Hydrogen: Alternate Business Models for Alternate Energy

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1. INTRODUCTION

India's push for alternate energy is driven by two imperatives – reducing its dependence on imported energy and reducing its climate footprint to meet environmental goals. It has made substantial progress. At the end of March 2021, renewable energy accounted for almost one-quarter of India's installed generation capacity and 11.8% of actual electricity generated during FY21. But increasing the share of renewable energy further without being able to store electricity at a grid scale is going to be difficult.

Table 1 Renewable Energy Generation Capacity (in Megawatts)

	Wind (MW)	Solar	Total Renewable	Total
FY18	34,046	21,651	69,022	344,002
FY19	35,625	28,180	77,641	356,100
FY20	37,694	34,628	87,027	370,106
FY21	39,247	40,085	94,433	382,151
Source: Central Electricity Authority				

Several factors cloud expectations that the trend toward renewable energy will continue:

- **Intermittency of Renewable Energy.** Solar and wind energy, by their nature, are intermittent. In absence of grid-scale storage, energy requirements for night-time still require conventional power – leading to duplication of infrastructure and undermining the long-term viability of renewable energy.

- **The Coal Conundrum.** During FY21, coal accounted for approximately 75% of all electricity generated in India, while hydro, renewable and nuclear energy accounted for the rest. Most of the coal used for power generation in India is produced domestically. Coal-fired electricity is the cheapest energy available in the country. During FY20, NTPC, India's largest thermal power generator, received a tariff of Rs 3.82/kwh, up from Rs 3.49/kwh for the previous year.[i]Thus, renewable energy in India is competing with the country's cheapest energy source, reducing its own financial viability.

- **Solvency of State Electricity Utilities.** State utilities are the biggest distributors of electricity in India – and therefore the biggest customers of generation utilities. State power utilities lose money. Their Aggregate Technical & Commercial (AT&C) losses added up to 22.03% of total power generated in 2018-19 (latest available figures). In 2018-19, state utilities incurred a collective loss of Rs. 52,838 crores. For the preceding two years as well, state utilities lost money collectively. This limits their ability to invest in alternate energy.

- **Barriers to expanding use of electric vehicles.** Increasing use of electric vehicles (EVs) could be one way to promote the use of renewable energy (to charge EV batteries). The Niti Aayog has been aggressive in pushing for electric mobility for India,[ii] but the results so far have not been very encouraging.[iii] At this point, an all-out push for electric vehicles may also be counterproductive for India because:

  - **Electric vehicles require minerals such as rare earths, cobalt and lithium,** which are not found in India and whose supplies in many cases is controlled by China. Wide adoption of EVs without securing raw materials thus could make a critical sector of the economy dependent on China.
  - **There are no viable electric solutions for heavy trucks.** About 40% of all oil consumed in India is in the form of diesel, which is mostly burnt by heavy trucks. At this point, lithium-based batteries for heavy-duty trucks are extremely inefficient due to the low energy density of lithium – about 1% that of petrol and diesel. As a result, even as it creates an infrastructure for EVs, India will have to retain its earlier infrastructure for petrol and diesel-fueled vehicles.

Is Hydrogen the Answer?

Using hydrogen as a vehicle fuel – and producing this hydrogen from water by using electricity from renewable sources – has advantages that can help resolve many of these issues faced by renewable energy and EV industries.

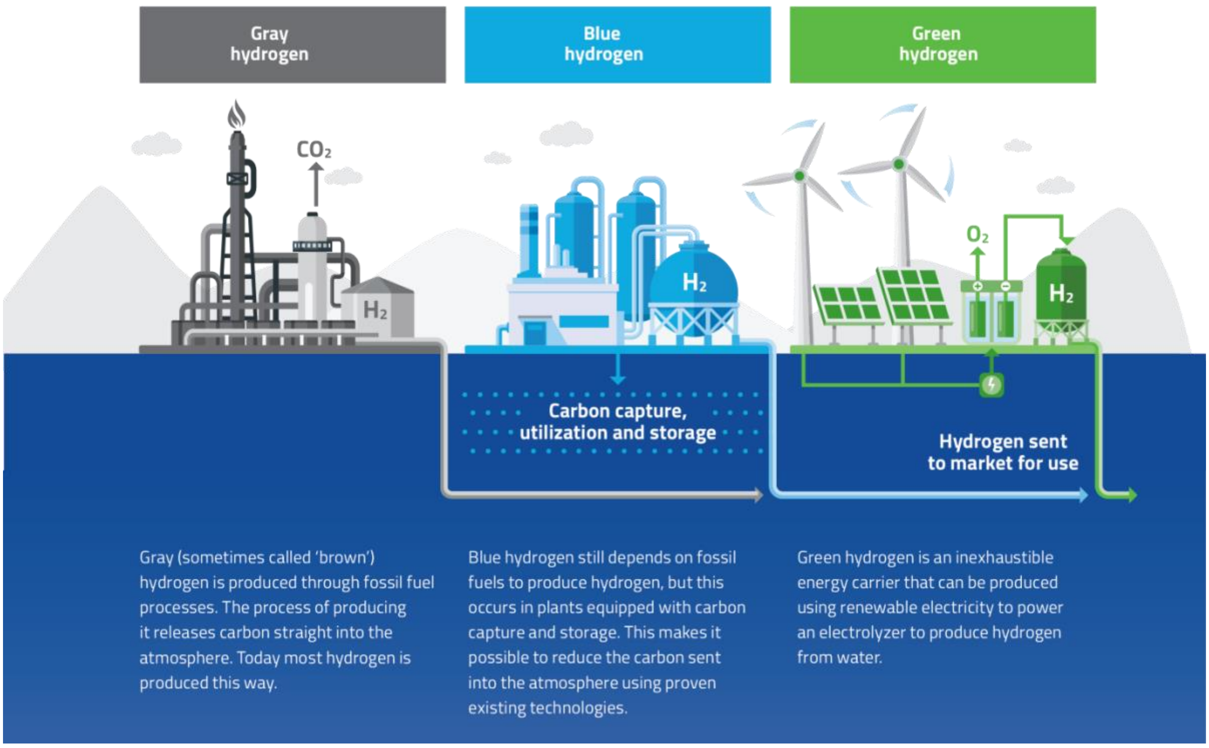
- **Intermittency/Storage.** Converting electricity into hydrogen is a way to store it and can be done on a large scale, unlike energy storage in the form of the lithium-ion batteries.
- **Commercial viability.** Using hydrogen as a vehicle fuel makes renewable power a direct replacement for petroleum, which costs 4-5 times as much as coal.
- **Reduced dependence on bankrupt utilities.** Selling hydrogen to fuel vehicles will reduce the dependence of renewable energy companies on bankrupt state utilities and will give them a set of financially solvent customers (oil marketing companies).
- **Reduced Dependence on Critical Minerals.** Using hydrogen in fuel cells or internal-combustion engines can reduce or eliminate the need for minerals such as lithium, cobalt and rare earths.
- **Technical feasibility for heavy applications.** Hydrogen has a higher energy density than petrol and diesel, and much higher than lithium, making it potentially viable for use in heavy trucks.
- **Reduced need for Parallel Infrastructure.** Initially, hydrogen can be used in a mixture with compressed natural gas (CNG), for which there is already infrastructure in multiple Indian cities, reducing the need to build a new, parallel infrastructure.

2. THE EMERGENCE OF HYDROGEN AS A 'CLEAN FUEL'

Hydrogen is fast emerging as a prominent alternative in the growing spectrum of clean fuels. It is making inroads into power generation and, more importantly, as an absolute and blended fuel in the road, rail, aviation and maritime transportation systems.

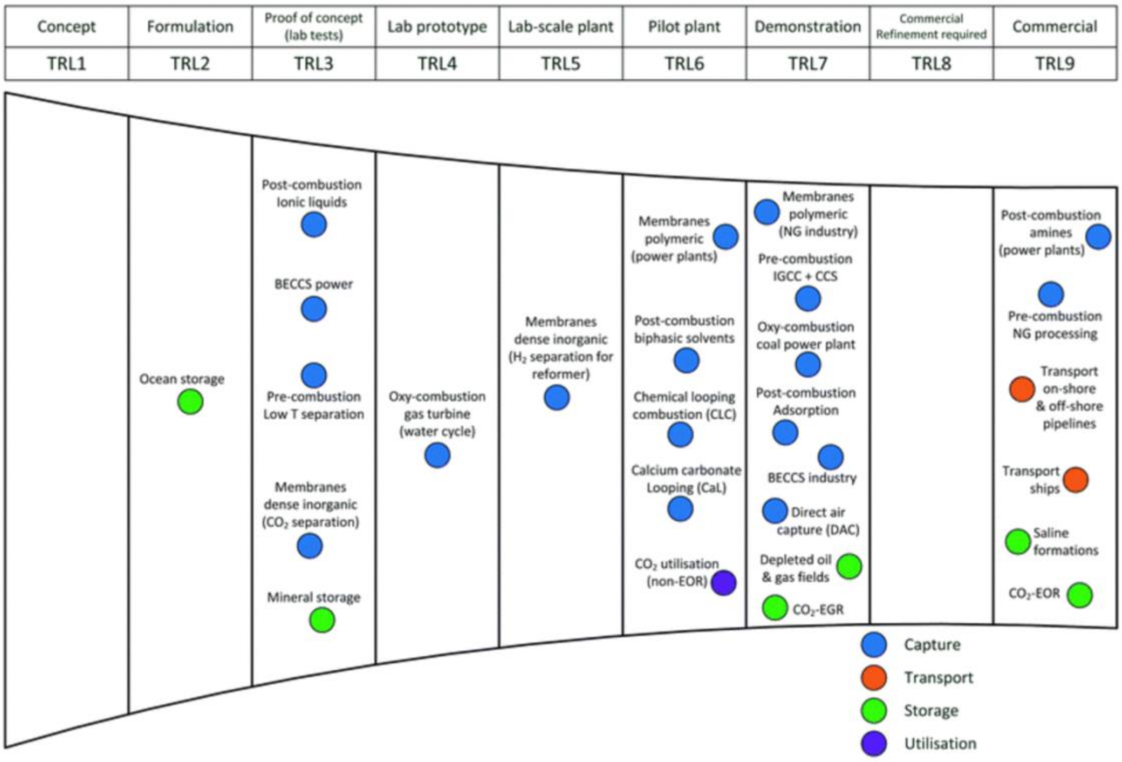
The petroleum sector has been economically and politically the most significant benefactor of the emerging hydrogen industry. The downstream petroleum sector has long carried out commercial-scale generation of "grey hydrogen," largely by reformulating methane derived from natural gas and coal gasification. This requires minimal new infrastructure, and the cost per unit volume of hydrogen generated is low, but the technology releases carbon into the atmosphere, so climate-conscious industries and governments have pushed for cleaner "blue" and "green" alternatives of hydrogen generation, which are environmentally less harmful but more costly at present. An explanation of the three technologies for production of hydrogen can be found in Figure 1.

Figure 1 The Differences between Grey, Blue and Green Hydrogen Technologies



The transition from grey-to-blue hydrogen requires producers to add carbon-capture and storage (CCS) technologies to their existing infrastructure. The transition from grey-to-green or even to blue hydrogen requires high levels of electrolysis instrumentation that can generate renewable hydrogen in commercial quantities – including water (H_2O) electrolysers, ammonia (NH_3) electrolysers, and steam methane (CH_4) electrolysers.

Figure 2 The availability of numerous carbon capture and storage technologies (CCS) at commercial-ready technology readiness levels is facilitating the transition from the long-running grey hydrogen generating units to blue hydrogen generating units



The oil, gas, and coal industries prefer blue hydrogen production because it would be easier for them to add CCS technologies to their existing infrastructure and thus garner greater socio-economic acceptance in this era of decarbonization. But the clean energy (wind and solar) energy industries prefer green hydrogen as they find it increasingly important to attract markets outside the power sector to make their investments viable. For India, another factor comes into play. Blue hydrogen is produced from natural gas, which India imports. So producing blue hydrogen will require increased gas imports. This paper therefore focuses on alternative business models for green energy producers.

Although the desire for socio-economic acceptance in the era of decarbonization is a driver of the transition towards hydrogen, the yearning for change is not enough. The single-largest drivers for the market readiness of the hydrogen sector are carbon-pricing mechanisms and emission-trading systems being adopted by various national and subnational governments all over the world. In June 2021, about 64 carbon pricing mechanisms had been implemented or scheduled globally, including 33 urban, national and regional carbon taxes and 31 emission trading systems (refer Table 2). These mechanisms are cumulatively deterring the use of carbon-intensive fuels and encouraging adoption of clean energy and fuel options across these geographies.

Table 2 The widescale implementation of carbon tax and emission trading system mechanisms by national and subnational governments is enforcing transition to clean fuels and clean energy alternatives

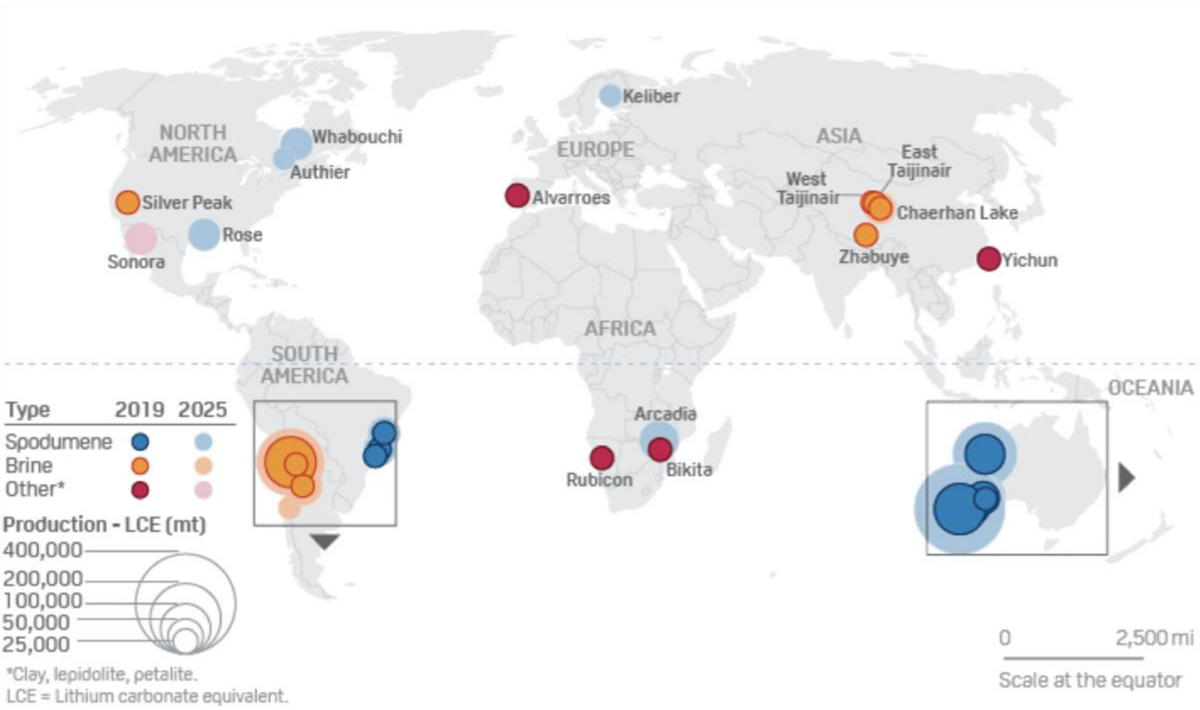
Carbon Tax (CT)			Emission Trading System (ETS)			ETS + CT		
Implemented	Scheduled	Under Consideration	Implemented	Scheduled	Under Consideration	Implemented	ETS-Under Consideration CT - Implemented	ETS - Implemented CT – Under Consideration
Argentina		Senegal	Germany		Indonesia	Canada	Chile	Netherlands
United Kingdom		Ivory Coast	Belgium		Turkey	Mexico	Colombia	
South Africa			Austria		Rio de Janeiro (Brazil)	Portugal	Ukraine	
Baja California (Mexico)	Tamualipas (Mexico)	Jalisco (Mexico)	Italy		Sao Paulo (Brazil)	Spain	Japan	
Zacatecas (Mexico)			Czechia		Thailand	France	Taiwan	
Namibia			Lithuania			Switzerland	Oregon (US)	
			Greece			Iceland	New York (US)	
			Hungary			Ireland	Connecticut (US)	
			Slovakia			Poland	Manitoba (Canada)	
			Croatia			Estonia		
			Bulgaria			Finland		
			Romania			Norway		
			Kazakhstan			Sweden		
			China			Slovenia		
			South Korea					
			Australia					
			New Zealand					
			Tokyo (Japan)					
			Washington (US)					
			California (US)					
			Alberta (Canada)					
			Saskatchewan (Canada)					
			Quebec (Canada)					
			Nova Scotia (Canada)					
			Massachusetts (US)					

3. HYDROGEN AS AN ANSWER TO INDIA'S DEPENDENCY ON LITHIUM IMPORTS FOR ELECTRIC MOBILITY

Electric vehicles are among the strongest contenders in the alternative energy space and a substitute for hydrogen-based mobility. Each has its own technological advantages and disadvantages, but India would benefit from a balanced energy strategy to develop all clean-mobility options, including electric and hydrogen.

India is using its massive market and robust Make in India program, to secure stable demand for lithium, cobalt, silicon metal and non-Rare Earth Elements (non-REEs), all of which are needed to manufacture batteries for electric vehicles. In 2019, three central public sector enterprises (CPSEs) – Mineral Exploration Corporation Limited, Hindustan Copper Limited and National Aluminium Company Limited – established a joint-venture company, Khanij Bidesh India Limited (KABIL), to secure supplies of these elements. Since then KABIL has engaged with corresponding entities in Australia, South America's Lithium Triangle, and Africa to secure a steady supply of the needed elements from these regions.

Figure 3 Transition to Lithium-Ion based Electric Mobility will create new import dependencies and will render troubleshooting mechanisms that India has developed with long-running petroleum imports of less or no utility (Source: S&P Intelligence)



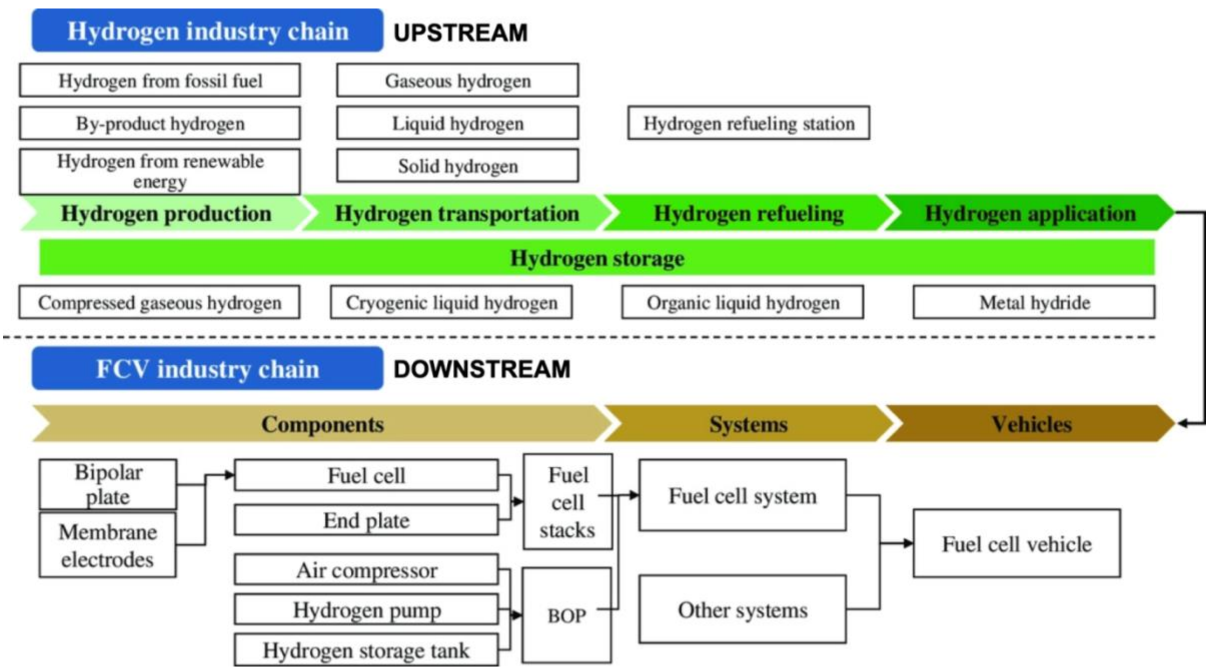
The lack of domestic commercially viable and operational mines for these minerals is bound to create new and uncharted import-dependency for India – a problem that is difficult to manage without experience. The Geological Survey of India (Ministry of Mines) and Atomic Minerals Directorate for Exploration and Research (Department of Atomic Energy) have begun exploring new commercially viable lithium reserves within India's territorial limits. Yet even if the search is successful, the transition from reconnaissance surveys to mineral processing could be excruciatingly protracted.

To overcome dependency on imported lithium, the Government of India has mandated its science and technology agencies – NITI Aayog, Indian Space Research Organization, Defence Research Development Organization, Council on Scientific and Industrial Research, Indian Institutes of Technology, and the Ministries of Micro, Small and Medium Enterprises, Science and Technology, Heavy Industries, Road Transport and Highways, and Commerce – to undertake R&D on alternatives to lithium-ion BES technologies such as metal-air, metal-ion and other potential technologies. IIT Hyderabad has been researching dual carbon batteries; IIT Madras is working on zinc-air, sodium-ion, and sodium-sulphur batteries; the Vikram Sarabhai Space Center has been working on potassium-ion batteries. The evolution of these low-technology, readiness level alternatives will continue in the coming years. However, none of these EV options alone will enable India to attain its 2030 decarbonization goals that it committed to pursue in the 2015 Paris Agreement.

Hydrogen-fuel vehicles are fast emerging as a robust alternative to electric vehicles for two important reasons. Firstly, automotive innovation has led to breakthroughs that are fast creating alternatives to the expensive REE- and platinum-consuming hydrogen fuel cell technologies. The newest and most promising innovation is a hydrogen internal combustion engine (ICE), which is a modified version of hydrocarbon-based engines.

A hydrogen ICE can operate with hydrogen-blended gasoline (up to 50% blending) or hydrogen-based, compressed natural gas along with pure hydrogen. The blending options are low-hanging fruits in the quest for decarbonized fuels that can be utilized expediently.

Figure 4 The transition from Hydrogen Fuel Cell to Hydrogen ICE will simplify the downstream and will only need tweaking of the extant gasoline ICE to accommodate hydrogen as alternative fuel.



Hydrogen-based internal combustion engines can drastically reduce the growing dependency on lithium, silicon metal, cobalt and REEs for electric-vehicle batteries, and therefore cut down on the import dependency. Hydrogen-CNG and hydrogen internal combustion engines can be immediately used to power buses, trucks, and industrial vehicles like forklifts.

4. HYDROGEN AS A GLOBAL FUEL

Hydrogen is already an important industrial gas used for petroleum refining and production of fertilizers and steel. This section will focus on efforts directed towards the future:

1. Use of green energy for hydrogen production
2. Use of hydrogen in the transport sector

Investments in Green Hydrogen

A number of Gigawatt-scale, green-hydrogen manufacturing facilities have been announced, but the largest green hydrogen plants that are currently operational, under-construction or have been announced are in the 10-40 MW range. The green hydrogen from these projects is not necessarily destined for transport sector; in many cases, this hydrogen is to be used for industrial applications. A facility in Taiwan (Table 1) will produce hydrogen for use in semiconductor manufacture. The oil industry, a major user and producer of hydrogen, is the key investor in some of these projects and also is involved in building hydrogen infrastructure. All the projects in this list are either operational, under-implementation or planned to be completed by 2024.

Table 1: Completed and Ongoing Green Hydrogen Projects

Project Name/Location	Country	Electrolyzer Capacity (MW)	Production Capacity (Kg)	Status	Technology
FH2R, Fukushima[iv]	Japan	20	100 kg/hr	Completed	
Bécancour, Québec[v]	Canada	20	8,200 kg/day	Completed	
Rheinland[vi]	Germany	10	1,300 tons/yr	Completed	PEM
Lancaster, California[vii]	U.S.		11,000 kg/day	Announced	
Tainan & Hsinchu[viii]	Taiwan	25	450 kg/hr	Under Construction	
Wunsiedel[ix]	Germany	8.75		Under Construction	
Masshylia[x]	France	40	5,000 kg/day	Announced	
Sardinia[xi]	Italy	20		Announced	
Leuna[xii]	Germany	24		Under Construction	PEM
GreenLab[xiii]	Denmark	24		Announced	
SEM-REV[xiv]	France			Announced	

A number of other large green-hydrogen projects have been proposed stage, but these “mega” projects are mostly on the drawing board and are a decade or more from implementation.

Table 2: Proposed Mega-Hydrogen projects

Project Name	Country	Capacity	Cost	Companies Involved
NEOM hydrogen project[xv]	Saudi Arabia	1.2 million tons of green ammonia per year	$7 billion	Air Products (US) & ACWA Power (KSA)

Asia Renewable Energy Hub	Australia	23 GW	$36 billion	AREH consortium
2 GW Green H2 Project	UAE	2 GW		TAQA & Abu Dhabi Ports
HyNetherlands	Netherlands	100 MW (expansion planned)		Engie & Gasunie
Silver Fox[xvi]	Italy	800,000 tons H2 (over 8 years)		Hydrogenics Europe, Meyer Burger, Ecosolifer, European Energy
H2morrow[xvii]	Germany	8.6 terawatt hours of hydrogen per year		Equinor & OGE
NorthH2[xviii]	Netherlands	4 GW (10+ GW by 2040)		Shell, Groningen Seaports Gasuine, Equinor
Black Horse[xix]	Poland, Czechia, Hungary, Slovakia	320 tons green H2 per day	Euro 5.7 billion	

Use of Hydrogen in Transport

Industrial uses of hydrogen in the petroleum refining, fertilizer, steel and electronics industries are already well established. Use of hydrogen as a transport fuel is still at a nascent stage. Use of green hydrogen in these applications will displace petroleum-based fuels, helping bring down carbon dioxide emissions.

Hydrogen in Heavy Vehicles

Electric two-wheelers and cars are already in use in almost all key markets. However, EV technology is not viable in heavier vehicles such as heavy-duty trucks, which account for a significant share of oil demand from the transport sector. But hydrogen-fuelled trucks are more promising, as some manufacturers are demonstrating:

1. **Hyundai:** In July 2020, Hyundai shipped 10 units of its XCIENT heavy duty truck, to Switzerland. The company expected to deliver 50 pieces in 2020 and 1,600 by 2025. This truck can pull a maximum load of 36 tons to a range of 400 kilometers on a 32 kg hydrogen fuel tank.[xx]
2. **Toyota-Hino:** In December 2020, Toyota delivered the first two FCEV powered Class 8 heavy trucks to a customer in Los Angeles, with eight more scheduled to be delivered during 2021.[xxi]
3. **Volvo-Daimler:** The two European automakers are competitors, but they formed a 50-50 joint venture in March 2021, with capital of 1.2 billion Euros, with the

objective of developing and commercializing fuel-cell systems for long-haul trucking.[xxii]

Hydrogen Locomotives

The first train to run on hydrogen fuel-cell technology started operations in 2018 in Germany.[xxiii] This train also completed a three-month test run in Austria.[xxiv] Orders for these trains have so far come from Germany,[xxv&xxvi] France,[xxvii] and Italy.[xxviii] These trains are designed to replace diesel-run trains on non-electrified tracks. In January 2021, China unveiled its first hydrogen fuel-cell hybrid locomotive, capable of 700 kW (940 HP) and running for over 24 hours.[xxix] A Japanese consortium that includes Toyota and Hitachi also is working on a hydrogen locomotive.[xxx] In North America, Canadian Pacific Rail is planning to test a hydrogen train as well.[xxxi] Indian Railways is looking at hydrogen too. In 2020, it invited bids for a hydrogen-powered locomotive for a special train; response to the tender is not known.[xxxii]

Electric locomotives are typically used on high traffic-density routes where engines don't need to carry fuel. On non-electrified tracks, diesel engines continue to be used worldwide, including in India. An electrical battery cannot carry the energy needed for railway applications, making hydrogen the only viable alternative to replace diesel engines.

Hydrogen Powered Marine Vessels

International shipping is a significant contributor to global greenhouse gas and particulate emissions because ships use heavy oil as fuel. As a result, there is interest in using hydrogen as a marine fuel.

The underwater arm of the Navy is also a user. Submarines have always relied on electric batteries for underwater propulsion, and with the exception of nuclear craft, still do. However, their underwater endurance is very limited because they use low-energy density batteries. A group of technologies known as Air Independent Propulsion (AIP) allows submarines to remain submerged for extended durations. Some AIP technologies are based on hydrogen fuel cells. Germany's Type 212 submarines use hydrogen fuel cells as a part of their AIP systems.

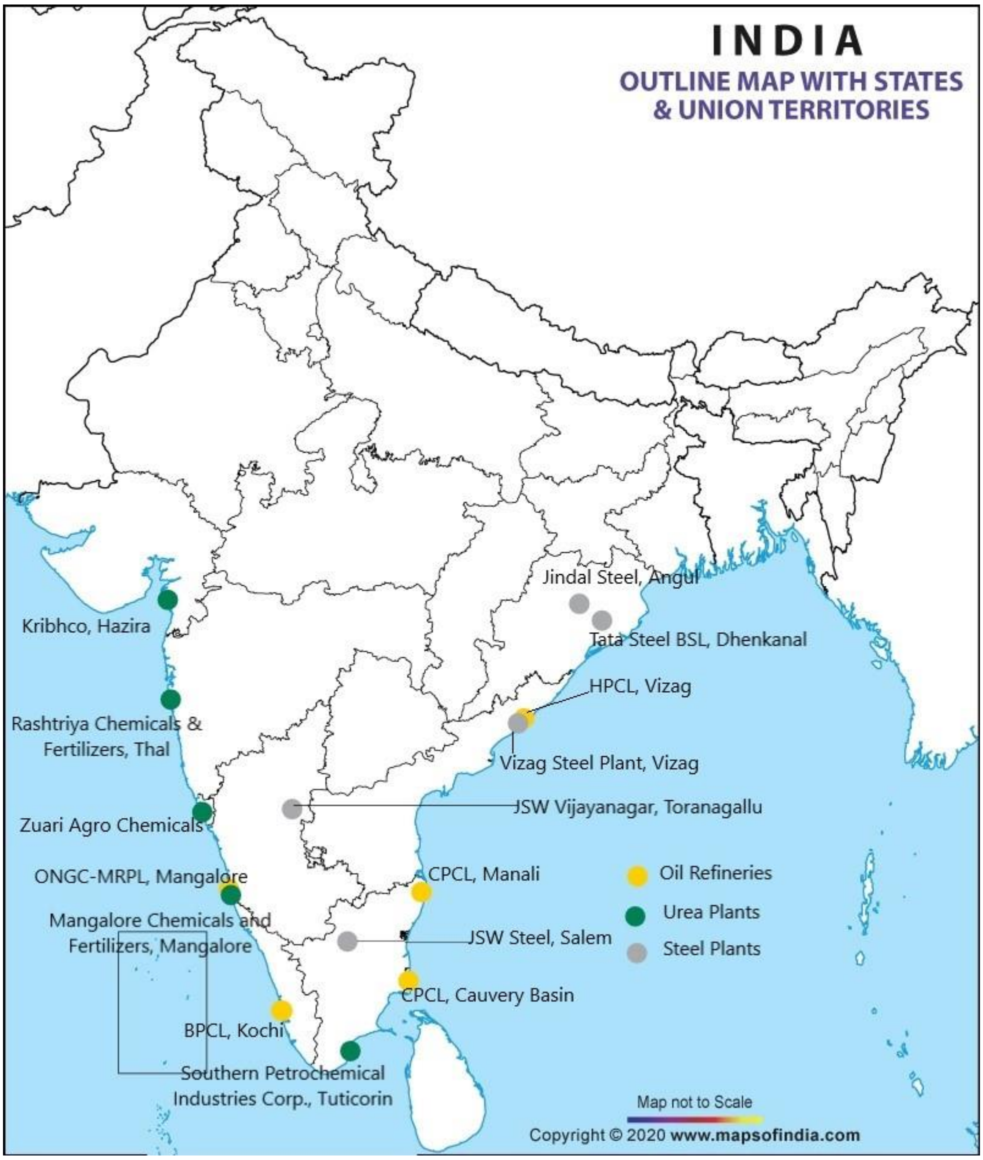
Norway is currently working on multiple hydrogen-powered marine vessels:

1. **MF Hydra:** This 82-meter-long boat, which can carry 299 passengers and 80 cars, will run on hydrogen fuel cells.[xxxiii]
2. **Hydrogen Powered Cargo Ship:** Norwegian shipping company Egil Ulvan Rederi has a contract to build and operate the world's first hydrogen-powered cargo vessel on behalf of two of its clients.[xxxiv]

Chapter 5: Business Models for Hydrogen

Hydrogen as Industrial Fuel

Hydrogen is an important industrial gas used in the petroleum refining, steel and fertilizer industries. Most of the hydrogen used in these industries is currently produced with natural gas (76%) or coal (23%).[xxxv] As use of coal, and to a lesser extent, natural gas, comes under pressure due to environmental concerns, India's large base of plants in these industries represent a large, ready market for green hydrogen in addition to the demand for other purposes, such as transport. (PLACEHOLDER MAP UNDER WORKS)



And unlike some other emerging technologies (including electric vehicles), green hydrogen production facilities are unlikely to become stranded assets. Drivers for shift to green hydrogen may come from regulatory/environmental space rather than commercial considerations – as was initially the case for renewable energy.

Petroleum Industry

Petroleum refining is likely to drive the shift towards green hydrogen. It is the most profitable of the three industries that will play this role, followed by steel, while the fertilizer sector requires government support. Also, oil companies elsewhere, including Exxon,[xxxvi] Shell[xxxvii] and Chevron,[xxxviii] are facing pressure from activists to reduce their carbon footprint.

1. State run Indian Oil Corp. (IOC) is planning to build India's first green hydrogen plant at its petroleum refinery in Mathura.[xxxix] This refinery is close to the Taj Mahal, an added motivation to go for cleaner technologies. In June 2021, IOC awarded a tender for 15 fuel cell buses to Tata Motors.[xl]
2. During its 2021 AGM, Reliance Industries Limited announced it will set up a giga-factory, an electrolyzer to produce green hydrogen at its Jamnagar refinery. The company also proposes to build a fuel cell factory at Jamnagar.[xli] RIL is a major exporter of refined petroleum products and may be sensitive to pressures faced by global oil majors. It is also exploring a partnership with Saudi Aramco; Saudi Arabia is also evaluating large investments in green hydrogen.

Steel Industry

Public sector Steel Authority of India Limited (SAIL) and private sector Tata Steel are the largest steelmakers in India. Tata Steel also has a large overseas presence, with facilities in U.K. and the Netherlands that it obtained through its acquisition of Corus in 2007.

Tata Steel is investigating setting up a 100 MW green hydrogen plant at one of its operations in the Netherlands.[xlii]This project was first proposed in 2018. Any move Tata makes to produce green hydrogen in India is likely to happen after its Europe project.

Other Industries

The renewable energy industry also may move into green-hydrogen production. Its motive would be to diversify its customer base beyond power distribution companies.

1. State-run National Thermal Power Corporation Limited (NTPC) will implement a pilot green hydrogen mobility project in Leh, Ladakh and Delhi, with five buses and five cars running on hydrogen-powered fuel cells in either location.[xliii]

2. ACME Solar, a renewable energy producer, has signed an MOU with Lhyfe of France on production of green hydrogen in Europe and India.[xliv] ACME has a pilot plant producing green hydrogen in Rajasthan.[xlv]

3. JSW Green Energy, a subsidiary of JSW Energy and a part of OP Jindal Group, which also has interests in steel, has recently signed an agreement with Fortescue Future Energies to collaborate on green hydrogen.[xlvi]

Hydrogen as A Natural Gas Additive

Hydrogen can be blended with natural gas and the mixture can be used in the pre-existing natural gas infrastructure. For instance, in some parts of U.K., a mixture with up to 20% hydrogen content has been used in the pipeline network with no noticeable impact on performance.[xlvii] India is currently working on supplying piped gas to households and industry in more than100 cities – offering another market for green hydrogen. Indraprastha Gas (Delhi NCR), Mahanagar Gas (Mumbai) and Gujarat Gas (Gujarat) are the three biggest players in the city gas business.[xlviii]

Startups based on Hydrogen/Fuel-cell Tech

A number of startup companies, particularly in the US, are trying to find a niche in the potential hydrogen market –by producing the gas, fuel cells to convert hydrogen to electricity or motive power, including for marine transport or even aviation. Some of these companies are discussed below.

Plug Power

Share Price	$31.5 (11 June, 2021)
M-Cap	$ 18.43 billion
Source[xlix]	

Plug Power describes itself as "…*a global leading provider of comprehensive hydrogen fuel-cell turnkey solutions. Plug Power has deployed over 40,000 fuel cell systems, designed, and built 110 refuelling stations that dispense more than 40 tons of hydrogen daily, and is a technology leader in green hydrogen solutions via electrolysis.*"

In January 2021, Plug Power formed a joint venture with Renault – HYVIA, which will operate in France. HYVIA will build light commercial vehicles that run on fuel cells. It also will build hydrogen charging stations and will ensure supply of green hydrogen to them.[l]

In June 2021, Plug Power announced it is setting up a green hydrogen plant in Camden, Georgia, powered by renewable energy. This plant will produce 15 tons of hydrogen per day using renewable energy at a capex of $84 million.[li]

Ballard Power Systems

Share Price	$17.11 (16 June, 2021)
M-Cap	$5.08 billion
Source[lii]	

Ballard provides hydrogen fuel cells for marine heavy-duty trucks, trains and vessels.[liii] The company has joint ventures with Weichei (China), Mahle (Europe) and Canadian Pacific (North America) for developing fuel cells for different applications. Ballard Fuel modules will be used in Canadian Pacific's hydrogen locomotive program.[liv]

Bloom Energy

Share Price	$24.29 (16 June, 2021)
M-Cap	$4.2 billion
Source[lv]	

Bloom Energy was founded by KR Sridhar, who worked on NASA's Mars Exploration program. The company's core technology is based on research done by its founders on using electricity generated by a solar panel to produce fuel and oxygen on Mars for NASA. Bloom Energy Servers reversed this process by taking in fuel and air to generate electricity. Bloom is capitalizing on this technology by taking terrestrial renewable power and producing hydrogen using solid oxide electrolyzers.[lvi]

In May 2021, Bloom Energy announced an agreement with the Idaho National Laboratory to explore the use of nuclear power to generate hydrogen using Bloom's solid oxide, high temperature electrolyzer.[lvii] Bloom is producing solid oxide fuel cells for South Korea in collaboration with SK Energy (Korean firm).[lviii]

Ceres Power Holdings

Share Price	GBP 992 (15 June, 2021)
M-Cap	GBP 1.89 billion
Source[lix]	

Ceres is a UK based fuel cell technology company whose work is based on research coming out of the Imperial College, London.[lx]Its biggest shareholders are Weichai Power (China, State owned, 19.94%) and Robert Bosch Gmbh (Germany, 17.75%).[lxi]

ZeroAvia

This is a US and UK-based company trying to develop hydrogen powered technology for short-haul (300-500 miles) flights. In September 2020, ZeroAvia carried out the world's first hydrogen fuel-cell powered flight,[lxii]powering a six-seat aircraft that flew up to 1,000 feet.[lxiii] Because of its higher energy density, hydrogen can match fossil fuels in powering aircraft in range. However, carrying liquefied or gaseous hydrogen at high pressure on board an aircraft will remain a major challenge.

Five T Hydrogen Fund

This is a 1billion-euro infrastructure fund set up to invest in hydrogen-only projects. Plug Power, Chart Industries and Baker Hughes are the anchor investors.[lxiv]

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[i]https://www.ntpc.co.in/sites/default/files/downloads/44-final-NTPC-AR-30082020.pdf
[ii]http://loksabhaph.nic.in/Questions/QResult15.aspx?qref=3236&lsno=17
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