

Electrolyzer Capacity Additions

India's ramp up of green hydrogen production capacity will need to be supported by a consistent supply of competitively priced electrolyzers. To meet the consumption demand under the same renewable energy assumptions as highlighted above, India will need to install up to 52 GW under the different demand scenarios. Procurement of this electrolyzer capacity is expected to cost upto US$27.1B by 2030.

	Business as Usual	Base Case	Pathway to NHM Target
Capacity Addition	12 GW	29 GW	52 GW
Investment demand	$ 6.1 Billion	$ 15.4 Billion	$ 27.1 Billion

India is well positioned to meet a significant portion of this demand through domestically produced electrolyzers, considering that 8 GW per annum manufacturing capacity is already in the pipeline till 2025 (PV Magazine, 2022). If these electrolyzer manufacturers can achieve globally competitive prices, India can also become also become a key exporter of electrolyzers. For example, India's largest domestic electrolyzer manufacturing facility by Ohmium already exports electrolyzer units to international markets (Ohmium, 2021).

Hence, **electrolyzer manufacturing is a key investment area in the value chain with an investment demand of $1.5B for the projected manufacturing capacity of 8 GW by 2025,** assuming setup costs of $175,000 per MW (ET, 2022).

Ammonia Production and Storage Capacity Additions

Green hydrogen production will also need to be complemented with significant additions to India's ammonia production and storage capacity. Until 2030, these would be primarily required for the fertilizer industry and the export-oriented projects, considering the other major use cases such as oil refining and natural gas blending would be largely catered to by captive green hydrogen projects. It is estimated that fertilizers and exports would require up to 14.5 MMT per annum ammonia production capacity additions by 2030. These will need to be complemented by adequate ammonia storage facilities as well.

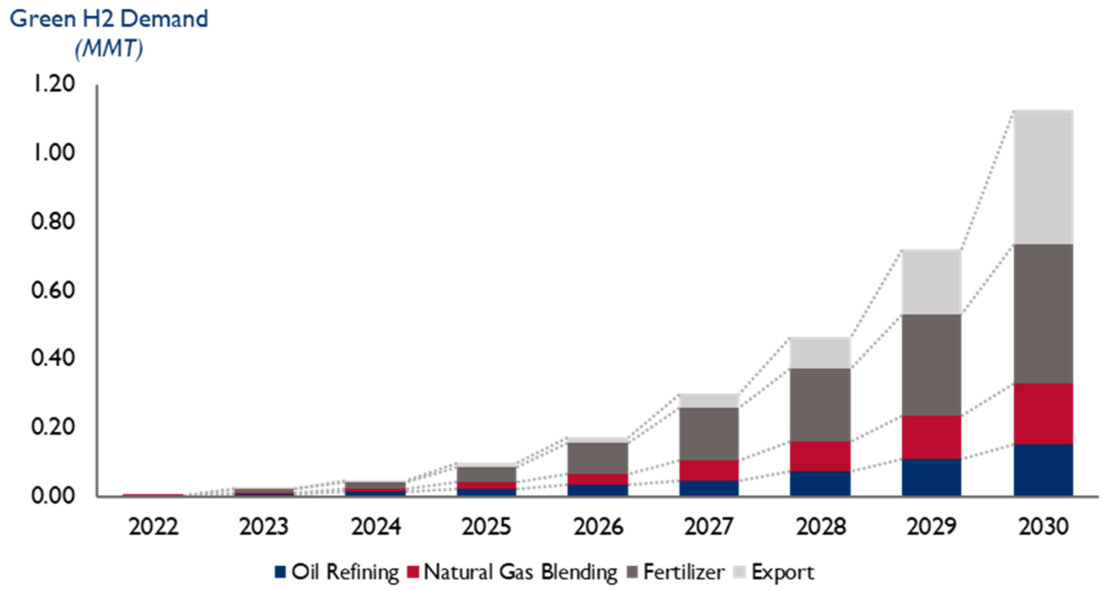
	Business as Usual	Base Case	Pathway to NHM Target
Capacity Addition	4.4 MMT	10.3 MMT	14.5 MMT
Storage Requirement	0.4 MMT	0.8 MMT	1.2 MMT
Investment demand	$ 2.7 Billion	$ 6.2 Billion	$ 8.8 Billion

SUMMARY: GREEN HYDROGEN DEMAND AND INVESTMENT REQUIRED

Business as Usual

The annual green hydrogen demand is estimated to reach 1.12 MMT by 2030. As per this conservative approach, a majority of the demand, ~34-35% each, is expected to arise from the fertilizer and export sector, which is understandable given that the country is focused on reducing its import dependence and becoming a leading exporter.

Figure 36: Green hydrogen demand till 2030 as per business as usual assumptions



The total investment required to support this transition is US$ 23.3 billion

Business as Usual – Green Hydrogen Requirement by 2030		
Industry	**H2 Demand**	**Investment Required**
Oil Refining	0.15 MMT	$2.6 Billion
Natural Gas Blending	0.18 MMT	$3.2 Billion
Fertilizer	0.41 MMT	$8.7 Billion
Exports	0.39 MMT	$8.3 Billion
Others	0.02 MMT	$0.4 Billion
Total	1.14 MMT	$23.3 Billion

CO_2 emissions avoided by 2030

24 MMT

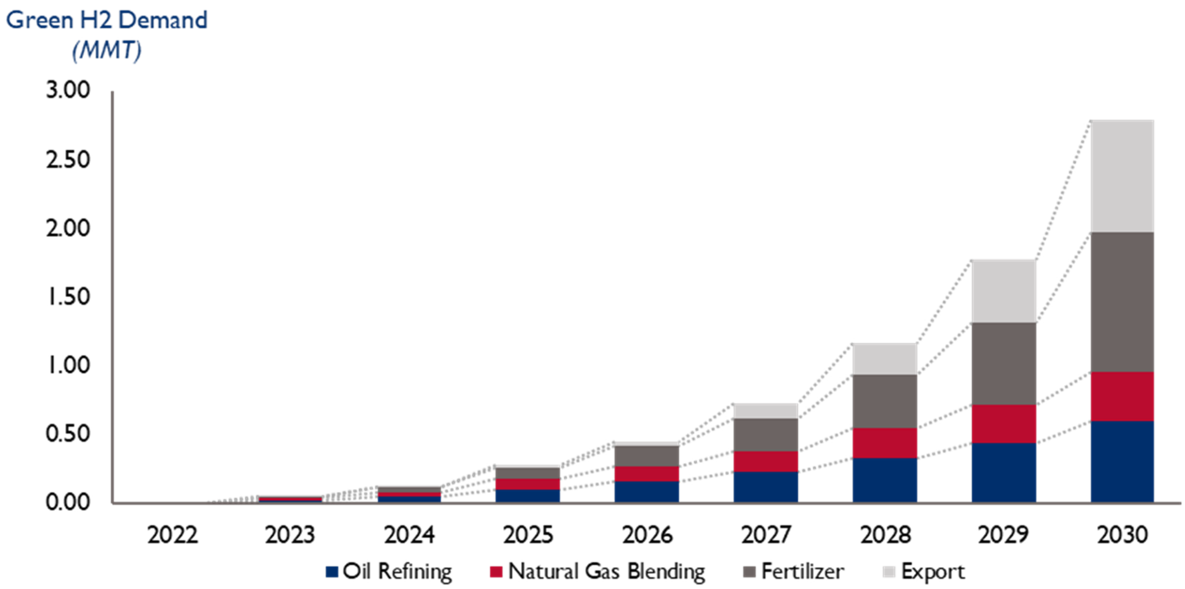
Renewable Energy Installations Required	*Electrolyzer Installations Required*	*Ammonia Production & Storage Infrastructure Required*
25 GW	**12 GW**	**4.4 MMT & 0.4 MMT**
$ 14.5B	**$ 6.1B**	**$ 2.7B**

Estimated Investment Required till 2030

Base Case

The annual demand for green hydrogen is estimated to reach 2.85 MMT by 2030. Much like the "business as usual" scenario, the fertilizer sector and export sectors account for nearly 37% and 29% of the total demand.

Figure 37: Green hydrogen demand until 2030 as per base case assumptions



The total investment required to support this transition is US$ 57.6 billion

Base Case – Green Hydrogen Requirement by 2030		
Industry	**H2 Demand**	**Investment Required**
Oil Refining	0.6 MMT	$10.8 Billion
Natural Gas Blending	0.36 MMT	$6.4 Billion
Fertilizer	1.02 MMT	$21.9 Billion
Exports	0.81 MMT	$17.5 Billion
Others	0.06 MMT	$1 Billion
Total	2.85 MMT	$57.6 Billion

CO_2
emissions avoided by 2030
61 MMT

Renewable Energy Installations Required

62 GW

$ 36B

Electrolyzer Installations Required

29 GW

$ 15.4B

Ammonia Production &Storage Infrastructure Required

10.3 MMT & 0.8 MMT

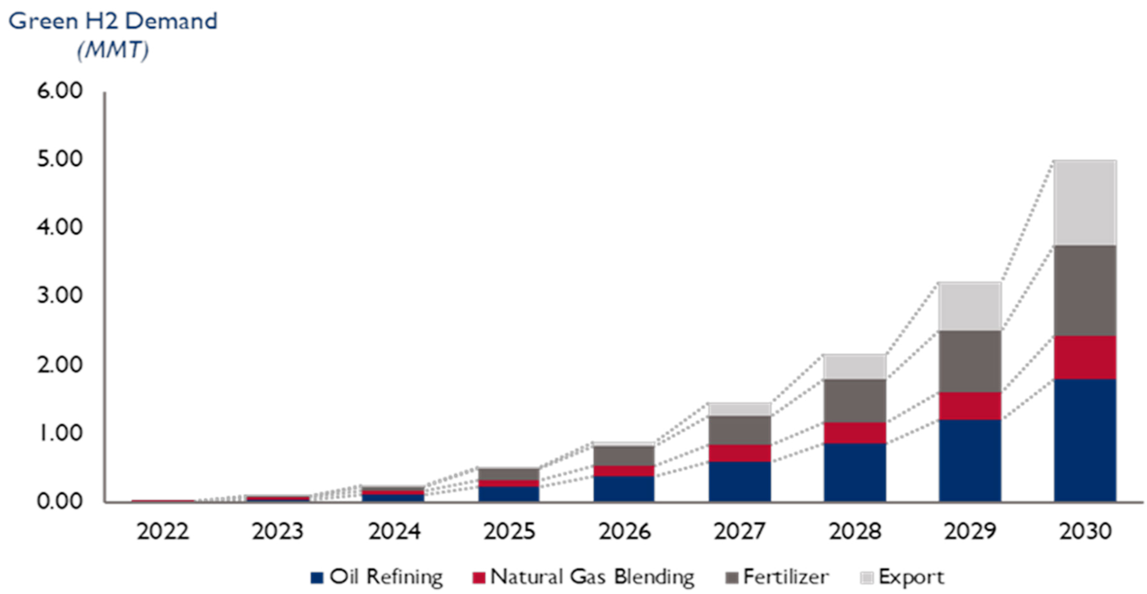
$ 6.2B

Estimated Investment Required till 2030

Pathway to NHM Target

The annual demand for green hydrogen is estimated to reach 5 MMT by 2030. The oil refinery sector accounts for ~48% of the total demand, however this is due to the ambitious targets set by PSUs in the beginning of 2021.

Figure 38: Green hydrogen demand till 2030 as per pathway to NHM target assumptions



The total investment required to support this transition is US$ 99.4 billion

Pathway to NHM Target – Green Hydrogen Requirement by 2030		
Industry	**H2 Demand**	**Investment Required**
Oil Refining	1.8 MMT	$32.5 Billion
Natural Gas Blending	0.54 MMT	$9.7 Billion
Fertilizer	1.32 MMT	$28.5 Billion
Exports	1.25 MMT	$26.9 Billion
Others	0.1 MMT	$1.7 Billion
Total	5 MMT	$99.4 Billion

CO_2 emissions avoided by 2030

114 MMT

Renewable Energy Installations Required	Electrolyzer Installations Required	Ammonia Production & Storage Infrastructure Required
109 GW	52 GW	14.4 MMT & 1.2 MMT
$ 63.5B	$ 27.1B	$ 8.8B

Estimated Investment Required till 2030

INVESTMENT SUPPLY

Green hydrogen sector's appetite for large ticket-size investments and strength of the sustainability agenda associated with it are in excellent alignment with investment preferences of most large project financiers, particularly those with major investments in the renewable energy sector. Most such financiers are actively pursuing investments in the green hydrogen sector and are mostly constrained only by limited availability of bankable projects.

> **We want to share India's ambitions on green hydrogen development and finance projects in the near future… We are looking for bankable projects to extend EUR 1 Bn funding for green hydrogen in India**
>
> Kris Peters, VP, EIB (ET, 2023)

POTENTIAL SOURCES OF PROJECT FINANCE

DEVELOPMENT FINANCE INSTITUTIONS

- Most global DFIs are active in India with significant investments in the country's renewable energy sector
- DFIs usually have a capacity to individually finance up to US$ 100-200 million subject to relevant caps for country and project (larger DFIs usually participate up to a maximum of one-third of project costs)
- Can unlock concessional financing for the green hydrogen sector, considering the sustainability agenda and additionality factor with green hydrogen (in terms of sector's development)
- Can offer up to 20-year loan duration based on offtake tenor
- Smaller DFIs usually prefer participation from larger DFIs for leading due diligence process, which is usually extensive and time-consuming for DFIs

Some Potential Participants

IFC, AIIB Asian Infrastructure Investment Bank, DFC U.S. International Development Finance Corporation, finnfund, PROPARCO Groupe AFD, BIO, European Investment Bank, ADB, FMO, KFW, British International Investment, Norfund

DOMESTIC AND INTERNATIONAL COMMERCIAL BANKS

- International and domestic commercial lenders act as a key source of large-scale project finance in India
- Can offer multi-billion financing capacity in consortiums
- Prefer to lend under an insurance cover from external agencies such as Political Risk Insurance from international agencies or debt cover from Export Credit Agencies (ECAs)
- Usually have more flexible terms than DFIs
- Less time-consuming due diligence process than DFIs

Some Potential Participants

इरेडा IREDA, IDBI Bank, ICICI Bank, Societe Generale, Mizuho, BNP Paribas, SBI, पी एफ सी PFC, SMBC, standard chartered, Barclays, MUFG, ING

EXPORT CREDIT AGENCIES

- ECAs participate against equipment procurement or equity participation from their home countries
- While China currently dominates the electrolyzer market, procurement from nations like Germany, Norway, UK, Japan, others can unlock cheaper credit from respective ECAs. Hence, equipment sourcing becomes a strategic decision for projects
- ECAs offer multi-billion financing capacity through direct lending, or unlock investments from commercial lenders by offering insurance covers on commercial lenders' portion of debt

Some Potential Participants

GREEN BONDS MARKET

- While still nascent for India, the green bond market can emerge as a key source for mobilizing large-scale finance for Green H2 projects
- As of January 2023, green bonds accounted for around US$ 20 billion (less than 4% of overall outstanding corporate bonds of US$ 500 billion
- India's renewable energy players, particularly solar project developers have recently been quite successful in raising large-scale capital from the market (ET, 2023)

Role of Blended Finance and Government Support in Catalyzing Investment Supply

Considering the green hydrogen industry's nascency, additional public and private sector support in the form of government subsidies and blended finance instruments are expected to play a critical role in supporting projects to cross hurdle rates and reach investment decisions. These will be catalytic to drive equity and debt investments to reach NHM targets.

The government has already announced a US$ 2.4B financial support for the sector, a large portion of which is expected to contribute to funding support for green hydrogen production. Under the Pathway to NHM scenario, this support could potentially cater to upto 10% capital expenditure (excluding renewable energy) for 2/3rd hydrogen capacity expected till 2030 (5 MMT per annum).

Additionally, project preparation capital would be critical in the initial phase of development. Assuming 5-7% project development costs, an estimated US$ 2B support may be required in project preparation and development support for these projects, excluding renewable energy assets.

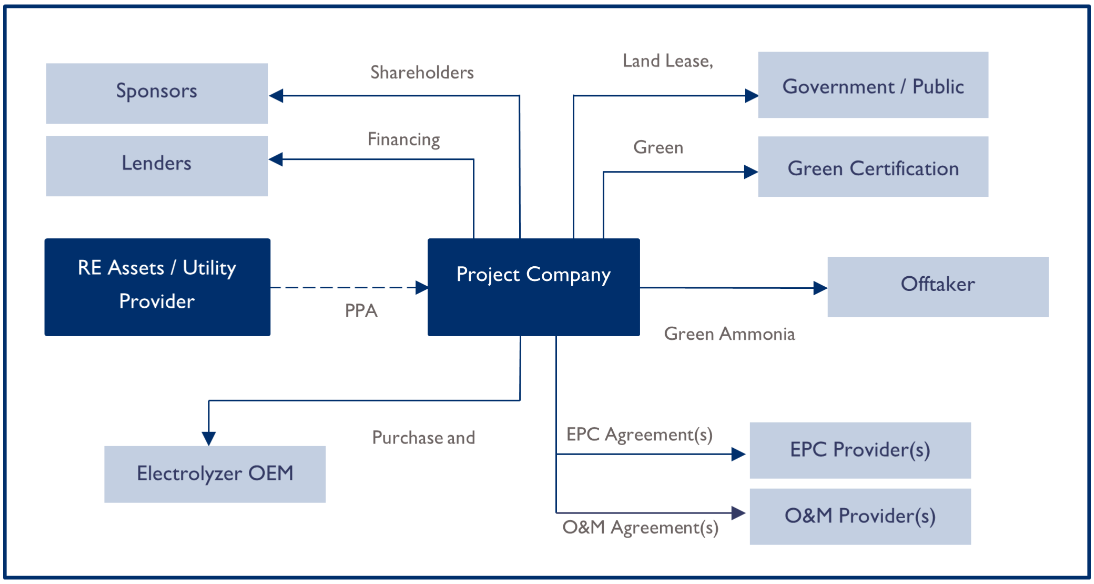
Apart from these, assuming an 80% leverage for renewable energy capacity and a lower 60% leverage for hydrogen and ammonia production, the sector will require an estimated US$ 25B in equity investments and US$ 70B in debt investments. There is a need for innovative financial structures to achieve a low cost of capital. These may be in the form of mezzanine instruments, green bonds, grants or guarantees however the quantum will depend on target hurdle rate necessary to ensure bankability.

Debt Finance	Equity Finance	Government Support	Development Support
US$ 70B	US$ 25B	US$ 2.4B	US$ 2.0B

BANKABILITY CONSIDERATIONS FOR GREEN HYDROGEN PROJECTS

While investors have a high investment appetite for green hydrogen sector in India and globally, only a few projects are 'bankable' i.e., have secure cash flows to service financial obligations during project life. In order to raise project finance, developers need to put together a strong and watertight contractual framework, allowing distribution of project risks to stakeholders best placed to manage it (leaving minimum exposure to the project company).

Figure 39: Representative Green Hydrogen Project Structure

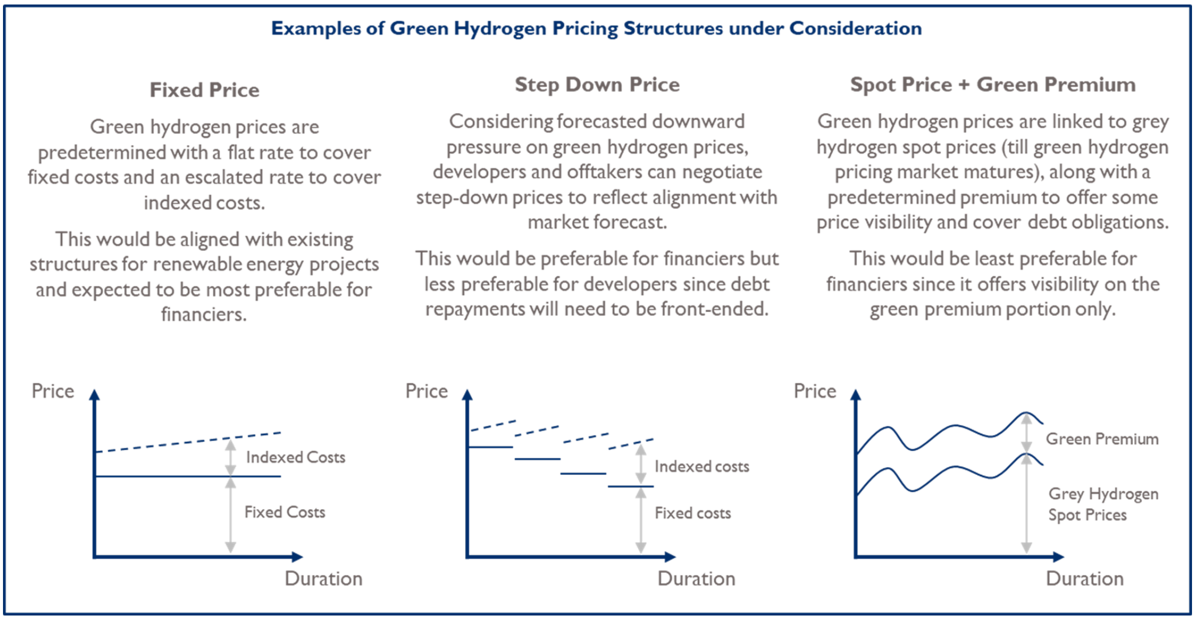


Green hydrogen projects are exposed to most risks that power and infrastructure projects are traditionally exposed to, with additional risks due to the nascency of market and technology. Some of the key risks in green hydrogen projects and their potential mitigation strategies include –

PRICE AND VOLUME RISK

Green hydrogen projects are quite similar to renewable energy projects in the sense that their production costs are primarily fixed and capex oriented. While renewable energy projects are often supported by government-backed Power Purchase Agreements with predetermined tariffs (due to limited marketability), green hydrogen is a commodity and unlikely to be supported by such strong offtake agreements. Further, the current (grey) hydrogen market is geared towards spot prices.

Due to the high capex and long project life, green hydrogen developers are aiming for long-term offtake contracts with predetermined prices, which minimize price and volume risks over project life. These will enable the developers to target better financing terms (no recourse, high leverage, high debt tenor, and competitive rates). Alternatively, in the absence of such price and volume visibility from buyers, developers will have to deal with expensive financing, affecting output prices / margins.



> The pricing structure being fixed, step-down, or with a green premium can affect front or back-ending of returns but ultimately the market should realize that price will have to support the Net Present Value of project's cash flows. Even a pre-determined 'green premium' over grey hydrogen will need to be calculated in such a way.
>
> **– Representative from one of India's top renewable energy developers**

PROJECT COMPLETION RISK

Green hydrogen projects are exposed to a higher completion risk due to the nascency of the technology market. Since there are no developers or EPC providers with significant experience in all major technology components – renewable energy, electrolyzers, and downstream production units such as ammonia synthesis unit, integrated green hydrogen projects face higher risks during the development and construction phases.

In such a scenario, it becomes critical to segregate the projects into these stages clearly and employ capital matching the respective risk profile of each stage.

Development Phase

- Significant uncertainty for development of a bankable project structure
- Sponsor and offtaker credibility act as key drivers
- High-risk capital from developers and donors is required
- Involvement of MDBs/DFIs at this stage can add significant credibility to the project

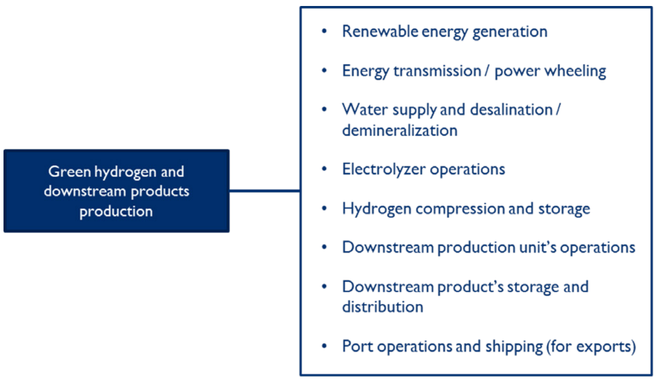
Construction Phase

- High completion risk due to variety of technology components and lack of experienced EPC and OEM providers in the sector
- EPC, OEM providers' credibility act as key drivers
- Medium to high risk capital from DFIs, commercial banks (backed by ECA guarantees), and other impact investors is required

Operations Phase

- Relatively low project risk arising from issues unforeseen during development stage
- Strength of contractual structure acts as a key driver
- Low-risk capital from conservative investors can be employed through exits by investors from previous stages

Figure 40: Potential scope of a green hydrogen project



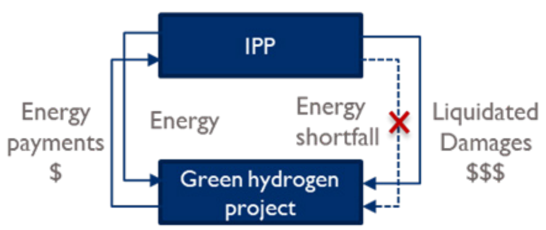
The varying risk profiles of these stages lead to a strong case for blended finance to drive green hydrogen projects' development and construction phases. This would require deployment of high-risk capital and grant funds in the initial stages, with the objective of refinancing these projects in the operations phase.

INTERFACE RISK

Green hydrogen projects involve integration of multiple technologies for a single project output in the form of green hydrogen or downstream products such as ammonia. These lead to multiple interface points for the project, leading to significant 'interface risk' from disruption in any of these components.

Figure 41: Example of a liquidated damages scenario

For example, consider a project that has a PPA to procure renewable energy from a third-party IPP and the IPP is unable to fulfill the supply obligations during a specified period, which causes decreased production at the green hydrogen plant. Here, the green hydrogen project company would ideally require LDs equivalent to lost revenues of hydrogen/downstream product, from the IPP (and not just the contracted power tariff).



Further, for project's internal components, financiers would ideally want developers to also allocate respective risks to EPC providers, OEMs, O&M contractors, and other relevant project stakeholders, to minimize the project company's exposure. This can lead to significant increases in project costs (when these guarantees are factored into EPC, OEM, O&M, and other costs). Alternatively, financiers may require sponsors to offer a 'wrap guarantee' to cover project's interface risks. Such guarantees can be offered by sponsors, or third-party providers.

OTHER PROJECT RISKS

Apart from some of the risks highlighted above, green hydrogen projects also have exposure to the risks seen in conventional power and infrastructure projects.

These risks have well-established allocation and mitigation structures from a number of banked precedents. Similar structures can be implemented in green hydrogen projects as well.

Green hydrogen project structures are expected to further evolve as more large-scale projects reach financial close and enter the construction phase.

- Solar and Wind Generation Yield
- Cost / Time Overruns during Construction
- Operations Risk
- Site and Environment Risk
- Foreign Exchange Risk
- Floating Interest Rate Risk
- Political / Natural Force Majeure
- Others


H2

ENHANCING GREEN HYDROGEN INVESTMENTS IN INDIA – KEY CHALLENGES AND POTENTIAL MITIGATION STRATEGIES

The launch of the National Hydrogen Mission has been catalytic in strengthening the industry and financiers' confidence in India's green hydrogen sector. However, as emphasized in the Market Landscape in India section, only a limited number of pilot-scale projects have successfully transitioned to the operational phase, and there are only a few large-scale projects that have moved to advanced stages of development. Through interactions with 20+ stakeholders including renewable energy producers, electrolyzer manufacturers, oil and gas players, ammonia producers, financial institutions, among others, several perspectives on India's current green hydrogen ecosystem, focusing on challenges and potential pathways to mitigate these were discussed.

ABSENCE OF A STRONG DOMESTIC CONSUMPTION MARKET CONTINUES TO BE HIGHLIGHTED AS THE BIGGEST BARRIER FOR INVESTMENTS IN THE SECTOR

Most of the stakeholders interviewed expressed that India's domestic consumption market is currently not ready for large scale procurement and is awaiting clarity on government policies and incentives for the sector. This is because industries find it commercially non-viable to adopt green hydrogen without any relief on the premium associated with it.

While production costs are anticipated to decline significantly and technologies in various consumption industries will continue to evolve, multiple stakeholders have highlighted the need for external intervention to kickstart replacement demand to support initial green hydrogen projects. Such interventions may include –

INDUSTRY-WISE MANDATES TO PUSH DEMAND

The government can consider Green Hydrogen Purchase Obligations (GHPO) to push primary grey hydrogen consumers such as ammonia fertilizer manufacturers, oil refiners, steel manufacturers, among others, to convert a fixed portion of their consumption to green. These can generate initial demand and drive investments in the production ecosystem, which in turn would lead to a reduction in prices, with learning and scale economies.

India recently passed the Energy Conservation (Amendment) Bill 2022, which allows the government to mandate "a minimum share of consumption" of non-fossil energy or feedstock for certain "designated consumers". The actual implementation of such purchase obligations can be complicated considering the direct potential impact on the competitive survival of these industries. In particular, the fertilizer industry is already heavily burdened and received a total subsidy support of ~US$ 14.2 billion in 2022-23 for ensuring affordability for the end user, highlighting its limitation to support such purchase obligations. (GH2, 2022)

> **India is not a market where corporates would be willing to pay a price premium solely driven by the sustainability agenda. Some form of mandates would be required to drive consumption demand, at least initially**
>
> *~Senior Executive, leading Oil and Gas PSU*

GREEN HYDROGEN SUBSIDIES / CONTRACTS FOR DIFFERENCE

Another option to improve viability of green hydrogen adoption is through subsidies. These are being considered as a feasible driver for initial demand in various parts of the world –

In August 2022, the US passed the Inflation Reduction Act, allowing tax credits of up to $3/kg to clean hydrogen producers for the first 10 years of a project's lifetime (GH2, 2022).

In September 2022, the European Commission announced plans to set up a 'European Hydrogen Bank', which will invest EUR 3 billion to help 'guarantee the purchase of hydrogen'. It will support '100% of the cost gap between green and grey hydrogen produced in the EU (Hydrogeninsight, 2022).

Similar plans of smaller scale have been announced by Germany, Canada, and the UK, among others (Carbon Credits, 2023). India is also expected to bring green hydrogen (and electrolyzer) production under a Production Linked Incentive (PLI) scheme, the details of which are yet to be announced.

The scope to use PLI subsidies to drive green hydrogen demand can be limited though, considering the large budgetary outlay required. For example, a **$3/kg subsidy on one-fifth of National Hydrogen Mission's target (1M MT) translates to $3B per annum for the government.** Apart from the fiscal impact, such subsidies also have complex geopolitical considerations, particularly for export-oriented projects.

The government's PLI scheme can also be implemented for electrolyzer and other plant capex in order to provide relief on upfront capex. A representative from a leading electrolyzer manufacturing company highlighted that when compared equally, an equipment linked PLI might be more favorable from a developers' perspective as benefit can be spread across project life and financing costs can be avoided.

> **It is quite bizarre that the European Union does not want to recognize green hydrogen produced with government support – they should be welcoming this instead.**
>
> *~Representative, leading renewable energy developer in India*

DEVELOPMENT OF CARBON MARKETS

The carbon abatement potential of green hydrogen can be monetized with the development of a strong carbon market in India. Green hydrogen projects have significant additionality associated, i.e. the emission reductions achieved are high compared to baseline emissions from alternatives. The carbon credits from these reductions can be issued to producers or consumers, allowing them to trade these as additional incentive for green hydrogen adoption.

Towards development of a domestic carbon market, Government of India has come up with a draft carbon credit trading scheme under the recently adopted Energy Conservation (Amendment) Bill, 2022. Additionally, while the government is simultaneously banning carbon credit exports to meet India's NDCs, green hydrogen has been included in its list of 13 carbon credit project types eligible for international trade under the recent as announcement by Government of India. (HT, 2023) Carbon credits are expected to emerge as a key incentive for green hydrogen production as the country's carbon market matures.

Apart from carbon credits, the government can also leverage carbon pricing through disincentives such as carbon tax on grey hydrogen consumption, with a potential objective to deploy proceeds for green hydrogen incentives.

EVEN WHERE CONSUMPTION DEMAND IS AVAILABLE, CONSUMERS ARE UNWILLING TO LOCK INTO LONG-TERM OFFTAKE CONTRACTS

As highlighted above, green hydrogen projects require a long-term, fixed price offtake agreement, as production costs are fixed and capex-oriented, similar to renewable energy production. This is quite different from grey hydrogen, which relies on natural gas as a key production input and hence benchmarked to natural gas costs.

Considering that the market is currently geared towards spot prices, consumers and traders of grey hydrogen and downstream products are unwilling to commit to long-term offtake agreements for green hydrogen at fixed prices. This is exacerbated by the fact that green hydrogen production costs are forecasted to decline significantly, with high uncertainty around the timing and scale of such cost decline.

POTENTIAL GAP FOR A MARKET FACILITATION INSTITUTION

Stakeholders have highlighted the crucial gap of a market facilitation institution that can operate with the objective to offtake from projects through long-term contracts and supply to consumers on short-term contracts. Such an institution can be the green hydrogen sector's equivalent of SECI (of renewable energy) and is expected to have multiple benefits for the sector.

Figure 42: Working of a Market Facilitation Institution

- Demand aggregation leading to competitive tenders and efficient pricing from green hydrogen/ downstream products
- Strong and bankable offtake, potentially backed by government guarantee on the institution's obligations
- Decentralization of green hydrogen consumption demand, allowing smaller entities with limited credit strength to procure on shorter-term contracts, among other benefits

However, operational challenges associated with green hydrogen / downstream products' distribution can be a key barrier for implementation of a market facilitator.

> **Offtake is the backbone of any PF transaction and quality of offtake would be of utmost importance while financing**
>
> *~Head of Regional Representation in South Asia, leading global DFI*

PRICING FOR GREEN HYDROGEN AND DERIVATIVES REMAINS A CHALLENGE AND IS EXPECTED TO BE MORE FAIRLY ADDRESSED AS TRADE VOLUMES INCREASE AND PRICE ASSESSMENTS BECOME MORE MARKET REFLECTIVE

Price assessment for green hydrogen and green ammonia will be a challenge if offtakers base their bidding on price of grey hydrogen and add a green premium. This is neither an accurate nor a desirable pricing mechanism because the methodology of producing green and grey alternatives is significantly different in terms of both fixed and variable costs. Based on discussions with some price assessment agencies, pricing could be calculated as a weighted average of cost of production (representing the seller's side), cost of replacement (representing the buyers side / cost of grey alternatives) and a green premium (for example pricing of emissions). The weightages for the individual components will initially be very specific to individual deals but is eventually expected to be more market driven as the trading environment matures.

Figure 43: Current Available Price Assessment Platforms

Examples of current available assessments

- S&P Global Platts Renewable power derived Ammonia assessments
- Far East Asia on CFR basis originating from Middle East, Australia, and West Coast (WC) of Canada
- Northwest Europe on CFR basis originating from Middle East, US Gulf Coast and East Coast (EC) of Canada.

Timing: Weekly assessments for CFR Far East Asia and CFR Northwest Europe are for parcels to be delivered 15-45 days.

Cargo Size: CFR Far East Asia: 20,000-40,000 mt and CFR Northwest Europe: 20,000-25,000 mt

Currently Indian producers can refer to certain price assessments that are available for green ammonia as mentioned in Figure 43. A price differential for the renewable energy and freight component can be applied to some of these assessments to calculate potential landed values. Indian developers could potentially look at existing assessments for cargo originating in Middle East and Australia and apply relevant differentials.

DEVELOPERS ARE UNCERTAIN ABOUT PRODUCTION TECHNOLOGIES, ASSOCIATED RISKS AND STANDARD SOLUTIONS FOR PROJECT DEVELOPMENT

The production of green hydrogen is a complex process, and many of the companies that have made large-scale announcements have experience in only a portion of the green hydrogen production value chain. This leads to uncertainty over various technical aspects – as an example, developing the project's renewable energy procurement strategy to optimize electrolyzer utilization and energy costs.

In the absence of committed consumption offtake and/or lack of successfully banked precedents, developers are hesitant to incur significant development costs on comprehensive project preparation. This leads to uncertainty around target pricing structure, project design, operational philosophy, among others, resulting in a "chicken and egg" problem for undertaking negotiations for offtake and other project agreements.

> **While it is great to see massive announcements by large players, a lot of ground-level work is required for them materialise**
>
> *~Investment Principal, global private equity fund with major renewables investments in India*

PROJECT PREPARATION FACILITIES AND DEVELOPMENT SUPPORT

Project preparation facilities have been previously employed for PPP energy and infrastructure projects (MOHUA, n.d.), and can catalyze the role of government and development-focused financial institutions in development of bankable, investment-ready projects.

A representative from a global DFI highlighted that due to their strong mandate and limited availability of bankable projects for the sector, global DFIs are already extensively engaging with developers during the project planning stage itself. Although they are limited by conflicting interests to offer any direct technical support, they are working with the government to structure green hydrogen projects within competitive processes. An example of this is EBRD's role in green hydrogen developments in Egypt.

EBRD and Green Hydrogen Cluster at SCZone, Egypt

European Bank for Reconstruction and Development

- Egypt has signed MOUs and 'Framework Agreements' with 16 global developers/consortia for multiple large scale green hydrogen projects at the Suez Canal Economic Zone. (Offshore Energy, 2022)
- European Bank for Reconstruction and Development (EBRD) has been supporting the Egyptian government in preparing the draft Hydrogen National Strategy, along with coordination of developments at SCZone. (MEED, 2022)
- In November 2022, EBRD extended a USD 80M loan to the first green hydrogen facility developed yby a consortium of Fertiglobe, Scatec ASA, Orascom and Sovereign Fund of Egypt. (EBRD, 2022)

THERE IS A LACK OF CLARITY AROUND GREEN CERTIFICATION AND REGULATORY STANDARDS FOR PRODUCTION IN INDIA

Grey and green hydrogen have the same physical characteristics, and hence, green hydrogen production needs to be supported with clear certification standards to define it as 'green'. Globally there are multiple standards being developed, with expectations of consolidation into widely acceptable common standards.

Adherence to different types of standards can have a significant impact on project implementation, as compliance requirements have significant variance at present. In particular, aspects relating to renewable energy procurement have a direct impact on project costs and are being assessed carefully before investment decisions can be taken (ThePrint, 2023).

Figure 44: Examples of Green Standards for Hydrogen and Ammonia across the globe. (USAID SAREP Analysis)

Public Regulatory Schemes

India	To be announced
Europe	EU RED II
Australia	Zero Carbon Certification Scheme
China	China Hydrogen Standard
Japan	Japan Certification Scheme
South Korea	Hydrogen Act
UK	UK Low Carbon Hydrogen Standard
US	US Low Carbon Hydrogen Standard

Private Voluntary Standards

- GH2 Green Hydrogen Standard
- Certify
- TUV Rheinland Standard H2.21
- AEA Low Carbon Certification Scheme
- Green Hydrogen Standard
- ISCC Plus

Green hydrogen will require a robust mechanism to ensure "guarantee of origin" of the source of electricity being renewable, particularly for grid-connected projects. While India has a well-established Renewable Energy Certificates (RECs) framework, it will need to be consolidated with other compliances to certify hydrogen produced in India as green.

HARMONIZATION BETWEEN GLOBAL AND INDIAN GREEN STANDARDS

As of March 2023, India is yet to announce its acceptable standards and regulations for green hydrogen, and stakeholders have highlighted that their introduction will lead to better clarity on key aspects such as additionality requirements for renewable energy capacity and maximum acceptable carbon emissions. These will need to be broadly harmonized with global standards, to allow ease of compliance for export-oriented projects (Reuters, 2023).

DOMESTIC EQUIPMENT MANUFACTURERS REQUIRE SUPPORT TO FACILITATE A ROBUST SUPPLY CHAIN LOCALLY, BUT DEVELOPERS PREFER EASE OF IMPORTS, ATLEAST IN THE SHORT RUN

As discussed earlier, the National Hydrogen Mission targets electrolyzer installations of 60-100 GW to meet the production targets by 2030. Multiple stakeholders have highlighted the need to develop a strong electrolyzer manufacturing ecosystem in India, considering global supply is limited and heavily concentrated. At present, more than 40% of global electrolyzers, mostly alkaline, are manufactured in China (BNEF, 2023).

During interactions with electrolyzer manufacturers, some global players highlighted their reluctance to undertake investments for setting up production units in India, due to lack of a robust domestic supply chain for electrolyzer parts and associated technical challenges. In this regard, the current momentum of partnerships between these manufacturers and players in the Indian ecosystem can be instrumental in driving local manufacturing.

Further, within the supply chain for electrolyzers, India can immediately target import substitution of balance of plant equipment, which can comprise over 50% of electrolyzer costs, with the remaining as stack costs (Mayyas, 2019). A representative from an electrolyzer manufacturing startup that aims to produce electrolyzers indigenously highlighted the challenges in obtaining key equipment such as instrumentation (totaling 30% of electrolyzer costs), which needs to be ordered from international markets due to unavailability in the Indian market. On the other hand, while most developers appreciated the need for a strong domestic electrolyzer market, they were against disincentives for imports at the market's nascent stage.

Additionally, considering that renewable energy costs comprise a majority of an integrated green hydrogen project's capex, the market can significantly benefit from removal of custom duties on solar panel and module imports for projects aimed at green hydrogen. This can be critical in lowering LCOH and improving global competitiveness for green hydrogen produced in India.

KEY TAKEAWAYS

- Absence of a strong domestic consumption market and consumers' unwillingness to lock into long-term offtake contracts are among the biggest challenges in the sector. These can be supported by mandates, subsidies, market facilitation and incentive schemes.
- Green hydrogen sector is subject to a 'chicken-and-egg' problem between developers and offtakers. The government and development-focused institutions can play a role here by supporting projects at the development stage itself.
- Various aspects of project implementation require clarity on India's green standards and regulations for the sector. Their introduction will allow developers to undertake development strategies more efficiently.
- Localization of electrolyzer manufacturing remains a challenge due to a complex, unorganized supply chain of electrolyzer equipment, highlighting the need of targeted support to the sub-sector. However,

disincentives for imports are non-desirable at this stage.

- Most of the challenges highlighted above are expected to be resolved as the sector's regulatory framework solidifies, consumption demand materializes, and the initial few large-scale projects reach operation stages to set precedents for the sector.
- India remains strongly positioned in the global green hydrogen economy with its excellent resources, large consumption markets, and proactive steps from the government and industry to drive investments in the sector.

ANNEXURE

KEY ANNOUNCEMENTS BY ECOSYSTEM PLAYERS IN INDIA

Green Hydrogen Ecosystem Player	Some Key Announcements
Adani Group	Partnered with TotalEnergies for US$50 B investments in India's GH2 ecosystem over next 10 years
Reliance Industries Ltd.	Investing over US$10 B in the next 3 years towards building an integrated new energy and new materials ecosystem in India
L&T	Partnered with HydrogenPro for large scale electrolyzer manufacturing; has commissioned small scale H2 production projects
NTPC Limited	Has set up NTPC Green Energy Ltd. for investments in green energy and fuels projects; initiated multiple micro scale production projects
ACME Group	Plans to set up a portfolio of 10 MTPA green ammonia projects in India and abroad by 2030
ReNew Power	Partnered with IOCL and L&T for development of green hydrogen ecosystem in India; announced multiple large scale production projects in India and globally
Greenko	Partnered with POSCO, ONGC, others for large scale green hydrogen/ammonia production in India; Plan to set up a 2 GW electrolyzer factory in India through their joint venture with John Cockerill, requiring investment of US$500 M
Jakson Green	Plans to set up a US$2.8 B green hydrogen and ammonia project in Rajasthan, among other initiatives
TotalEnergies	Partnered with Adani Group for US$ 50 B investments in India's GH2 ecosystem over next 10 years, among other initiatives
Hero Future Energies	Partnered with Ohmium for development of 1 GW of hydrogen production capacity in India, UK, and Europe
HygenCo - The Hydrogen Company	Hygenco will invest more than US$300 M to build green hydrogen projects in the next three years
GreenZo Energy	Plans to set up a full-fledged made-in-India 250 MW electrolyzer factory with an investment of US$ 35 - 50 M by the end of 2025
H2e Power	Setting up 1 GW electrolyzer manufacturing plant in Maharashtra, for producing solid oxide electrolyzers by 2023
Ohmium India	Has 500 MW PEM electrolyzer facility (expandable up to 2 GW) in Karnataka; was the first to export a Made in India electrolyzer recently
Bloom Energy	Supplying electrolyzer, fuel-cell tech for India's first green H2 microgrid project in Andhra Pradesh
Thyssenkrup	Major global electrolyzer manufacturer that recently partnered with shell to set up a green hydrogen plant in Rotterdam port They have the potential for large scale supply in India,
Newtrace	Developed technology for "5x cheaper" electrolyzers in India. They recently raised U$1M in pre-seed from Speciale Invest and Micelio Fund.
PlugPower	Major global electrolyser manufacturers that recently partnered with Acciona energy to build an industrial-scale, green hydrogen production plant in Rocaforte, Sangüesa. They have the potential for large scale supply in India.
Welspun Corp	Member of H2Pipe, DNV's Joint Industry Project on design and operation of hydrogen pipelines. Also partnered with Tata Steel to develop the "framework for and subsequently manufacturing" pipes for transportation of pure hydrogen.
INOXCVA	Offers multiple hydrogen storage and distribution solutions; recently developed India's largest-ever bulk Liquid Hydrogen Storage Tank
Indian Oil Corporation (IOC)	Targeting to replace 10% of current fossil-fuel based H2 at refineries by GH2 by 2029-2030, and 15% by 2035
Bharat Petroleum Corporation Limited (BPCL)	Multiple green H2 project announcements, including tender for GH2 blending in natural gas pipelines
Oil and Natural Gas Corporation (ONGC)	Partnered with Greenko for $6.2 billion investment for renewable energy and GH2 projects

GAIL Ltd.	Awarded EPC contract for green H2 plant in Madhya Pradesh, for GH2 blending in gas network
Hindustan Petroleum Corporation Limited (HPCL)	Constructing a 370 TPA GH2 plant at Vizag Refinery to meet a portion of refining process requirements
Oil India Limited (OIL)	Has set up a small scale GH2 plant in Assam, among other projects; partnered with Homihydrogen for large scale electrolyzer manufacturing
Jindal Stainless Ltd.	Signed first long-term green hydrogen offtake (20 years) with Hygenco India
JSW Ltd.	Entered into agreement with Fortesque Future Industries for GH2 production
Gujarat Alkalies and Chemicals Limited (GACL)	GACL entered into agreement with NTPC to power 75 TPD e-methanol and 35 TPD GNH3 for captive use
KPIT Technologies	Working in GH2 implementation in mobility - launched India's first FCEV bus in collab with CSIR, in Pune
Medha Group	Rail system integrator contracted to develop India's first H2-powered trains - placed order for same with Ballard
Erisha Hydrogen India	Delhi-based EV maker Erisha E Mobility, which has partnered with Germany's Greenbox Global to establish Erisha Hydrogen India.
Triton EV	Announced plans to manufacture H2-run 2 and 3 wheelers at its EV manufacturing facility in Gujarat
GR Promoter Group (GreenH Eletrolysis)	Have entered a JV with H2B2 for deployment of a 100MW electrolyzer production plant that will escalate into a hydrogen Gigafactory.
Greenstat Hydrogen India	Partnered with PTC India for developing green hydrogen solutions jointly for the Indian power market.
IH2A - India Hydrogen Alliance	Announced Kochi Green H2 hub (KGH2), modelled after the Hydrogen Valley projects in the EU, to create production, storage, transmission, and end-use infrastructure for green hydrogen in a 50-km radius in Kochi.
Avaada Energy	Investing around $5 billion to build an integrated green hydrogen and ammonia plant with captive renewable energy capacity in Rajasthan, among other projects
Axis Energy Group	Plans to invest $6 billion in setting up green hydrogen, ammonia facility in Karnataka through subsidiary ABC Cleantech
Petronas Hydrogen	Partnered with Continental Automotive for large scale green hydrogen project in Karnataka, among other initiatives
Fortum India	Member of IGHPA, group for GH2 advocacy; plans to invest in Indian GH2 sector in upcoming years. Most recently, they supplied electricity to a green steel and green hydrogen plant in Sweden
O2 Power	Member of IGHPA, group for GH2 advocacy; plans to invest in Indian GH2 sector in upcoming years. Further, O2 had expressed interest to work with the government of Karnataka to set up a hydrogen cluster
Nel Hydrogen	Major global electrolyzer manufacturer with potential for large scale supply in India. They most recently signed a firm contract with HH2E in Germany for 120 MW of alkaline electrolyzer equipment
Siemens	Major global electrolyzer manufacturer with potential for large scale supply in India. Most recently, NTPC signed an MOU with Siemens to explore hydrogen blending with natural gas for power generation
Cummins	Major global electrolyzer manufacturer with potential for large scale supply in India. They recently partnered with Tecnimont Private Limited to build India's largest Proton Exchange Membrane for GAIL's project in Madhya Pradesh
Advik Hi Tech	Partnered with Pure Hydrogen to establish a hydrogen production facility in India. Also plans to supply HFCEV buses and trucks.
Amara Raja Group	Bagged contract from NTPC to set up green hydrogen refueling station in Leh, aimed at H2 buses planned in the region

GLOBAL POLICIES AND TARGETS ON GREEN HYDROGEN

Country	Policy	Target
India	In 2023, the cabinet approved the Green Hydrogen mission in India	Mission will result in a green hydrogen production capacity of at least 5MMT per annum by 2030 / 60 – 100 GW of electrolyzer capacity, with an aim to reduce 50MMT of annual greenhouse gas emissions.
Argentina	In 2022, the Argentine government developed the 2030 national low-emission hydrogen strategy	Install 5 GW+ electrolyzer capacity by 2030
Australia	In 2018, the CSIRO launched the National Hydrogen Roadmap, which was supported by several government agencies "Australia's National Hydrogen Strategy". Many states have launched their own schemes and road maps as well.	Overarching target to reduce hydrogen costs to below AU$ 2/kg. States such as NSW have set their own production target of 110,000 TPA from 700 MW electrolyzer capacity by 2030 tons
Canada	The government of Canada launched the Hydrogen strategy for Canada in 2020	Targets have not been set; however, Canada has committed to reducing GHG emissions 30% below 2005 levels
Chile	Chile launched its national green hydrogen strategy in 2020	Have 5 GW of electrolyzer capacity by 2025, become the producer of the lowest cost green hydrogen by 2030 and largest hydrogen exporter by 2040
China	The government of China launched its first "long term" Green H2 plan in 2022	Produce 100,000t – 200,000t of green hydrogen and increase adoption of FCEVs to 50,000 by 2025
Egypt	There is no unifying law the applies directly to hydrogen projects, however it does come under the gas market law. In 2022, it signed 8 framework agreements to setup ammonia and hydrogen production units	Become production hub for green hydrogen and capture 5% of the market by 2040
France	The government launched its hydrogen plan in 2018, which was followed by the hydrogen strategy in 2020	Install 6.5 GW of electrolyzer capacity by 2030
Germany	The government of Germany launched the national green hydrogen strategy in 2020	Build 10 GW Capacity by 2030
Japan	The government of Japan released the "Basic Hydrogen Strategy" in 2017, followed by the "Strategic roadmap for Hydrogen and Fuel Cell" in 2019	Increase annual hydrogen consumption to 3 Mt per year by 2030 and 20 Mt per year by 2050
KSA	Official Strategy under development (ongoing)	Increase production to 2.9 Mt per year by 2030 and 4 Mt per year by 2050
Netherlands	The government of Netherlands first set the hydrogen target in 2019 in the Dutch climate agreement. This was followed by the national hydrogen strategy in 2020	Attain 4 GW of power from green hydrogen production by 2030, and 10 GW by 2040
Norway	The government launched the "The Norwegian Government's hydrogen strategy" in 2020. Following this they also launched a road map in 2021	Create facilitating environment by increasing CO2 tax by 5% every year until 2025, provide tax breaks to hydrogen vehicles, 5 hydrogen hubs to be developed, one – two industrial projects to be developed by 2025
Oman	Establishment of Hydro Oman (Hydrom) in 2022	Produce 1 Mt per year of green hydrogen by 2030 and 8 Mt per year by 2050.
Spain	The government of Spain launched the Spanish hydrogen strategy in 2020	Install 300 MW to 600 MW of electrolyzer capacity by 2024, and 4 GW of electrolyzer by 2030. Replace 25% of the current 500,000 ton of grey hydrogen with green hydrogen by 2030. The main aim is to reduce 4.6 million ton of CO2 by 2030.

Sweden	The Swedish Energy Agency put in a proposal for the "national strategy for fossil-free hydrogen, electro-fuels and ammonia" in 2021	Build 5 GW by 2030 and 15 GW of Hydrogen capacity by 2045, 5 GW by 2030
United Kingdom	The government of the United Kingdom launched the UK Hydrogen Strategy in 2021	Scale production up to 10 GW of low carbon hydrogen production capacity by 2030
United States	The US department of energy released the draft green hydrogen roadmap in 2022 highlighting hydrogen production, storage, transport, and use	Reduce the cost of clean hydrogen to just $1/kg by 2031 & Produce 50 Mt per year by 2050

ASSUMPTIONS FOR INVESTMENT POTENTIAL BY CONSUMPTION

Industry	Assumptions
Base Assumption	Green hydrogen demand is expected to ramp up significantly from 2027 onwards as large scale projects enter operations
Oil Refinery	Hydrogen consumed / unit of oil refined is ~0.012. However, this estimate is an average as, amount of hydrogen required typical depends on the quality of crude oil[1]
Natural Gas Blending	As per the NHM, hydrogen will be blended in city gas distribution pipelines. • CGD accounts for approximately 20% of the total consumption. This % is assumed to remain constant.[2]
Fertilizers	As per NHM, the industry is expected to transition 2025 onwards. Demand in the industry is expected to arise from Urea, DAP and Ammonia specifically • Hydrogen consumed per unit of DAP is ~0.04 (Ammonia required is 0.2 / unit of DAP)[3] • Hydrogen consumed per unit of Urea is ~0.10[4] • Hydrogen consumed per unit of Ammonia is ~5.6
Exports	Demand is expected to arise from Japan, South Korea, European Union, and Singapore • As per government statements, Japan is looking to import at least 300,000 tons / year of hydrogen by 2030. However, India cannot be expected to capture too much of this market as, competitor markets such as the Middle East, Australia and Brunei are targeting it as well.[5] • South Korea as per government statements is looking to import 1.96 million tons / year by 2030. However, like Japan, the country is being targeted by the Middle East, etc.[6] • The EU has proposed to import 10 million tons / year by 2030. India's penetration in this market will be low, due to competition from markets such as Middle East and LatAm[7] • Singaporean market is a prime target for India. An MOU has already been signed for an offtake of .25 million tons[8]
Steel Industry	No significant demand is expected from this sector as government has clearly announced that till 2030, they will only be exploring pilots.

Sources: (Niti Aayog ; RMI, 2022), (ORF, 2022), (Mosaic, n.d.), (Adani, 2022) (International Trade Adminstration, 2021), (S&P Global Commodity Insights, 2021), (European Comission, n.d.) (Economic Times, 2022)

ASSUMPTIONS FOR INVESTMENT POTENTIAL BY VALUE CHAIN

Inputs	Assumptions		
	Production Capacity	**Electrolyzer Utilisation**	**Average Capex**
Combined Solar+Wind - both equal to electrolyzer capacity ($/MW)	75%	60%	1310000
Combined Solar+Wind+Battery for round-the-clock ($/MW)	25%	85%	3000000
	Values		
Decline in average renewable energy capex (till 2030)	20%		
Electrolyzer capex ($/MW)	700000		
Decline in average electrolyzer capex (till 2030)	25%		
Conversion (MWh/MT H2)	55		
Hours of operations (annual)	8760		
Electrolyzer (TPA/annum)	150		
Ammonia Synthesis Unit capex ($/TPD)	160000		
Ammonia storage (months of annual production - exports, fertilizers)	1		
Ammonia Storage capex ($/ton)	2000		
Ammonia per ton of hydrogen	5.6		
Electrolyzer manufacturing ($/MW)	175000		

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ABOUT USAID SAREP

The South Asia Regional Energy Partnership (SAREP) serves as a flagship program to advance objectives of the U.S. Government's Clean Asia Enhancing Development and Growth through Energy (Clean EDGE) initiative. SAREP improves access to affordable, secure, reliable, and sustainable energy in six countries – Bangladesh, Bhutan, India, Maldives, Nepal, and Sri Lanka – to strengthen systems and processes, in line with the economic and energy-security priorities of these countries. For more details please visit: https://sarepenergy.net/

ABOUT MNRE

The Ministry of New and Renewable Energy (MNRE) is the nodal Ministry of the Government of India for all matters relating to new and renewable energy. The broad aim of the Ministry is to develop and deploy new and renewable energy to supplement the energy requirements of the country. For more details please visit: https://mnre.gov.in/


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