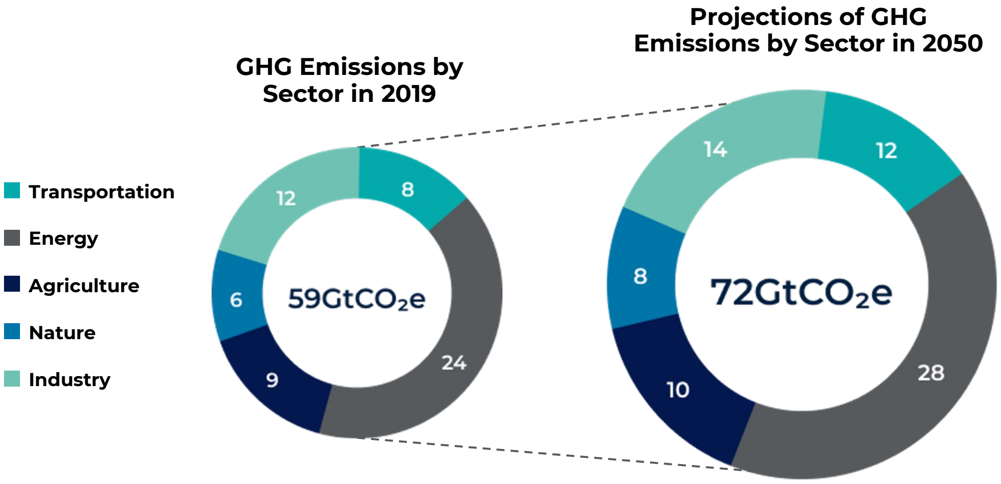
Green Hydrogen BLUprint

January 2024

BLUME

Net-Zero Commitments take centerstage, propelling adoption of renewables



Surge in Renewable Energy Demand

The International Renewable Energy Agency (IRENA) estimates that the share of renewable energy in total final energy consumption (TFEC) could double by 2030, from 18% in 2010 to 36% in 2030.

Challenges of Renewable Energy Transition

Intermittency & Infra Issues: Renewable sources can produce energy during off-peak demand hours, creating an energy storage challenge coupled with lack of infra available for the clean transition

Hydrogen's Role: Green Hydrogen will be a key element in delivering 90% of the required reductions, with 75% achievable through renewable power and the electrification of heat and transport.

- The shift towards electrification powered by hydrogen in **buildings, transportation, and industry** will contribute to reducing the energy intensity of GDP and, consequently, CO2 emissions.
- However, Non-energy-related CO2 emissions, including agriculture and deforestation, are expected to decline more slowly.
- Green Hydrogen will be a key element in delivering 90% of the required reductions, with 75% achievable through renewable power and the electrification of heat and transport.

Source: McK 2050 Emissions Report, IRENA 2050 Roadmap

Hydrogen to play an instrumental role in reaching global mitigation targets

Common goal of reducing emissions to curb climate change

66 countries

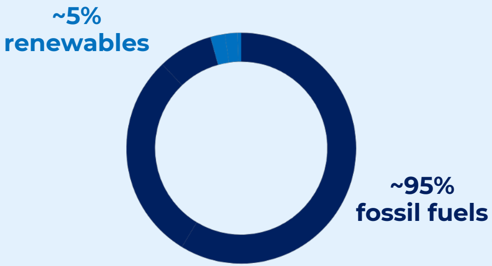
globally have announced commitments to reach net-zero emissions by 2050

45% reduction

in Indian greenhouse gas (GHG) emissions targeted by 2030

The current energy mix remains heavily dependent on fossil fuels

Indian primary energy demand by source (2021)



Major challenges exist to reaching decarbonisation goals

1

The sectors emitting the most GHG depend heavily on fossil fuels & are **difficult to decarbonise**

Energy	Transportation	Industry
~41%	**~21%**	**~20%**

% of contribution to total GHG emissions

2

Wide scale integration of renewable energy **requires a viable energy carrier & storage solution to bridge intermittent supply & demand**

Supply

Renewable energy exhibits short- and long-term variation

Demand

Intra-day, weekly & seasonal variations are sizable

Hydrogen can be instrumental in meeting these changes

Key advantages of hydrogen

- Net-zero emissions when produced (if produced as green hydrogen using renewable energy) and when used
- Highly Versatile with both direct applications in transportation and industry, indirect applications in Power-to-X and for grid stabilisation
- High gravimetric energy density, allowing easy and efficient storage and transportation of energy over time and distance

Decoding CO_2 Emissions Reductions through targeting End-Use Sectors that offer early adoption of Green Hydrogen (1/2)

Energy CO_2 Equation	
Subsector	**Current $GtCO_2e$**
Power (Electricity & Heat Producers)	14.0
- Coal	10.1
- Oil	0.6
- Natural Gas	3.1
- Other	0.2
Other Energy Industries	1.6
Buildings (Residential + Commercial & Public Service)	2.9
Other & Fugitive Emissions	5.9

Transport CO_2 Equation	
Subsector	**Current $GtCO_2e$**
Road Transport	6.0
- Passenger	3.6
- Buses & Minibuses	0.1
- Two/Three Wheelers	0.1
- Freight (Heavy & Medium Trucks)	2.4
Aviation	0.9
- Passenger	0.7
- Freight	0.2
Maritime	0.9
Rail	0.1
Other (Pipe, etc.)	0.4

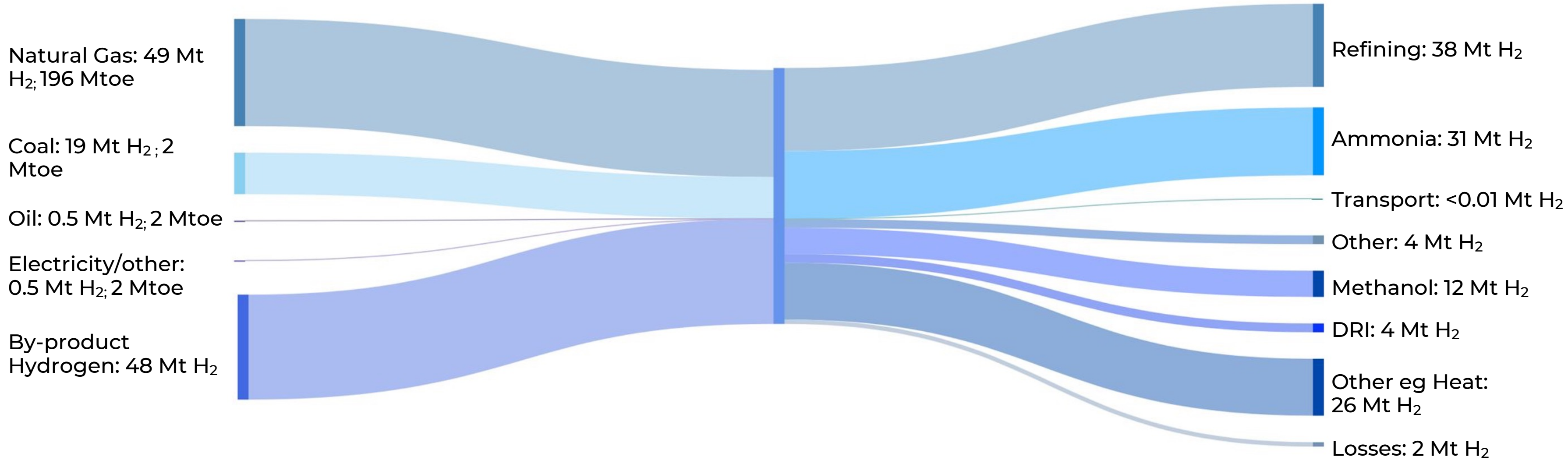
Green Hydrogen being most effective in decarbonizing these hard-to-abate themes

Decoding CO_2 Emissions Reductions through targeting End-Use Sectors that offer early adoption of Green Hydrogen (2/2)

Agriculture CO_2 Equation	
Subsector	**Current $GtCO_2e$**
Agricultural Production	6.9
- Ruminant Enteric Fermentation	2.3
- Energy on-Farm	1.1
- Rice (Methane)	0.9
- Soil Fertilization	0.6
- Manure Management	1.5
- Ruminant Waste on Pastures	0.5
Energy (Ag Energy Sources)	0.4
Waste	1.6

Industry CO_2 Equation	
Subsector	**Current $GtCO_2e$**
Iron & Steel	3.8
Cement	3.0
Other Materials	5.0
- Chemicals (Plastics & Rubber)	1.4
- Other Minerals	1.1
- Glass & Wood Products	1.3
- Other Metals	1.2

Hydrogen carries the right to win with its versatility as an energy carrier and wide breadth of end use-cases



Production

Hydrogen as a versatile energy carrier can be produced from a variety of feed-stocks, including natural gas, coal, biomass, waste, solar sources, wind, or nuclear sources

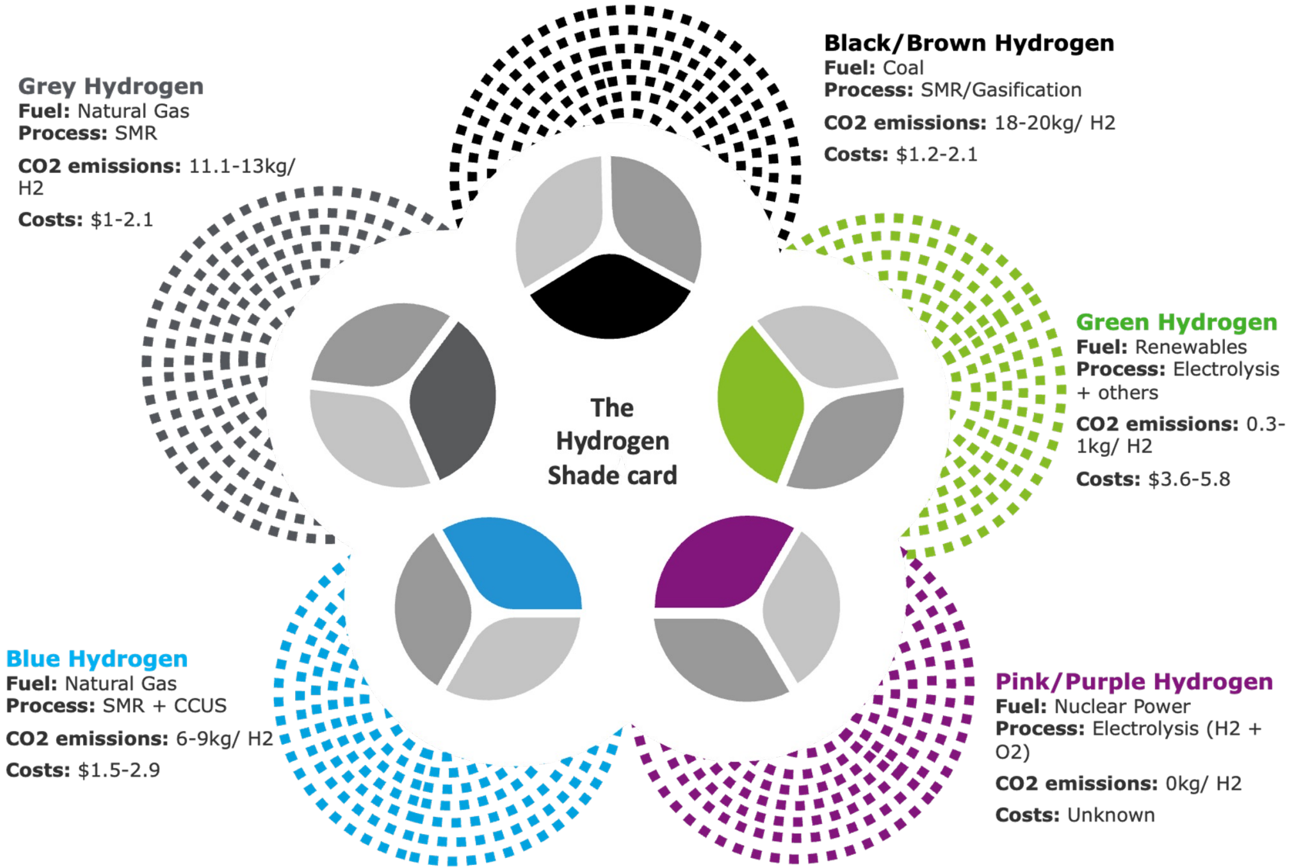
Consumption

Hydrogen is an energy carrier and can be used for a wide array of energy and industrial applications like Power Generation, Steel Making, etc.

** all figures in Mt H_2*

Source: IEA

The Hydrogen Shade Card - Based on the sources and processes of Hydrogen production, it can be classified into various colors



Source: Blume's Market Analysis & Multiple Reports

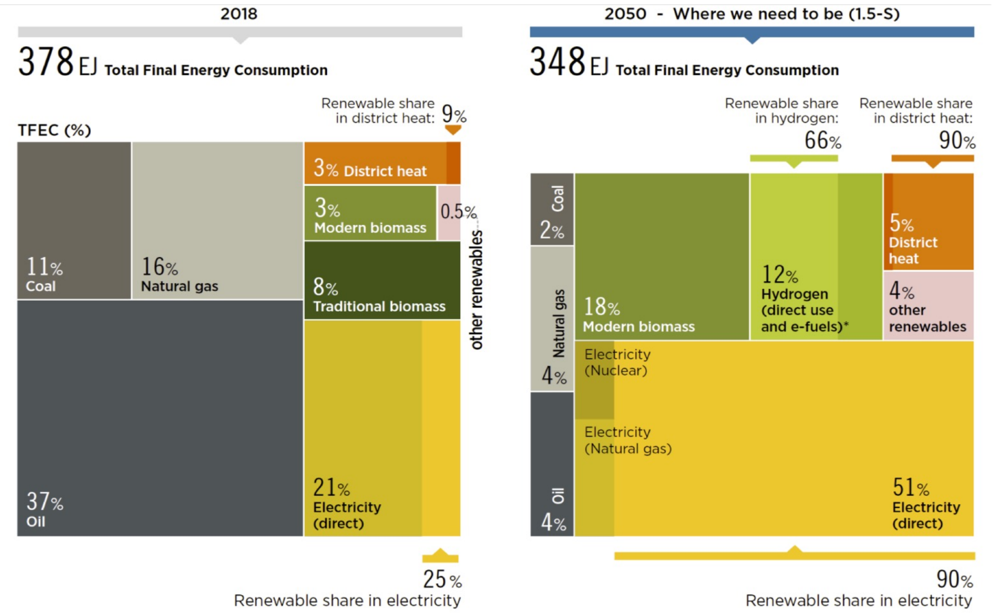
Future of Hydrogen - Green

Basics

Green hydrogen, often referred to as "green H_2," is hydrogen produced through a process called electrolysis using renewable energy sources such as wind, solar, or hydropower. The electricity required for this process is generated from renewable sources, which makes the overall production of hydrogen environmentally friendly and carbon-neutral.

> *Plummeting cost of renewable electricity and Zero emissions in production and end use make hydrogen a pivotal resource to drive the world energy transition*

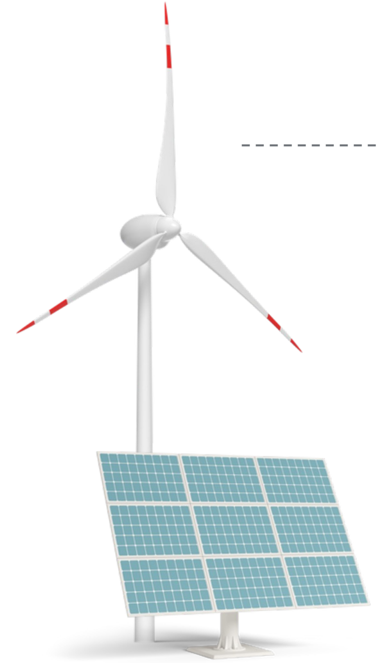
Why now for Green H_2?



Source: IRENA Insights webinar series

Mapping Green Hydrogen's Journey: From Production to Powering the Future

Renewable Energy Production



Hydrogen Production Methods

- Steam Methane Reforming
- Coal Gasification
- Electrolysis
- Biological

Storage and transportation of hydrogen

Direct Applications in transportation and as feedstock in the industry

- Buses & Trucks
- Smaller Ships
- Refineries
- Industry Feedstock
- Steel Production

Power-to-X: Indirect use as the basis for production of green fuels/e-fuels

- Conversion via synthesis
- Transport, Aviation and Shipping
- Fertiliser *(e-ammonia)*
- Replace Natural Gas

Grid stabilisation through storage of hydrogen and re-conversion to energy through fuel cell technology

- **Conversion via fuel cells**
- **Electric Grid**

Hydrogen Adoption Matrix- Mid to Long term

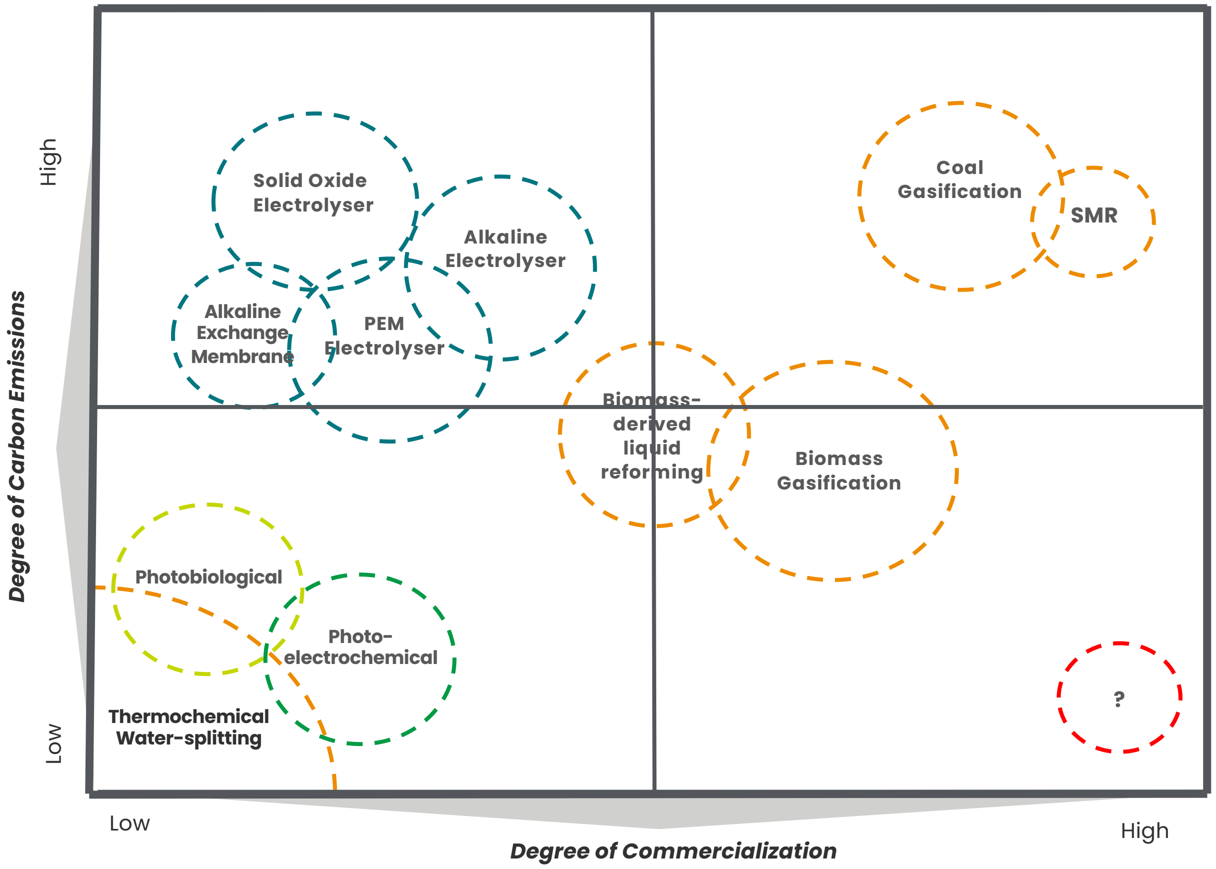
High H2 Adoption
Hydrogen being highly competitive in the long term

Fertilizers	Methanol	Desulphurization	Hydrocracking	
Chemical feedstock	Steel	Long term storage	Shipping	
Long haul Aviation	Remote Trains	Coastal and river vessels		
Medium haul Aviation	Long distance trucks & coaches	Generators		
Short haul Aviation	Commercial Heating	Clean power imports	Uninterruptible Power Supply (UPS)	
Light Aviation	Regional Trucks	Domestic Heating	Low Temperature Industrial Heating	Rural trains
Metro trains	Buses	H2FC Cars	Urban Delivery	

Long H2 Adoption
Hydrogen being highly uncompetitive for these use-cases

Potential Targets for the next 3-5 years

Hydrogen Production Methods - Overview

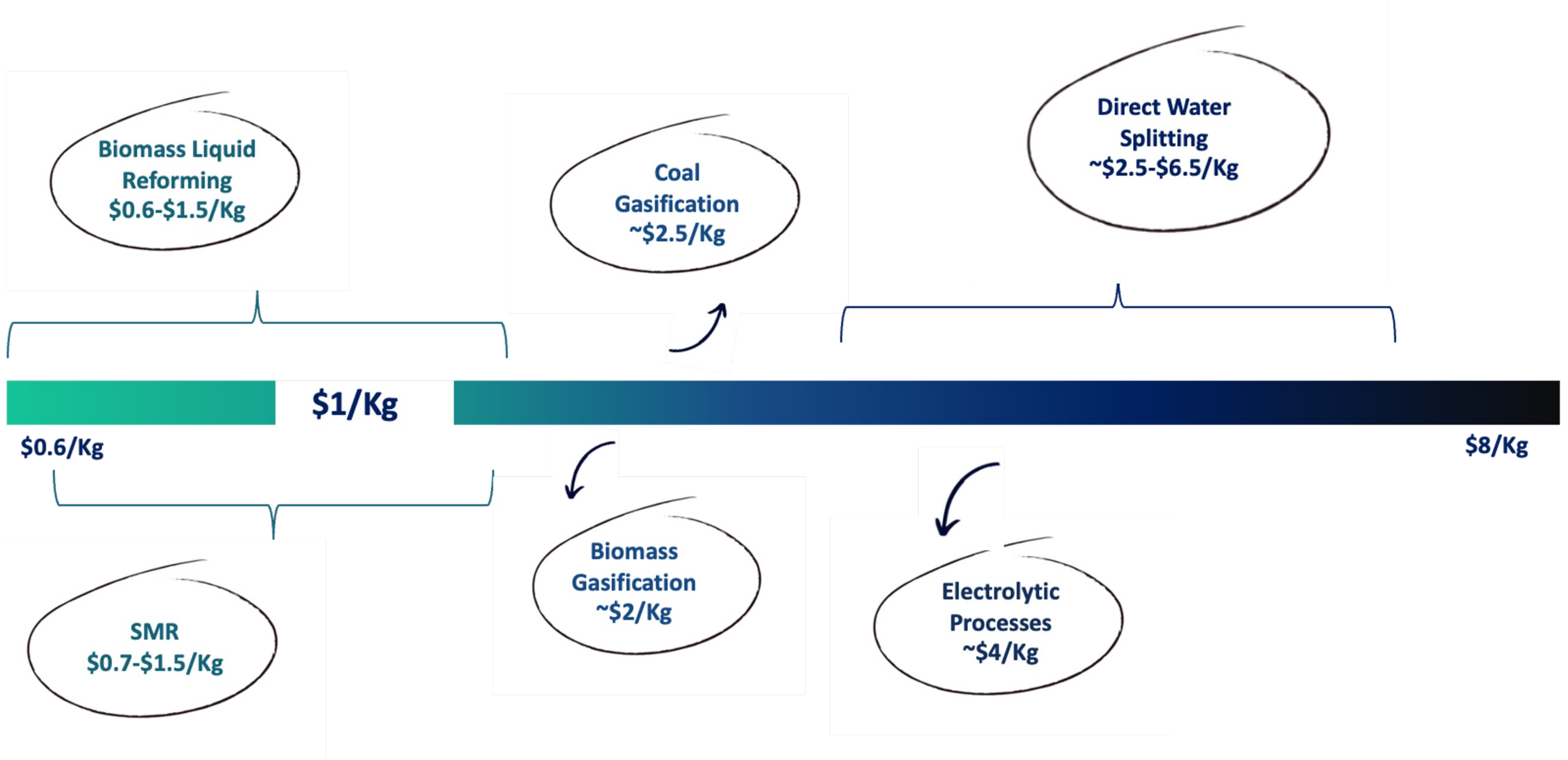


Methods of Hydrogen Production

- Thermochemical
- Electrolysis
- Direct Solar Water Splitting
- Biological

Size of the Bubble represents $/per kg cost of Hydrogen Production

Estimated Price Range of existing Production Processes



Hydrogen Storage- A bumpy road with no shortcuts

Why is Storage an Issue for Hydrogen?

- **Low Energy Density:** Hydrogen, in its gaseous form, has a lower energy density by volume compared to conventional fuels, making storage for substantial energy needs challenging.
- **High Pressurization Requirements:** To store hydrogen compactly, it often needs to be compressed to very high pressures(350-700 bar or 5,000-10,000 psi) , which can be energy-intensive and poses safety risks.
- **Cryogenic Challenges:** Liquid hydrogen storage requires cryogenic temperatures(-252 C), adding complexity and energy overhead to the storage process.
- **Material challenges:** Some materials become brittle (“hydrogen embrittlement”) after exposure to hydrogen

Impact on End Use-Cases:

- **Mobility Applications:** For hydrogen to be a viable fuel for vehicles, efficient storage solutions that don't take up excessive space or add considerable weight are essential.
- **Grid Storage & Energy Reserves:** To leverage hydrogen for grid energy storage or as backup reserves, scalable and safe storage solutions are crucial.
- **Industrial Uses:** Industries require a consistent hydrogen supply. Efficient storage can dictate the feasibility of hydrogen as a primary resource in various industrial processes.

How is the Green Hydrogen economy shaping up for India?

Forecasts

- The cumulative value of the green hydrogen market in India could be **$8 bn by 2030** and **$340 billion by 2050** ($31bn coming from just the electrolyser stack)
- Bigger conglomerates like Reliance and Adani are expected to end up owning **60-70% of the green value chain. ~$80-100bn+** investments announced in this space by veterans like **Adani, Ambani and Tata** in the upcoming decade
- **Electrolysers** seem to be the fastest-growing production tech, which also invites **huge capex commitments**. We believe much of the electrolyser stack in the country would again be owned by the veterans
  - India has **6 alkaline electrolyser** manufacturers and a few PSUs manufacturing BoP components, but domestic production of electrochemical stacks remains muted- India will need **~50 GW of electrolyser capacity** (installed) to achieve **5 mn tons** of production target for green hydrogen by 2030
- Capital allocation by the rest of the market would only happen when **cost parity** is achieved

Why is it tough for startups to win in this ecosystem

- Very **high entry barriers** - 1 mn ton of H_2 = ~20bn in capex
- Geopolitical, energy security, and macro-level issues likely to create much disturbance in the market
- Likely no opportunities for independent developers at scale

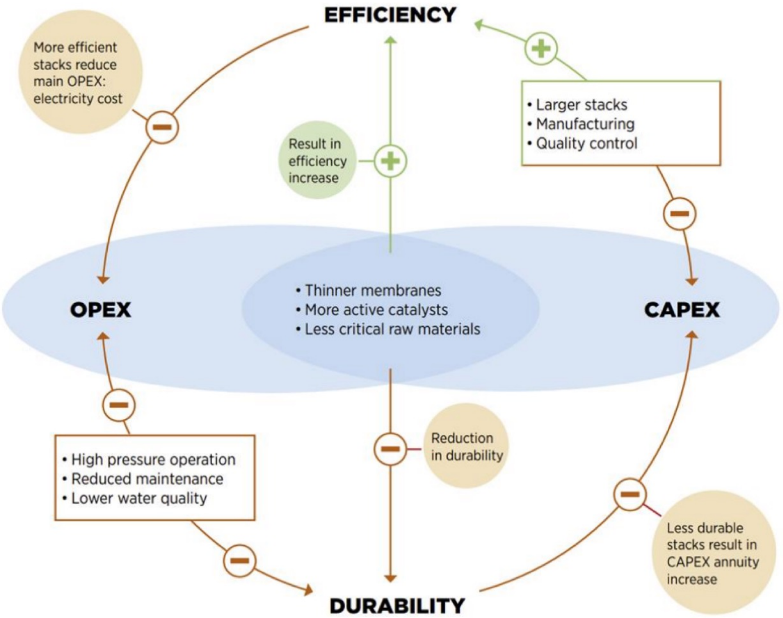
What does winning look like for the electrolyser market?

Grounds of innovation in electrolyser tech- Membrane thickness, Gas Permeation, Catalyst Layers, Critical Materials, Current Densities

Increasing manufacturing capacity and module size- benefits the stack cost and cost of BoP

Reducing (Critical) Material Use – Reducing materials use, increasing yield and recycling solve for cost, supply chains and lifetime

Optimising electrolyser design and manufacturing based on trade-offs and applications seems to be the winning strategy for now.

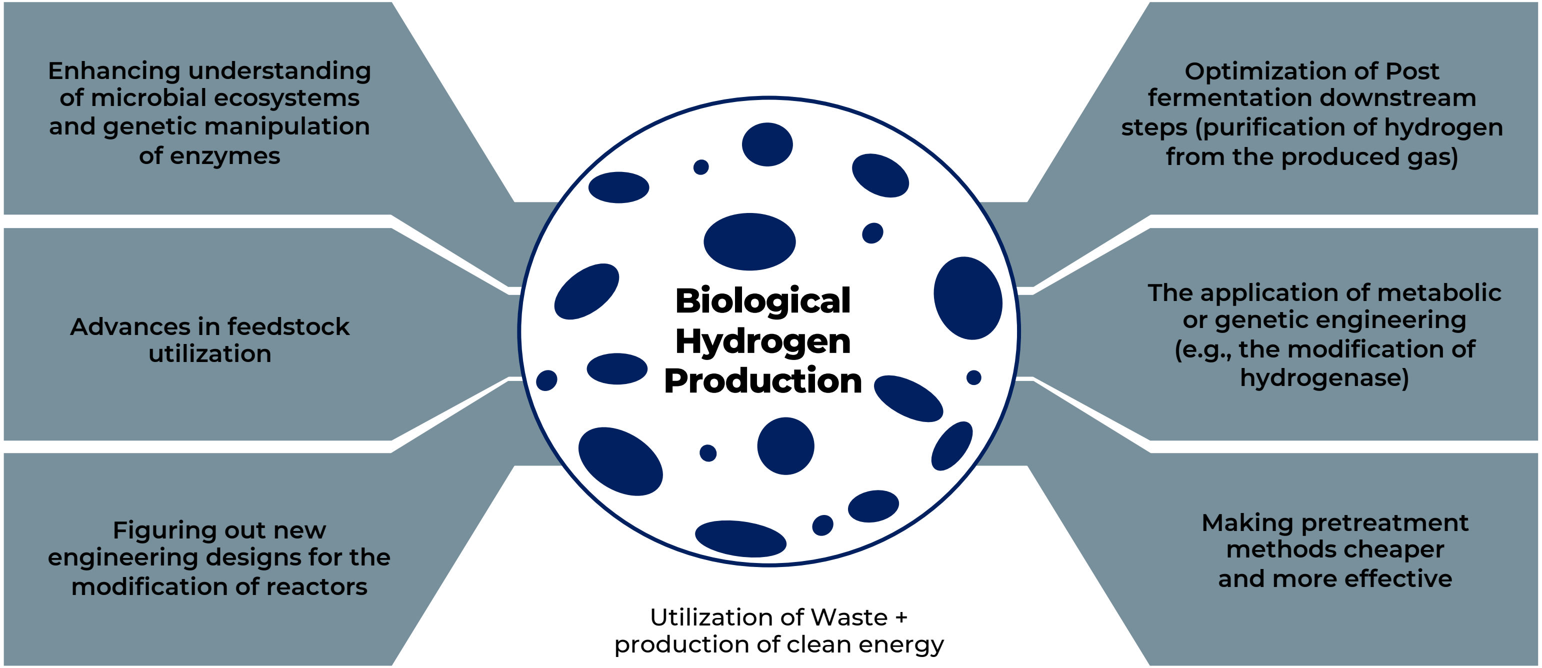


Achieving large cost reductions via innovation and scaling up manufacturing seem to be the strategy for solving for the Electrolyser whitespace*

*Source: IRENA Insights webinar series

Biohydrogen production- Biggest ground for Start-up Innovation

The possibility of using industrial wastewater as raw material coupled with low energy and infra requirements holds immense potential in India. A lot needs to be figured out in terms of effective sourcing of waste biomass, enzymes involved, pre-treatment methods, use of integrated and hybrid systems etc for Biological Hydrogen to take off in India



The Start-up Innovation Response for the glaring gaps in India's Hydrogen Fuel Cell Economy

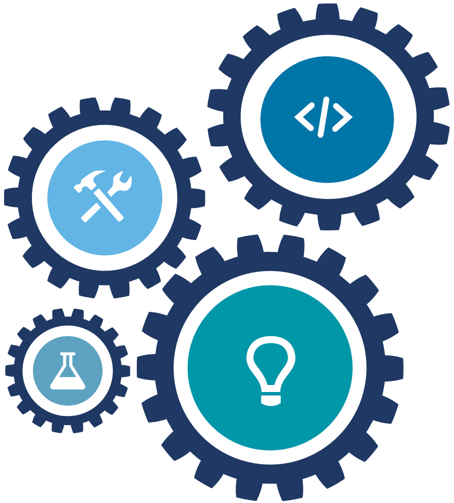
At present, lithium batteries & fuel cells are the main technical approaches to replacing fossil fuel in vehicles. Presently, lithium battery-based vehicles are cheaper than FCVs. However, where long driving range, short refuelling time and high sustained power output are required, like for many heavy-duty vehicles, HFCs, are likely to offer important advantages & development opportunities.

DEVELOPMENT

- **Manufacturing costs** dominate the total cost of PEM fuel cells, whereas the share of materials cost is much lower.
- An increased scale in production can bring the manufacturing costs down by as much as ~50%

RESEARCH

- Alternatives to imported **hydrogen cell materials**, developing high-pressure hydrogen **storage tech**, cylinder manufacturing tech and reducing **efficiency losses** due to multiple conversions seem to be the top innovation grounds
- Develop strong IP (Patents) for Fuel Cell Technology



ENGINEERING INPUT & INFRA

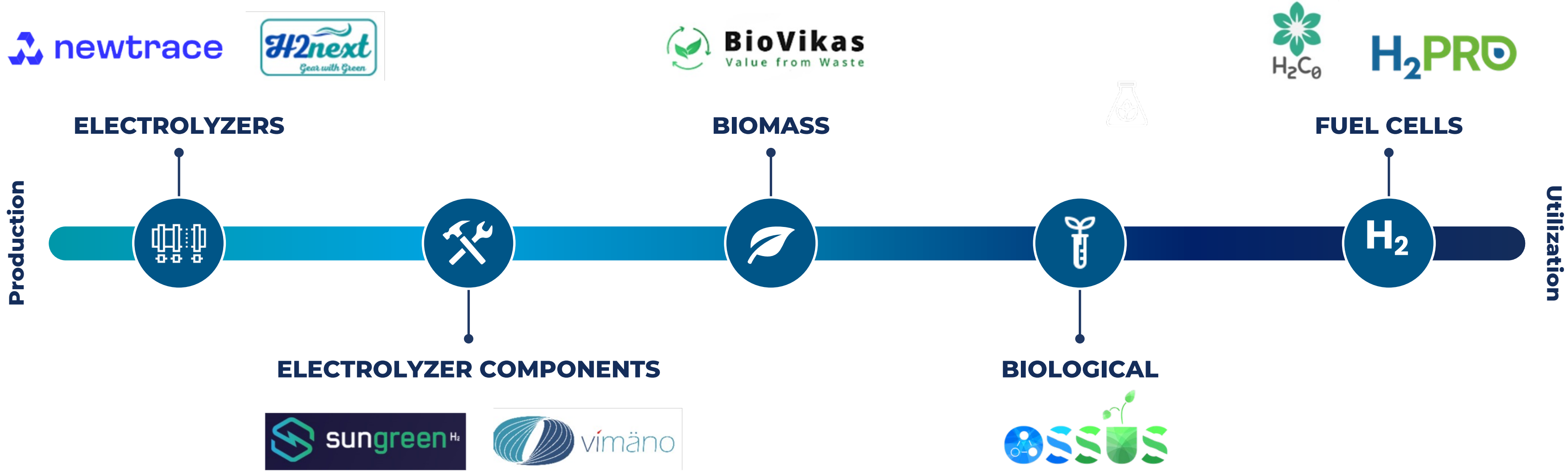
- **On site hydrogen generation units** (reformers) operating on commercial fuels such as LPG, methanol etc are not available in the country
- An infrastructure for the mass-market availability of hydrogen, or methanol fuel initially is needed

INDIA NEEDS TO FOCUS ON

- Novel materials, catalysts for durable and low-cost PEM Fuel Cells.
- Compressed Hydrogen FC integrated system suitable for even LDVs.
- Fwd and backward integration of mass produced less expensive FCs

The current landscape of the Indian startup ecosystem is confined to just two spectrums

In the context of hydrogen production technologies and fuel cells, Indian startups have carved a niche for themselves. However, the innovation playground seems vast, with limited ventures exploring the uncharted territories of distribution, storage, and technology platformization



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