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BRC BYTES

Green Hydrogen: Powering the Future

Sector Research

Summary

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Green Hydrogen

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- Climate Actions over the Years
- Net Zero Emission by 2050 - Global Goal

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- Significance of Green Hydrogen
- Hydrogen Fundamental Properties
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- Current startup and funding landscape - Indian and Global

Climate Actions over the Years

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Net Zero Coalition

2015

Paris Agreement

196 Countries agreed to reduce the global warming to below 2 °C, while pursuing efforts to limit the increase to 1.5 °C

2015 -17

Action Plans

Countries submitted action plans. However, even if fully implemented, would only be enough to slow the warming by 3°

2020 - 21

Revised Action Plans with Urgent Actions

Countries revised their action plans with urgent actions to reach net zero by 2050.

2030

Emission Reduction Required

To keep warming to 1.5°, countries should cut emission by atleast 45% compared to 2010 levels

2050

Net Zero Emission

The transition to net zero emissions should be fully complete

Source : Net Zero Coalition | United Nations

Net Zero Emission by 2050 - Global Goal

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Problems	Heatwaves Low Renewable Energy Mix Extreme Weather Events	Huge CO_2 emission from fossil fuels	1/3 rd of the CO_2 emission comes from sectors which are Hard to abate and energy uses cannot be electrified
Solutions	Energy Landscape needs a remarkable shift The Renewable Energy Mix in the Global Energy should increase from 16% in 2020 to 77% by 2050	More than 2/3rd of CO_2 Emission reduction can be achieved via Electrification	Decarbonizing Hard- to-abate sectors may require solutions beyond electrification - Green Hydrogen can bridge the gap

Renewable Energy Mix includes energy produced from sources like hydro, solar, wind, bioenergy, geothermal and ocean energy.

Electrification refers to the process of replacing traditional fossil fuel-based technologies with electric-powered alternatives. An example of electrification is the widespread adoption of EVs.

Hard-to-abate sectors like steel, cement etc employ extremely high-temperature processes that can, as of today, only be achieved in a cost-effective way by burning fossil fuels.

Source : IRENA

Growing Significance of Green Hydrogen

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Current H2 production emits around 1100-1300 Mt of **CO_2**

Decarbonization

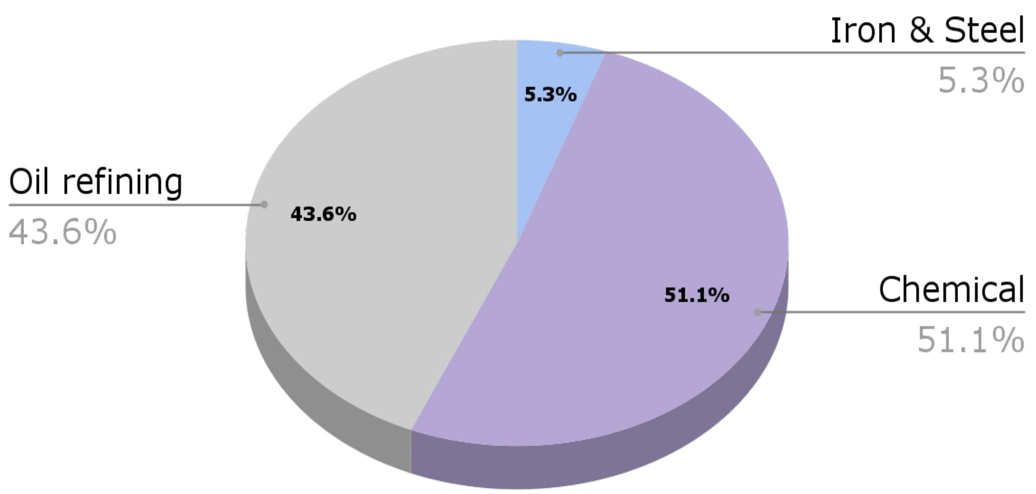
Very low CO_2 Emission

Global Current Hydrogen **Demand ~95 Mt**
(Predominantly covered by **Grey** H2 produced from fossil fuel without Carbon Capture)

5x Increase in Demand

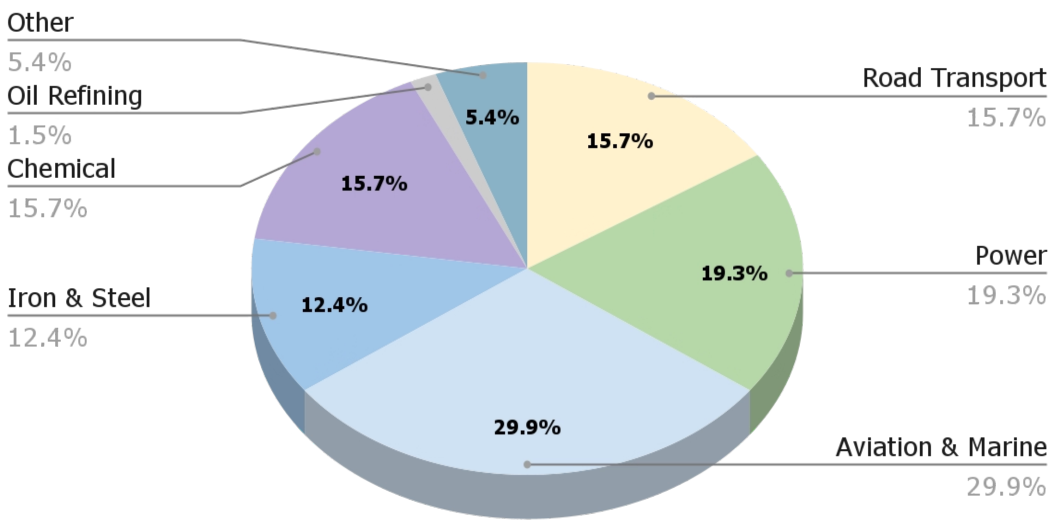
Global Projected Hydrogen **Demand ~530 Mt**
(Around 67% could comprise of **Green** H2 & remaining can be a mix of **Blue** and some residual **Grey**)

Hydrogen Demand Sectorwise



Hard to abate Sectors

Projected Hydrogen Demand Sectorwise



2022

2050

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Green Hydrogen : Basics

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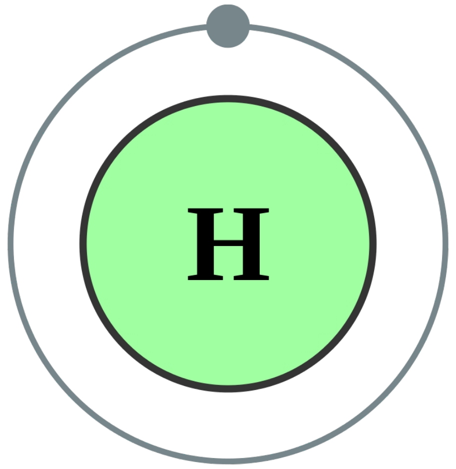
A Basic Roots Consulting Deck

Hydrogen Fundamental Properties

- Most Abundant Element
- Highly flammable and burns with an invisible flame
- Not found as Isolated element



- Lowest Atomic Mass
- Colorless, odorless & tasteless gas
- Forms compounds with a wide range of elements

Phase transition from gas to liquid at extremely low temperatures (-252.87°C or 20.28 K) and at high pressures

Exists as H2 gas at standard temperature and pressure (STP)

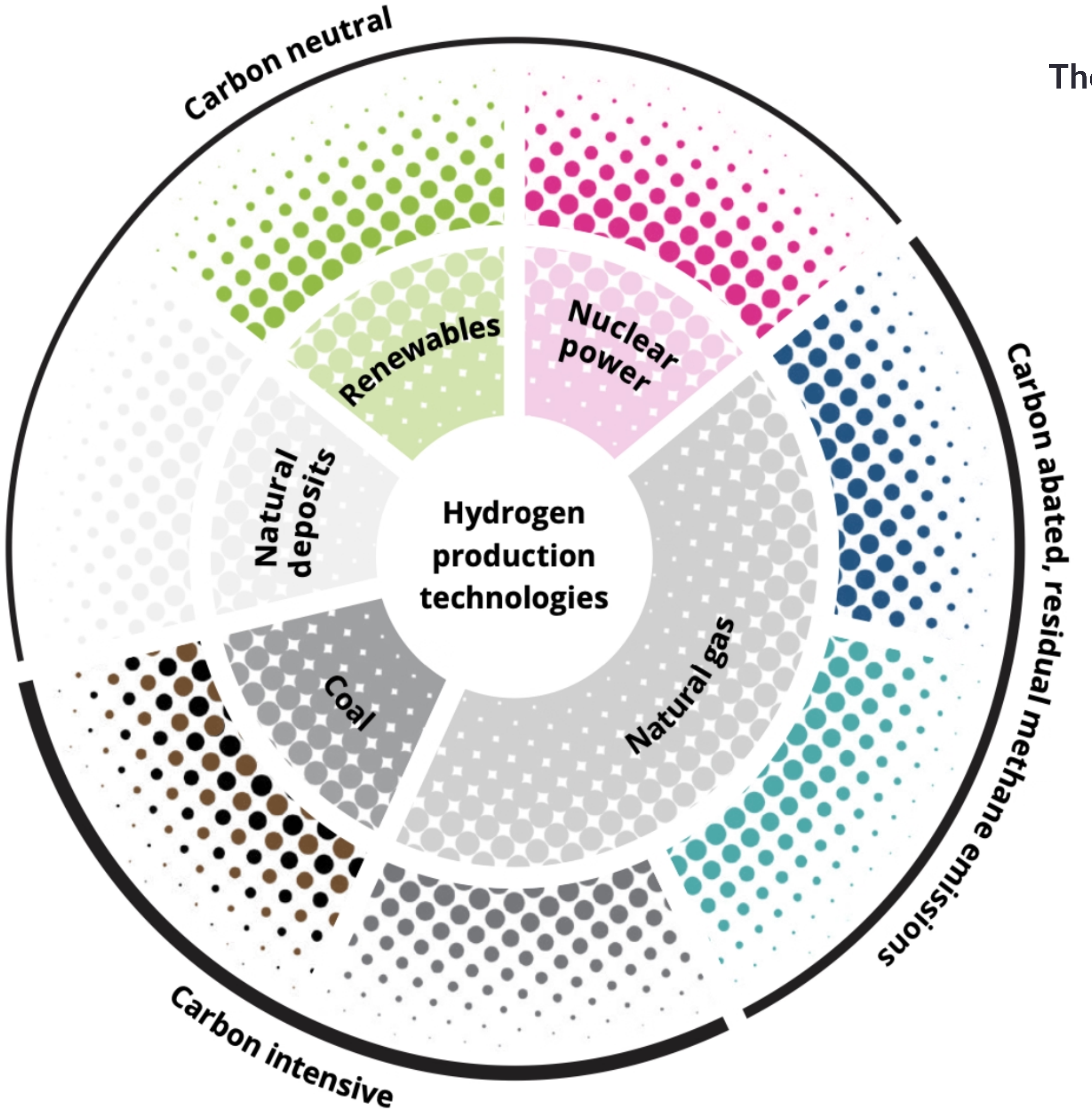
Why it is an important source of energy

- Energy carrier - that can store & transport energy
- Diversifies Energy sources and reduces dependence on Fossil fuels
- Various applications - transportation, heating, electricity generation
- Excess renewable energy can be used for producing H2

But what are the challenges

- High productions Costs
- Significant Infrastructure investment needed
- Difficult to transport
- Scaling up is a challenge

Types of Hydrogen - Hydrogen Rainbow with Carbon Footprint



The Key to Sustainable Future

Type	Process	Carbon footprint
Green Hydrogen	Electrolysis	Carbon Neutral
Pink Hydrogen	Electrolysis	Carbon Neutral
White Hydrogen	Natural Deposits	Carbon Neutral
Blue Hydrogen	SMR*	Carbon Captured
Turquoise Hydrogen	Pyrolysis	Solid Carbon Released
Grey Hydrogen	SMR*	~9Kg CO_2e/KgH_2
Black or Brown	Gasification	~20Kg CO_2e/KgH_2

*** SMR - Steam Methane Reforming**

Source : Deloitte

Hydrogen Supply Chain and Ecosystem

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Generation

1. Steam Methane Reforming (SMR)
2. SMR combined with Carbon Capture
3. Electrolysis with Renewable Electricity
4. Biomass Gasification and Reforming
5. Biogenic/ Waste Treatment

Storage

1. Liquefaction
2. Compression
3. Methanation
4. Ammonia

Transportation, Distribution and Retail

Transportation and distribution

1. Membrane Transportation
2. Pipeline Distribution
3. Road and Rail Transportation

Retail

1. Distribution Logistic and Private Storage
2. Hydrogen filling stations

End Use

1. Industrial Feedstock (ammonia, methanol)
2. Industrial Energy Supply (heat generation)
3. Transportation (Private and Public)
4. Power Generation and Storage (fuel cells)

Source : EY

Green Hydrogen Generation Methods

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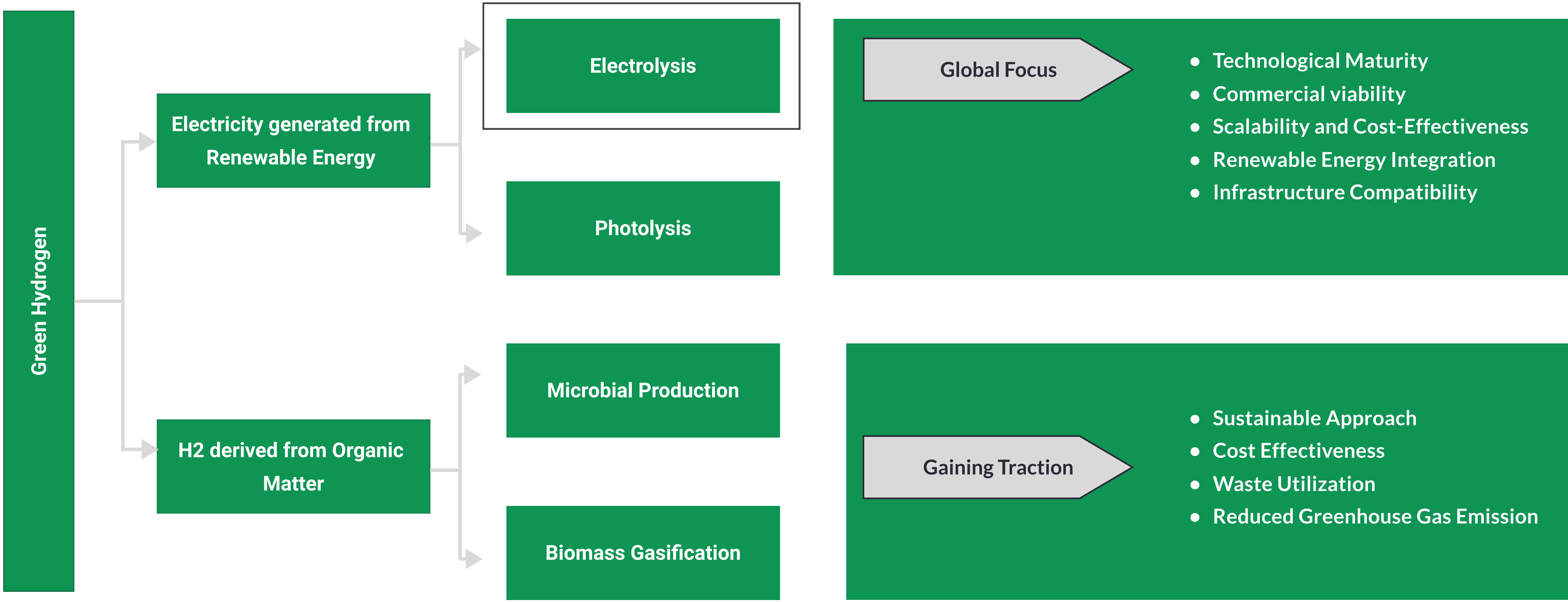

Electrolysis - Hydrogen Generation Method

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Electrolysis is a process happens through Electrolyzers which splits water into hydrogen and oxygen by passing electric current. It is a key step in production of green hydrogen and is both carbon neutral and energy efficient.

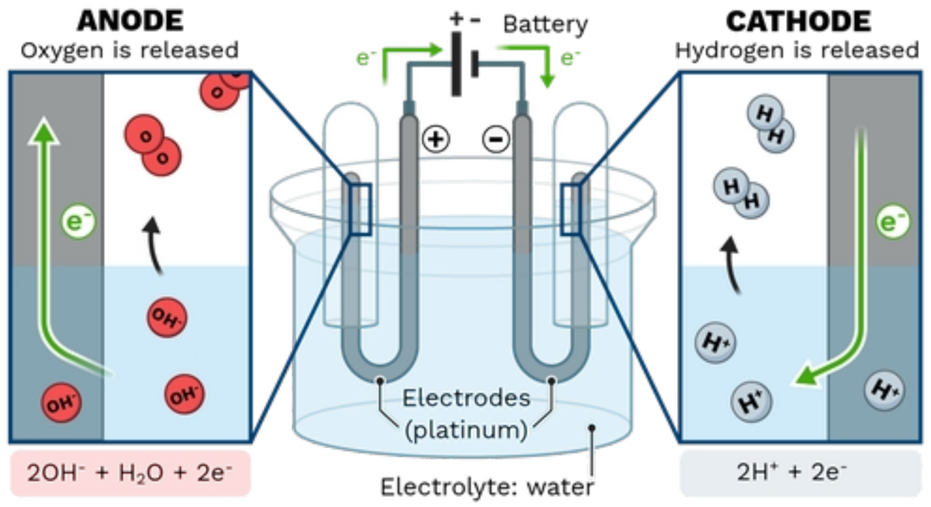
How does this works?

Water (H2O)

Water Molecules (H2O) are placed between two electrodes (cathode and anode) in an electrolytic cell

Hydrogen

Hydrogen ions move to the cathode and combine with electrons to form Hydrogen Gas



Electricity is applied

Water Molecules (H2O) break down into hydrogen ions (H+) and hydroxide ions (OH-)

Oxygen

Hydroxide ions move to the anode and combine with electrons to form oxygen gas

Electrolysis offers a sustainable and flexible method for producing green hydrogen, crucial for the transition to a clean energy future.

Source : Labster Theory

Electrolyzer - Capacity & Demand

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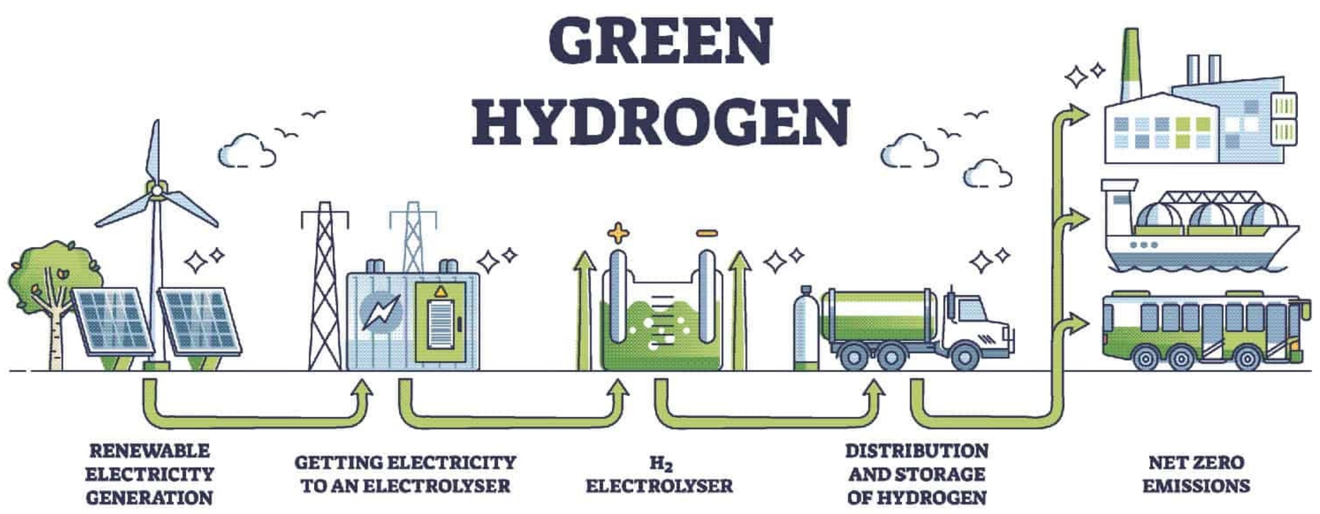
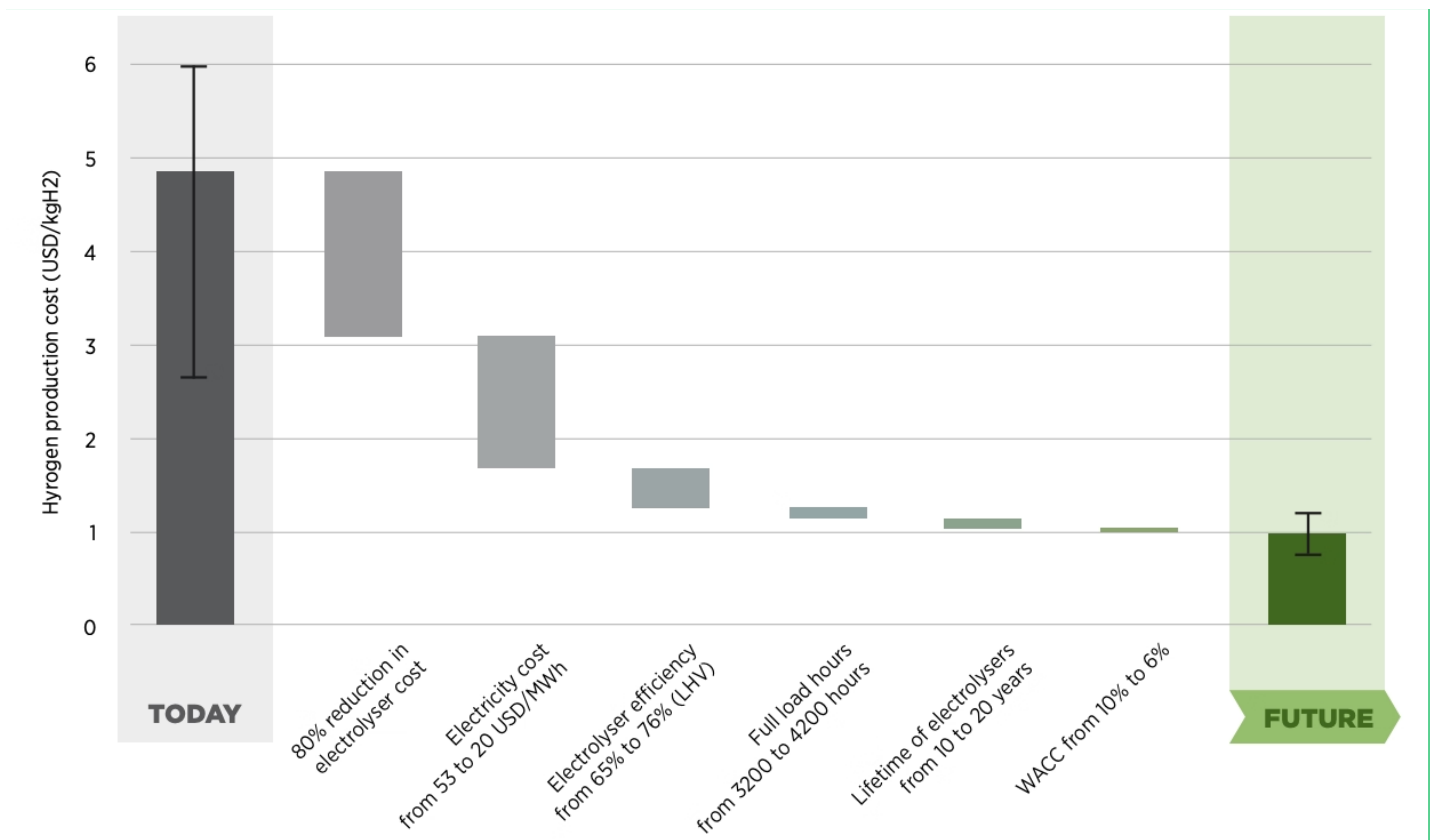


Year	H2 Demand (Mt/yr)	Electrolyzer capacity required (in GW)
2020	95	617
2030	217	1340
2050	530	3272

Electrolyzer capacity required based on Green Hydrogen demand



A combination of factors can result in 80% reduction in Hydrogen costs and drive the demand for Hydrogen

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Source : Blume, IRENA, BMarko

Types of Electrolyzers : Refer to Appendix

Hydrogen - Storage

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Compressed Gas

High Pressure
- Hydrogen is stored under high pressure (20-50 MPa)

Mature Technology
- Generally used for small-scale applications

Limitation
- Lower Energy Density
- Higher Storage Cost
- High flammability and wide flammability range

Storage
- Salt Caverns

Liquid Form

Cryogenic Temperatures
- Hydrogen is stored at cryogenic temperatures (-253°C)

High Energy Density
- As compared to compressed gas, liquid form has higher energy density

Limitation
- Energy intensive liquefication process
- Complex storage & handling
- Extremely low boiling point of -253°C

Storage
- Cryogenic Tanks
- LOHC Tanks

Solid-Stage Storage

Hydrides and Absorbents
- Metal hydrides, Chemical hydrides, and absorbents

Higher Volumetric
- Potential for higher volumetric and gravimetric energy densiity

Limitation
- Cost
- Kinetics and scalability of the technologies

Storage
- Metal Hydrides
- Chemical Storage Tanks

Solving for Storage can help in quick transition to Green Hydrogen. There's a huge scope for R&D in hydrogen storage with innovative methods like storing hydrogen as a **powder** or in the form of **ammonia**, which can store 50% more hydrogen by volume than liquid or gaseous hydrogen.

Hydrogen - Transportation, Distribution & Retail

Modes of Transportation & Distribution

Trucks, Trailers & Tankers	Pipelines	Shipping
Small volumes, Short distances	Large volumes, Long distances	Large volumes, Long distances
Compressed Gas Liquid (Cryogenic) Chemical Forms	Compressed Gas	Liquid (Cryogenic) Ammonia
$0.5/kg for 50 km	$0.3-1/kg for 500 km	>$2/kg for 3000 km

Due to a limited pipeline network, shipping hydrogen as ammonia is the most efficient method for long-distance transport, though

Transportation Cost > 3x Cost of Producing Hydrogen

Hydrogen Filling Stations

Year	No. of Hydrogen Filling Stations
2023	550
2025	2800
2030	15000

No. of Hydrogen Filling Stations

~$20 Billion of investments are required by 2030 to build the global hydrogen refueling infrastructure of 15,000 stations

Source : Blume, McKinsey

Hydrogen - End Use

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Green Hydrogen as 'Feedstock'

Crude Oil Refining	Fertilizers	Metals	Bulk Chemicals

Green Hydrogen as 'Energy Carrier'

Industrial Process Heat	Blending with Piped Natural Gas	Transportation	Power Generation & Storage

As Energy Carrier / Vector, hydrogen can be used in hard-to abate sectors like industrial applications, transportation through H2 fuel cells, energy storage etc.

Energy carrier or vector is a substance or system that can store and transport energy rather than being a primary source of energy itself

Source : EY

Green Hydrogen - Challenges

High Cost of Green Hydrogen

The production is currently expensive compared to conventional fuels, posing a significant barrier to widespread adoption.

Cost of Electrolysers

Electrolysers have high capital costs. Reducing these costs is crucial for making green hydrogen economically viable.

Dependency on Renewable Energy

The production requires substantial renewable energy, which can be inefficient and challenging to scale up to meet global demand.

Water Resource Constraints

The production requires significant amounts of water, potentially straining local water resources and impacting regions with limited water availability.

Green Hydrogen - An Opportunity for India

Hydrogen is expected to be **10-20% of the world's energy mix by 2050** and could create an economic opportunity of nearly **USD 0.5 trillion.**

Global Trade Opportunity - The EU, Japan, and South Korea lead in green hydrogen imports, driven by ambitious consumption targets and limited domestic production.

For instance, the EU's REPowerEU plan targets 20 Mt of green hydrogen consumption by 2030, with half to be imported.

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Factors that determine Nation's competitiveness for Green H2:

- Renewable Energy Resources
- Manufacturing, Engineering, & Construction Competitiveness
- The Electricity Ecosystem
- Cost of Capital

Countries (**India**, Egypt, Saudi Arabia, UAE, China, US, Australia among few others) rich in renewable energy resources like solar and wind are well-placed to take advantage of this opportunity

Actions in India

National Green Hydrogen Mission with Funding Allocation of **Rs.19,744 Crs**

By 2030:

- Green H2 Production Capacity - **5 Mt/Yr**
- Add Renewable Energy capacity by **125 GW**

- Investments Over **INR 8 Trillion.**
- Create **600,000+ Jobs**
- Cut **50 Mt GHG** annually

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Source : Alvarez & Marsal

Investments & Targets of Big Indian Conglomerates

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$10 Bn	1 Mn Tonnes of Green Hydrogen annually by 2030	Reliance Industries
$1 Bn	0.5 Mn Tonnes of Green Hydrogen annually by 2025	Adani Group
$500 Mn	0.2 Mn Tonnes of Green Hydrogen annually by 2025	Larsen & Toubro
$200 Mn	0.1 Mn Tonnes of Green Hydrogen annually by 2025	IOCL
$100 Mn	0.05 Mn Tonnes of Green Hydrogen annually by 2025	ONGC

With significant investments and initiatives from both the government and private companies. The sector has the potential to play a crucial role in India's transition to a low-carbon economy and achieve energy independence by 2047.

The current landscape of the Indian startup ecosystem

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Electrolyzers

Startup	Raised, Round & Top Investor
newtrace	$6.7 Million, Seed, Peak XV, Aavishkaar Capital
H2next	Unfunded

Biomass

Startup	Raised, Round & Top Investor
BioVikas (Value from Waste)	Unfunded

Fuel Cells

Startup	Raised, Round & Top Investor
HYDROVERT	Unfunded

Electrolyzers Components

Startup	Raised, Round & Top Investor
vimäno	Unfunded
sungreen	$3.5 Million, Seed, Sabanci Ventures, SG Innovate

Biological

Startup	Raised, Round & Top Investor
ossus	$2.4 Million, Seed, Shell E4, Rainmatter, Gruhas

Production ⟷ Utilization

Vast opportunity of innovation exists in distribution, storage and technology platformization

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Source : Blume, Tracxn

Global startups and funding

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ohmium
PEM Battery Solutions | $250 Mn | The Rise Fund, Energy Transition Ventures, Fenice Investment Group

stargate hydrogen
Electrolysers | $44.8 Mn | UGI

Heliogen
Solar Thermal Technology | $111 Mn | ArcelorMittal, Prime Movers Lab

Electric Hydrogen
Electrolysers | $603 Mn | Breakthrough Energy, Temasek

H2 MOBILITY
H2 Filling Stations | $130 Mn | Vinci, Hy24, Shell, TotalEnergies

KOLOMA
Geologic H2 | $403 Mn | Khosla Ventures, Breakthrough Energy, Energy Impact Partners

C-ZERO
Decarbonizing Natural Gas | $45.5 Mn | Engie New Ventures, AP Ventures

AVINA Clean Hydrogen Inc.
H2 adoption in Hard-to-abate Sectors | $10 Mn

H2GO Power
H2 Storage Technology | $8.64Mn | Gov.uk, EIC Fund

First Element Fuel
Fueling Stations | $177 Mn | California Energy Commission, Air Water, MUFG

Hydrogenious LOHC
Storage & Distribution | $84.3 Mn | Temasek, Pavilion Capital, Vopak, AP Ventures, EIC Fund

hypoint
H2 Fuel Cell System | Acquired | ZeroAvia

Few more public companies

Hydrogenics
Fuel Cells & H2 Storage | Public

Plug Power
H2 based Fuel Cells | Public

Ballard
H2 Fuel Cells | Public

Enapter
H2 Production | Public

Nel Hydrogen
H2 Production and Storage | Public

Greenko Group
Decarbonization solutions | Public

Can be a tough journey for startups to win in this ecosystem

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Hydrogen Market Size in India → 2030 - USD 8 Billion → 2050 - USD 340 Billion

Challenges for Startups	=	Opportunity for Bigger Conglomerates
Electrolyzers production tech requires huge capex commitments		Greater access to capital and can leverage economies of scale to reduce costs.
1 Mn ton of H_2 =INR~20 bn in Capex		Expected to end up owning 60-70% of the green value chain.
Regulatory & Safety Issues		INR 80-100 billion in investments announced by industry giants like Adani, Ambani, and BPCL for the next decade.

Key Funds & Corporates investing in this space

Investors

Global

AP Ventures	Hydrogenious LOHC, Hystar
Breakthrough Energy	Electric Hydrogen, H2PRO
EIC Fund	H2Go Power, Hydrogenious LOHC
Mitsubishi Industries	Cemvita, Electric Hydrogen
Prelude Ventures	Electric Hydrogen, Koloma
Temasek	Electric Hydrogen, H2Pro, Verdagy
Energy Impact Partners	Electric Hydrogen, Koloma
Climate Capital	Cemvita, HGen

Indian

- Speciale Invest
- Micelio
- PeakXV Partners
- Aavishkaar Capital
- Axilor Ventures

newtrace

- Shell E4
- Rainmatter
- Gruhas
- Zerodha

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Thank you!

Appendix - Types of Electrolyzers

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Proton Exchange Membrane (PEM)

1

- Proton selective membrane
- Efficient, high-purity hydrogen
- Higher cost

Alkaline

2

- Uses a basic solution (alkaline) as the electrolyte
- Produces lower-quality hydrogen gas
- Less expensive

Alkaline Exchange Membrane

3

- Uses a membrane that allows protons to pass through but also uses alkaline solution as electrolyte
- Combines the benefits of alkaline and PEM electrolyzers
- More expensive than alkaline

Solid Oxide

4

- Uses a solid oxide material as the electrolyte
- Most efficient and produces highest-quality hydrogen gas
- Most expensive