GREEN HYDROGEN

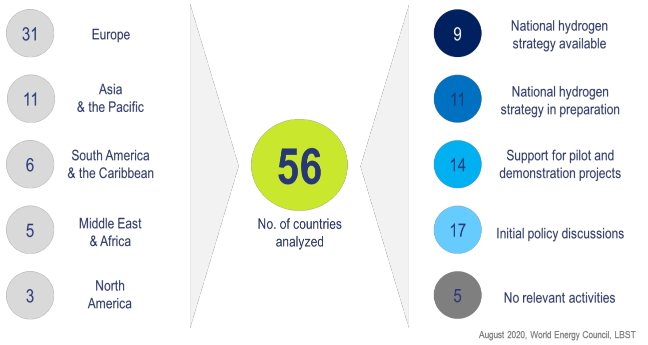
Early mover business case ?

India's emerging policies in Green Hydrogen space

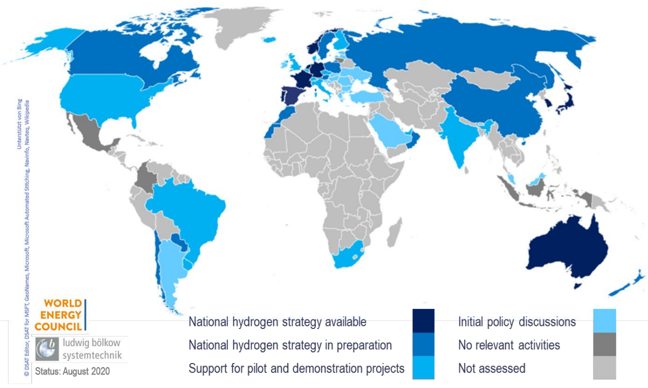
Following COP26 pledge by India towards net-zero by 2070, aim to target 500GW non-fossil fuels electricity by 2030, Faster Adoption and Manufacturing of Electric Vehicles- Phase II (FAME II) for Electric Vehicles and over Rs 18100 Cr (> USD 2.3 billion) production linked incentives in advanced cell batteries are strong policy commitment to reach the goals. Complementing these efforts further is a great push for Green Hydrogen (GH2) as a potential solution to decarbonise sectors like refinery, ammonia, methanol, iron and steel and heavy duty trucking. India's National Hydrogen Mission was set up for aiming to make India the world's hydrogen hub which has further resulted in the recently approved Green Hydrogen policy (17 February 2022). The policy majorly covers i) waiver of inter-state transmission charges for 25 years, ii) open access for sourcing renewable energy, iii) Banking for 30 days for renewable energy for making GH2, iii) land availability in renewable energy parks, iv) facility for storage at ports for export of GH2, v) single portal for all clearances, vi) aggregation of demand from different sectors by MNRE for floating consolidated bids etc. Additionally, Ministry of coal has allowed 50% reduction in the coal mines revenue sharing for the project leading to coal gasification which in turn can convert the Syngas to Green Hydrogen with carbon capture.

Global efforts in Green Hydrogen space

According to World Economic Council report, a preliminary screening of hydrogen strategies in 56 countries around the world[1], representing over 90% of global GDP, reveals that nine countries already have an existing comprehensive national hydrogen strategy and further eleven are in the process of developing one (see Figure below).



Together, these 20 countries stand for 44% of global GDP. Another 14 countries (38% of global GDP) are already supporting hydrogen pilot and demonstrations projects (without dedicated hydrogen strategy) and in 17 countries first government and/or stakeholder discussions regarding hydrogen are ongoing. Hydrogen activities are well spread around the globe with major interest being located in Europe, in the Asia and Pacific region, as well as in the Americas (see Figure below).



One issue is very clear Green Hydrogen is an emerging business opportunity for a careful evaluation.

1 WEC_H2_Strategies_final report September 2020 - World Energy Council

Various colours of Hydrogen in vogue - an understanding

Hydrogen–The lightest element in the periodic table and the most common in the universe. Because of its natural tendency to form bonds with other molecules, it is rarely found unbounded in nature. It can therefore be considered as a storage of energy because the molecules can be easily encouraged to form bonds with other elements through either chemical or combustion processes.

Green hydrogen–This term is used for hydrogen produced from 100 percent renewable sources. It most commonly refers to hydrogen created from a process called electrolysis, which can use 100 percent renewable power and water to create pure hydrogen and oxygen. Other green hydrogen production methods include hydrogen extraction from reformed biogas and hydrogen extraction from waste.

Gray hydrogen–This term usually refers to hydrogen produced via steam methane reforming (SMR), and it is the most common type of hydrogen produced globally. Gray hydrogen can also refer to hydrogen that is created as a residual product of a chemical process–notably, the production of chlorine from chlor-alkali plants[2]. Hence the companies in the choler alkali plants business may find a natural diversification choice for Hydrogen production.

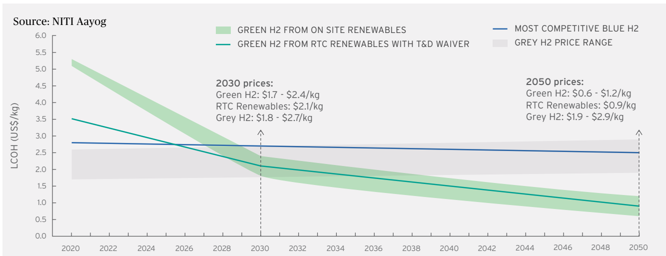
Blue hydrogen–This term is used for hydrogen produced using low-carbon processes. It is almost exclusively used to refer to hydrogen produced via natural gas or coal gasification but combined with carbon capture storage (CCS) or carbon capture use (CCU) technologies in order to reduce carbon.

Black hydrogen–Hydrogen produced from coal via coal gasification and extraction.

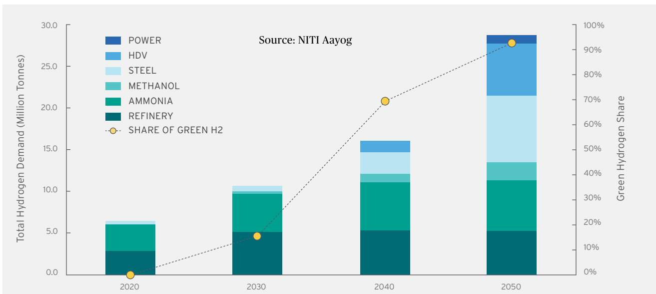
Brown hydrogen–Hydrogen produced from lignite via gasification.

Hydrogen - market analysis - India/Global

The usual questions are what is present market, future demand & supply and Hydrogen economics. Let us deal these one by one. The Green Hydrogen market is nascent but evolving with strong footings. Hydrogen production today is dominant based on fossil-fuel based (Gray/Blue Hydrogen) intensive process and needs upscaling to decarbonise the existing production. The most common methods to extract hydrogen are through the reforming of natural gas–a process that accounts for around 6 percent of global natural gas demand–and gasification–for which about 2 percent of total coal production is allocated, most of which is in China[3], together constituting 96 and 98% of global hydrogen production. The global water electrolysis deployment has increased to ~260 MW in last 05 years. The size of electrolyzers is also rising,



resulting into lower cost of Green Hydrogen. India's distinct advantage in low cost renewable energy generation makes Green Hydrogen the most competitive form of Hydrogen in long run in the range of GH2 : $0.6 to $1.2/kg from present $5 to $7/kg. Hydrogen demand in India could grow more than fourfold to around ~25 MT by 2050 representing almost 10% of the global hydrogen demand. Green



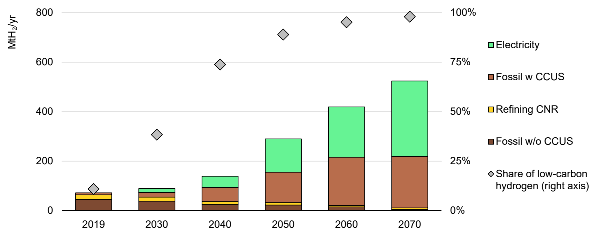
Hydrogen's share of this demand could grow from 16% in 2030 to almost 94% by 2050. This translates to

[2] Utilization of hydrogen as clean energy resource in chlor-alkali process (https://journals.sagepub.com/doi/full/10.1177/0144598719839767)

[3] Green Hydrogen in developing countries, Energy Sector Management Assistance Program (ESMAP), part of the World Bank.

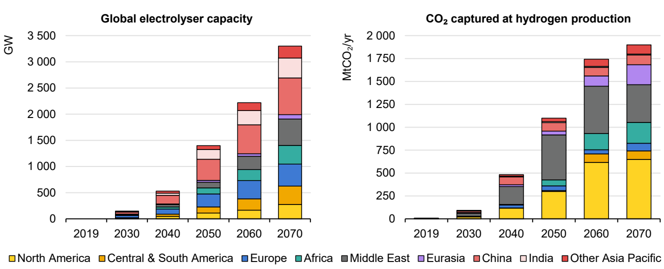
an implied cumulative electrolyzer capacity demand of 20 GW by 2030 and 226 GW by 2050, promising a sizeable opportunity for indigenous manufacturing of a global emerging energy technology. The cumulative value of the green hydrogen market in India could be $8 billion by 2030 and $340 billion by 2050[4]. Electrolyzers market size could be approximately $5 billion by 2030 and $31 billion by 2050. 1 million tonnes of green hydrogen corresponds to around 11-13 GW of electrolyzer capacity.

Globally, Hydrogen is today produced mainly by the steam reforming of natural gas and is mainly used for the chemical and refining industries. As per the IEA report[5], in the sustainable development scenario, the global hydrogen production may be to ~445 MT for energy use and ~75 MT for the process use by 2070. The below graph shows the Global Hydrogen production in the sustainable



Note: CNR = hydrogen as by-product from catalytic naphtha reforming in refineries.

development scenario from 2019 to 2070. Global installed electrolyzers capacity is estimated to be rapidly increased from 170 MW in 2019 to 3300 GW by 2070. Global development of electrolyzers and CO2 capture by region (2019-2070). Production and



technology choice profiles for low-carbon hydrogen differ across regions reflecting factors such as the availability of suitable renewable energy resources, CO_2 storage and access to low cost natural gas. The assumptions for Hydrogen demand can vary significantly between 6 to 25%[6] depending on the various assumption like global warming target of temperature rise <1.8°C , 1.8°C to 2.3°C and >2.3°C, hydrogen policies (strong or weak) etc.

HYDROGEN DEMAND SCENARIOS

	Acil Allen Report	BP Energy Outlook 2020	Hydrogen Economy Outlook	Hydrogen Council – 2DS	IEA	Powerfuels in a Renewables World	Shell – Sky scenario	World Energy Council
Total hydrogen demand estimates (Mt)	**High:** - 2030: 93 - 2040: 161 - 2050: 401 **Medium:** - 2030: 84 - 2040: 113 - 2050: 213 **Low:** - 2030: 77 - 2040: 94 - 2050: 148	**Net Zero:** - 2030: 104 - 2040: 282 - 2050: 560 **Rapid:** - 2030: 102 - 2040: 173 - 2050: 284	**Strong policy:** - 2030: N/A - 2040: N/A - 2050: 696 **Weak policy:** - 2030: N/A - 2040: N/A - 2050: 187	- 2030: 111 - 2040: 201 - 2050: 567	**Energy Technology Perspectives (ETP) 2020 - SDS:** - 2030: 90 - 2040: 135 - 2050: 290 **Net Zero Scenario:** - 2030: 212 - 2040: 391 - 2050: 528	- 2030: 86 - 2040: 164 - 2050: 346	- 2030: 80 - 2040: 94 - 2050: 149	**Unfinished symphony:** - 2030: 117 - 2040: 164 - 2050: 228 **Modern Jazz:** - 2030: 99 - 2040: 125 - 2050: 185
Hydrogen production route		Green, Blue, Grey hydrogen			**ETP 2020:** Electricity, Fossil w CCUS, Refining CNR, Fossil w/o CCUS **Net Zero Scenario:** Fossil fuels, Refining CNR, With CCUS, Electricity, Biomass	Green hydrogen		
Projected demand by application	Transport, Space heating and cooling, Power sector	Power, Buildings, Transport, Industry	Buildings, Power, Industry, Transport	Buildings, Power, Industry, Transport, Energy system	Net Zero Scenario: Transport (shipping, road, aviation), Iron and steel, Chemicals		Industry (heavy, light), Transport (road, air, ship)	
Ambition to limit global warming	**High:** a 50% chance of limiting the peak in global temperature (temp.) to between 1.5-2°C **Medium:** a 50% chance of limiting the peak in global temp. to 2°C **Low:** 50% chance of limiting the peak in global temp. between 2-4°C	**Net Zero:** limiting temp. rise to 1.5°C above pre-industrial levels **Rapid:** limiting temp. rise to well below 2°C above pre-industrial levels	**Strong policy:** H2 supply 27EJ of energy in global economy, meeting 4% of projected final energy needs in 2050 or 7% in 1.5°C scenario **Weak policy:** H2 supply 99EJ of energy in global economy, meeting 15% of projected final energy needs in 2050 or 24% in 1.5°C scenario	Limit global warming to 2°C	**ETP 2020:** hold the temp. rise to below 1.8°C with a 66% probability without reliance on global net-negative CO2 emissions **Net Zero Scenario:** a 50% chance of limiting the temp. rise to 1.5°C	Achieve the goals of the Paris Agreement of achieving zero GHG emissions from the energy sector by 2050	Limiting the global average temp. rise to well below 2°C from pre-industrial levels	**Unfinished symphony:** <2.3°C confirmed with study authors **Modern Jazz:** >2.3°C confirmed with study authors

Source: PwC

HYDROGEN ON THE HORIZON: READY, ALMOST SET, GO?

Strategy and road map for Hydrogen development by each country becomes very important to asses the scenario in leading countries. As per Niti Aayog report[7], mapping of the emerging hydrogen roadmaps and strategy of the leading countries and regions are evaluated as per below table shows the active early mover investments and developments:

	Current Hydrogen Demand	Policy Target Demand	Capital Allocated (US$)	Focused Hydrogen Source	Demand Focus: Industry	Demand Focus: Transport	Demand Focus: Others	Export/ Import Focus
European Union		6 GW capacity by 2024; 40 GW by 2030; 10 MMTPA green H_2 by 2030	609 billion	Low Carbon - Blue / Green	1. Chemical feedstock 2. Refining	1. Medium and Heavy Duty 2. Buses 3. Rail		
Germany	1.65 MMTPA	2.7-3.3 MMTPA by 2030	15-20 billion	Carbon free - Blue / Green	1. Iron and Steel 2. Chemical feedstock 3. Refining	1. Medium and Heavy Duty 2. Buses 3. Rail		Import
France	0.9 MMTPA	6.5 GW via electrolysis by 2030	> 7 billion	Low Carbon - Blue	1. Iron and Steel 2. Chemical feedstock 3. Refining 4. Others	1. Medium and Heavy Duty 2. Buses 3. Rail 4. Aviation		Export
Netherlands	1.5 MMTPA	Not Available	40-55 million/yr	Blue / Green	1. Iron and Steel 2. Chemical feedstock 3. Refining 4. Others	1. Passenger Vehicle 2. Medium and Heavy Duty 3. Buses 4. Rail	1. Heating	EU Export/ Import Hub
Hungary	160 ktpa	36 ktpa (low carbon) + 138 ktpa (grey) by 2030	450 million	Low Carbon - Grey / Blue	1. Chemical feedstock 2. Refining	1. Medium and Heavy Duty 2. Buses	1. Heating	
Portugal	~150 ktpa	2-2.5 GW via electrolysis by 2030 400 ktpa overall by 2030	No dedicated capital	Green	1. Iron and Steel 2. Chemical feedstock 3. Refining 4. Others	1. Passenger Vehicle 2. Medium and Heavy Duty 3. Buses	1. Heating	Export
Spain	0.5 MMTPA	4 GW via electrolysis by 2030	No details	Green	1. Chemical feedstock 2. Refining			Export
United Kingdom	0.7 MMTPA	5 GW/a electrolysis capacity by 2030	2 billion	Blue / Green	1. Chemical feedstock 2. Iron and Steel	1. Medium and Heavy Duty 2. Buses 3. Rail 4. Aviation 5. Shipping	1. Heating 2. Power	Export
Norway			23 million	Clean	1. Chemical feedstock	1. Maritime		
Japan	2 MMTPA	3 MMTPA by 2030 and 20 MMTPA by 2050 (5-30 by 2050)	935 million / yr	Blue		1. Passenger Vehicle	1. Heating 2. Power	Import
South Korea	220 ktpa	3.9 MMTPA by 2030 and 27 MMTPA by 2050	653 million / yr	Grey / Blue / Green		1. Passenger Vehicle 2. Medium and Heavy Duty 3. Buses	1. Power	Import
United States	10 MMTPA		> 15 billion	Low Carbon - Blue / Green / Others	1. Refining 2. Others	1. Passenger Vehicle 2. Medium and Heavy Duty 3. Buses 4. Aviation	1. Heating 2. Power 3. Energy storage	
Canada	3 MMTPA	20 MMTPA	1.2 billion	Low Carbon Intensity - Grey / Blue	1. Iron and Steel 2. Chemical feedstock 3. Refining 4. Others	1. Passenger Vehicle 2. Medium and Heavy Duty 3. Buses 4. Rail	1. Heating	Export
Australia	650 ktpa		278 million (annual support)/ yr	Clean - Blue / Green	1. Chemical feedstock	1. Medium and Heavy Duty 2. Buses	1. Heating	Export
Chile	58.5 ktpa	5 GW/a (2025) 25 GW/a (2030)	50 million	Green	1. Chemical feedstock 2. Refining	1. Medium and Heavy Duty 2. Buses	1. Heating	Export
China	22 MMTPA	35 MMTPA (by 2030); 160 MMTPA (by 2050)	13 million	Green (long-term)		1. Passenger Vehicle 2. Medium and Heavy Duty 3. Buses	1. Power	
Russia	2-3.5 MMTPA	7 MMTPA by 2035 and 33 MMTPA by 2050 (export only)	1.2 billion	Low Carbon - Blue / Nuclear	1. Refining	1. Rail		Export

[4] Niti Aayog - Harnessing Green Hydrogen 2022

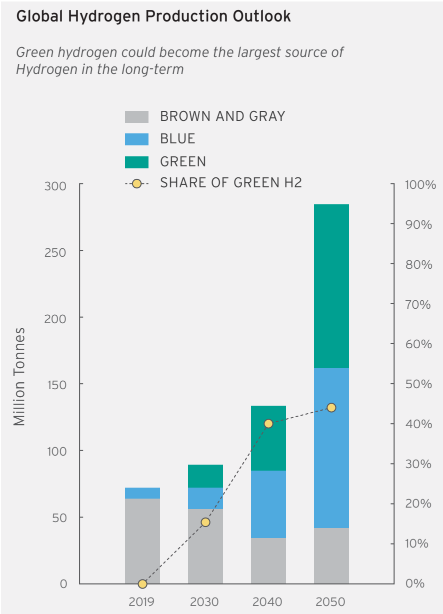
[5] IEA - Report - Energy_Technology_Perspectives_2020_PDF

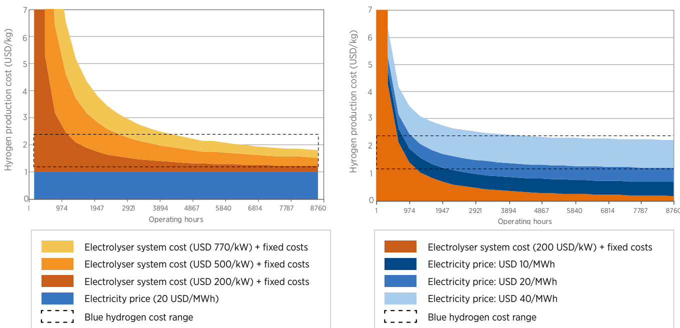
[6] WEC- Innovation Insights - Hydrogen on the Horizon

[7] Niti Aayog - Harnessing Green Hydrogen 2022

Hydrogen Economics

Niti Aayog has further summarised the potential share of Green Hydrogen vis-a-vis other Gray/Blue Hydrogen globally looks that share of green hydrogen will be 45% by 2050 from minuscule share presently. The driving force for the development of the Green Hydrogen are 1) lower costs of the renewable power cost, 2) the lower costs of the electrolyzers and 3) Operating hours. As per IRENA analysis[8], please see below:





Note: Efficiency at nominal capacity is 65% (with an LHV of 51.2 kWh/kg H_2), the discount rate 8% and the stack lifetime 80 000 hours.

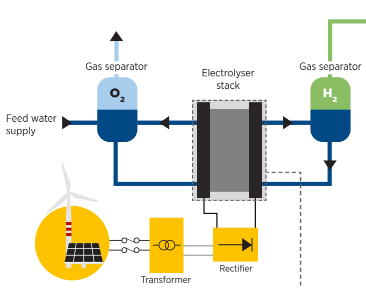
Based on IRENA analysis.

With the electricity price (wind/solar) available in the range of USD 20/MWh, electrolyzers cost in the range of USD 200/kW with >8500 operating hours, we may achieve the Green Hydrogen production cost in the range of USD 1/kg. Presently high cost of electrolyzers (in range of USD 600-800/kW) the GH2 production cost may be in the range of USD 4.5 to 7 per kg. Also witnessing the declining renewable costs with hybrid options of wind and solar power leading to electricity cost in the range of USD 10-20/MWh with the long term cost reduction in electrolyzers costs to sub USD 200/kW level may look quite feasible to achieve the GH2 production cost lower than the USD 1/kg. Blue hydrogen production cost on a long term basis ranges between USD 2-3 /kg presently. On a long term basis, it looks to be quite possible the GH2 production cost may come lower than the Blue hydrogen. An immense investment opportunities are available in R&D, Development of Green Hydrogen projects and manufacturing of Electrolyzers space.

Green Hydrogen Production

The GH2 production plant consists of mainly 1) Electrolyzer, 2) Balance of Plant and 3) Storage.

The electrolyzer is composed of the stack (where the actual splitting of water into hydrogen and oxygen takes place and the balance of plant, which comprises power supply, water supply and purification, compression, possibly electricity and hydrogen buffers and hydrogen processing. The flexibility of alkaline and PEM stacks is enough to follow fluctuations in wind and solar[9]. There are four types of electrolyzers: Alkaline and polymer electrolyte membrane (PEM) are already commercial, while anion exchange membrane (AEM) and solid oxide, now at lab scale, promise a major step forward. Water is the main input other than electricity and typically 1 kg of Hydrogen needs around 9 kg of demineralised water making that around 18-20 kg of water would be needed to produce 1 kg of GH2. Various opportunities are available for investment in the area of Electrolyzers, efficiencies, system design to optimise the utility consumptions, storage and transport.



Source : IRENA

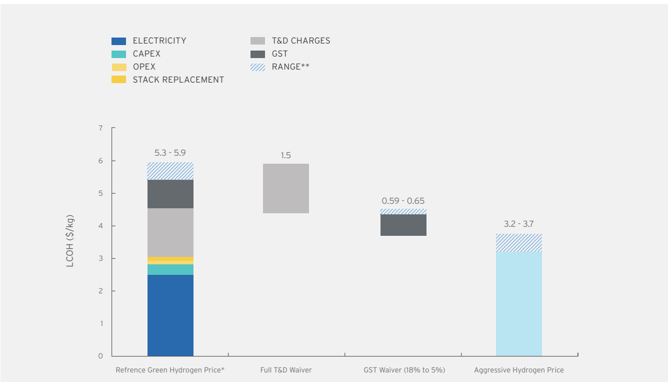
[8] IRENA Green Hydrogen cost 2020

[9] IRENA Green Hydrogen cost 2020

India's Case - Future of Green Hydrogen

The production cost from electrolysis today is relatively high in the range of USD 5 to 7 /kg compared to USD ~3/kg for Blue Hydrogen (Natural gas/Coal based with Carbon capture & Storage). However, as we discussed above on a long term scenario, GH2 has a brighter future due to falling costs of renewables energy and electrolyzers. However, argument also goes in favour of coal based Hydrogen with carbon capture & storage due availability of coal in abundance in India. Additionally, govt of India has reduced the 50% share in the revenue to be given to the govt for the coal gasification project in order to promote the clean technologies. Natural Gas based hydrogen is not an option due to only import-availability of the natural gas in India.

Indeed electrolyzers and electricity costs will guide the long term price profile of Green Hydrogen, there are soft costs element which can also help to reduce Green Hydrogen cost even today. As per Niti Aayog/ RMI analysis[10] Govt of India's waiver of inter-state T&D charges for electricity used for production on Green Hydrogen may reduce cost by USD 1.5 per kg. Additionally GST waiver (from 18%-5%) may also contribute the reduction around USD ~0.6 per kg thereby producing the Green Hydrogen in the range USD 3.2-3.7 per kg from USD 5.5 - 6 per kg presently. Of course in the long run the cost will be $0.6 to $1.2/ kg.



Source: RMI Analysis

* Hydrogen price calculated for RTC renewable (@ ₹3.6/kWh) with average T&D charges
** The range is based on high and low end of electrolzyer capex price: $500 - 969/kW

There are development opportunities available in the coal fields to develop both Green and Blue Hydrogen. Most of the coal mines are situated on the east zone of India for example Talcher coal field. The vast overburden land lying vacant can be used for solar/wind power for producing Green Hydrogen and even the option for export can also be evaluated due to nearby Paradeep Port. The present govt of India policy allows storage facility for Green Hydrogen at port. Such projects may yield the lower cost of production even today. Another alternate can be coal to Hydrogen projects in the coal mine area as the govt incentive of 50% reduction in revenue share is available for such projects. Large mines are available in the coal mine bidding auction which come time to time. The Hydrogen can be used to heavy duty trucks, ammonia production, partial inducement of Hydrogen in steel making as a reductant (DRI furnace or BF/BOF replacing coking coal which is an import solution currently) and to export.

The manufacturing opportunity are available in the field of Electrolyzers (~45% of the total plant costs) as the demand is expected to grow 20 GW by 2030 and 226 GW by 2050. There are several R&D opportunities available on the size, scale and efficiency of the electrolyzers including further development of PEM stacks compared to Alkaline stacks. There are many international funds which are supporting such initiatives and available on very attractive terms.

To summarise, the early mover advantages in Hydrogen space are very compulsive and needs a serious evaluation.

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[10] Niti Aayog - Harnessing Green Hydrogen 2022