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Primer on Hydrogen fuel cells

A light weight taking on the heavy weights

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Executive summary

- Hydrogen (H_2) is a credible alternative to battery technology in multiple applications that are looking at decarbonizing away from internal combustion technologies.
- Increasingly focus will be on Green H_2 while dependence on Blue and Grey H_2 will be transitionary.
- Globally, there is a policy push and federal and state incentives driving investments in H_2. India also has a National Hydrogen Mission, fiscal incentives are still under works.
- Like all evolving technologies, costs curves for H_2, particularly Green H_2, are expected to sharply decline from US$ 6-10/kg currently to US$ 3-5/kg by 2030. Increasing adoption should bring down costs for electrolysis, membrane electrode assembly (MEA) and distribution.
- Proton Exchange Membrane (PEM) and Solid Oxide Fuel Cell (SOFC) will be the dominant technologies in fuel cells in the medium term. PEM has wider applications due to its low ramp up/down time and operating temperatures.
- Globally, the H_2 ecosystem is still in the build out stage with large companies consolidating technologies across production, conversion and distribution.
- In India the supply chain is still in the process of development. Recent announcement by Reliance Industries (RIL) will fast track this process. We expect the ecosystem in India to grow going forward.
- Key players in India that would participate in the H_2 economy in our view are: Reliance Industries (NR), NTPC (NR), Tata Power (NR), Cummins (NEU), Siemens (NEU), Thermax (SELL), MTAR (NR), Carborundum Universal (NR), Elgi Equipments (NR), Linde (NR), and Tata Motors (BUY)…
- **Conclusion:** With growing focus on decarbonization adoption of Hydrogen technologies particularly in transport, stand-by operations such as data centres and government subsidies should lead to decline in costs. Companies in India will most likely be part of the supply chain given long gestation and front loaded R&D (top four pure play global companies have cumulatively invested >$700mn in R&D in past five years) for developing customized fuel cells. Domestic companies will increasingly develop products for the H_2 ecosystem. However, sizeable, commercial and tangible opportunities will take > 2-3 years to play out, in our view.

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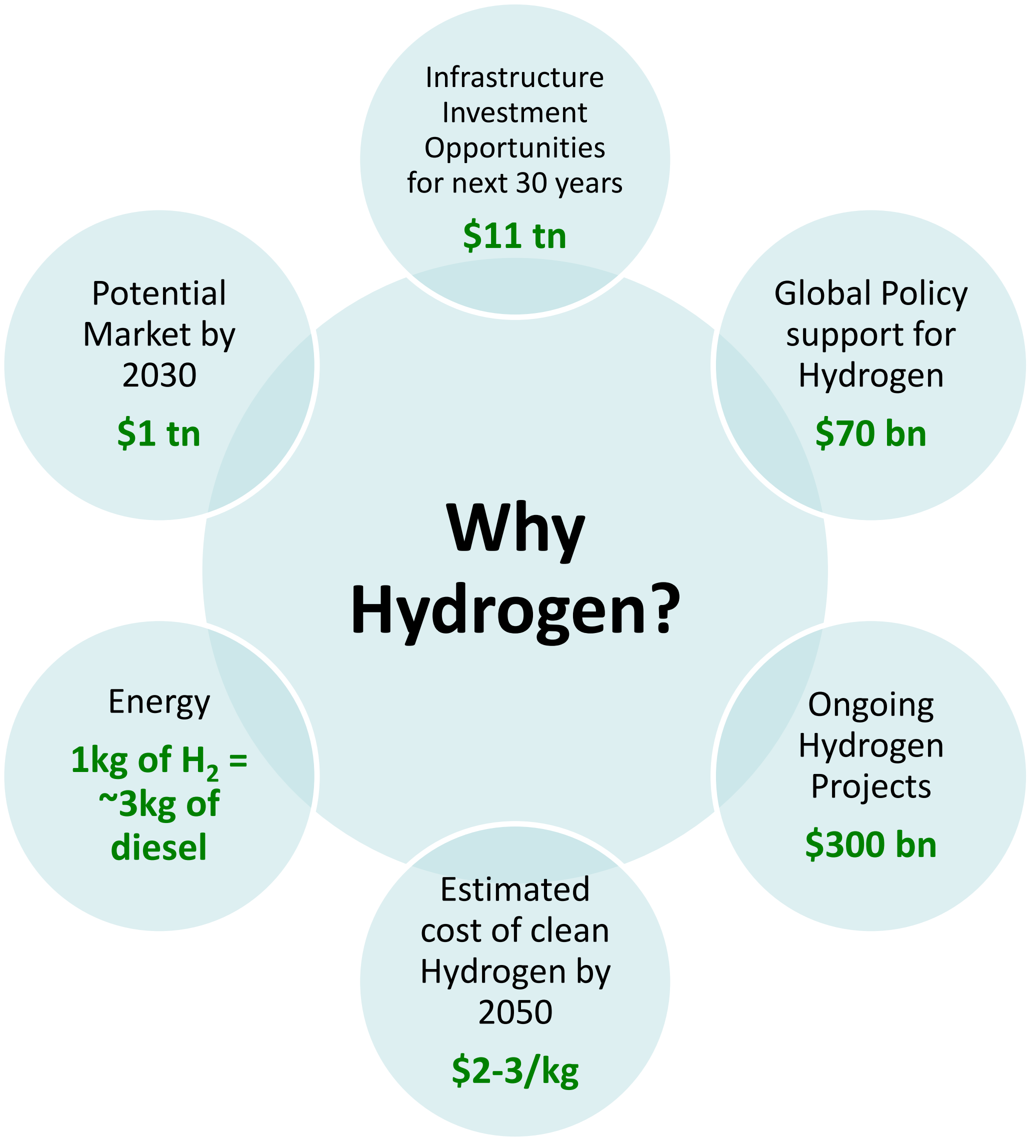
Why Hydrogen?



Source - HydrogenOne Capital, PhillipCapital India Research

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Global policy support for Hydrogen

Global policies to encourage Hydrogen economy

European Union	• Twenty-eight European countries signed the Linz Declaration "Hydrogen Initiative" • The EU targets 6 GW by 2024 and 40 GW by 2030, with a working assumption of 500 GW by 2050
China	• Subsidies for each module in the hydrogen supply chain. • The goal of the subsidies on hydrogen refuelling cost is to reduce hydrogen cost per 100km to be less than or on par with that of ICE vehicles.
Japan	• Updated its Strategic Roadmap to implement the Basic Hydrogen Strategy • The Development Bank of Japan joined a consortium of companies to launch Japan H_2 Mobility with a target to build 80 hydrogen refueling stations by 2021
Korea	• Published a hydrogen economy roadmap with 2022 and 2040 targets for buses, FCEVs and refueling stations • Vision to shift all commercial vehicles to hydrogen by 2025. • Provided financial support for refueling stations and eased permitting • Announced a technological roadmap for the hydrogen economy
US	• Extended and enhanced the 45Q tax credit that rewards the storage of CO2 in geological storage sites • Added provisions to reward the conversion of CO2 to other products, including through combination with hydrogen.
Australia	• Announced more than AUD 100 million to support hydrogen research and pilot projects. • Commonwealth Scientific and Industrial Research Organisation (CSIRO) published a technical roadmap for hydrogen in Australia.
India	• Draft National Hydrogen Energy Mission 2021 • NTPC Vidyut Vvyapar Nigam to provide ten hydrogen fuel cell based buses and cars in Leh and Delhi along with storage and dispensation facilities as a part of its pilot • Indian Oil has floated a tender to purchase fifteen hydrogen fuel cell fitted buses that produce their own electricity

FOCUS

Increasing electrolyzer capacity
Production of lower-cost green hydrogen
A larger and better utilized distribution system
Bigger and better utilized hydrogen refueling stations
Zero carbon emissions by 2050

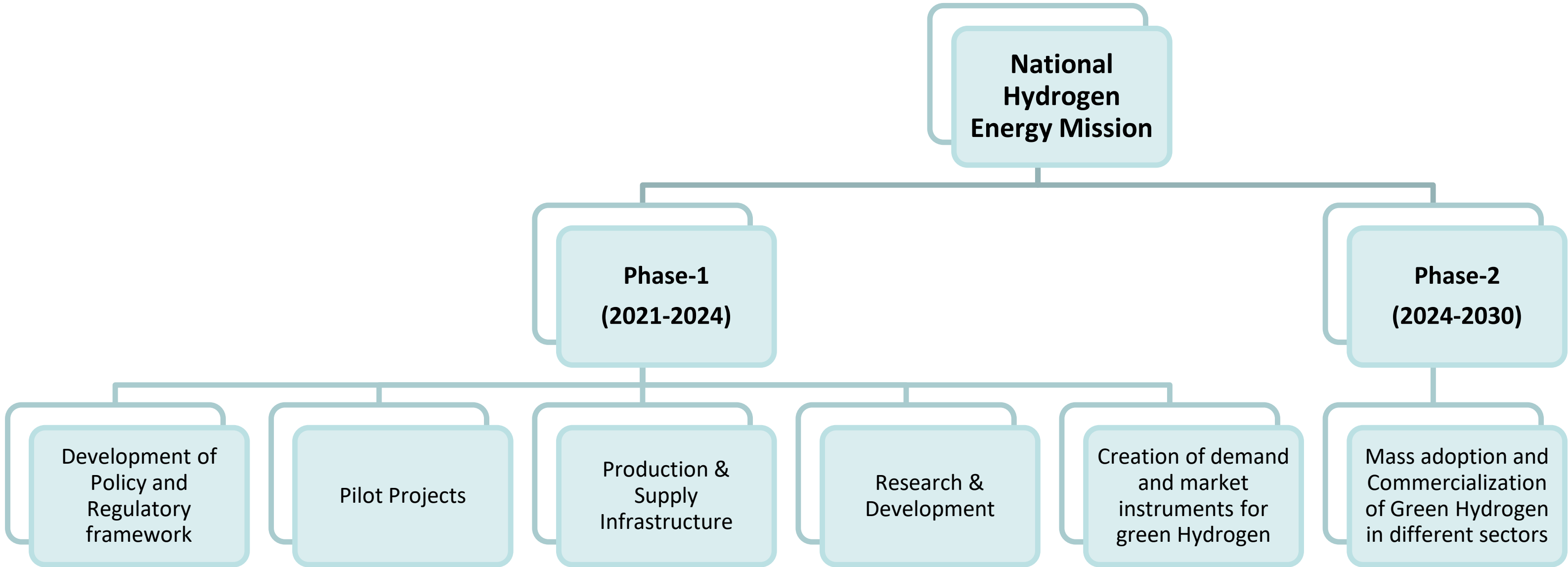
India towards Hydrogen economy

Draft National Hydrogen Energy Mission 2021

- Roadmap for using H_2 as an energy resource

- 2021-22 budget allocated **Rs 15bn** for renewable energy development and National Hydrogen Mission
- Contribute towards reducing our dependency on import of fossil fuels
- Focus on R&D and demand creation
- Hydrogen as a replacement for coke in the steel industry
- Hydrogen as a fuel in the fertilizer sector.

- Delhi became the first city in India to operate buses with hydrogen-enriched CNG
- NTPC is working on a pilot project to run 10 Hydrogen Fuel Cell (FC) based electric buses Hydrogen Fuel Cell-based electric cars in Leh and Delhi.



Source – MNRE, Draft National Hydrogen Energy Mission Document, PhillipCapital India Research

Roadmap for National Hydrogen Energy Mission Phase – 1 (2021-2024)

Market Development
- Green Hydrogen Consumption
- Competitive Bidding for Green Hydrogen
- Introduction of Green Hydrogen in new sectors

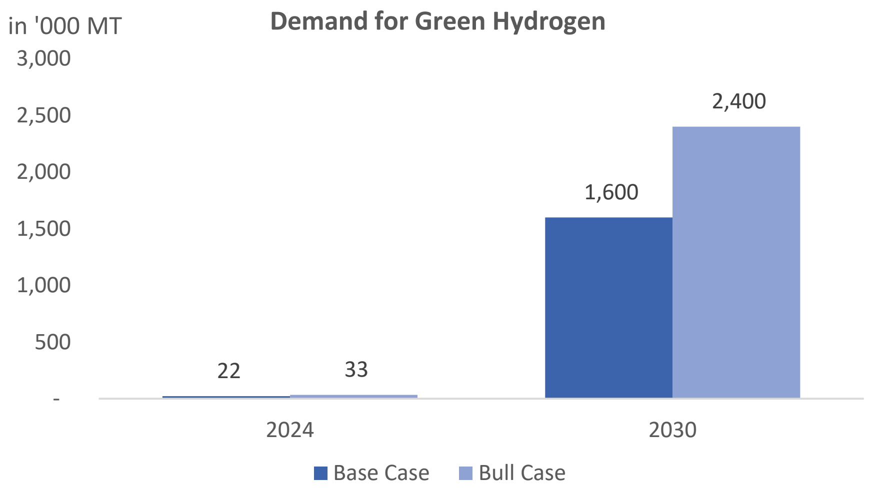
Pilot Projects
- Buses, CVs, Railways
- Green Steel, DG Replacement and CHP
- Hydrogen from Biomass, Methane pyrolysis

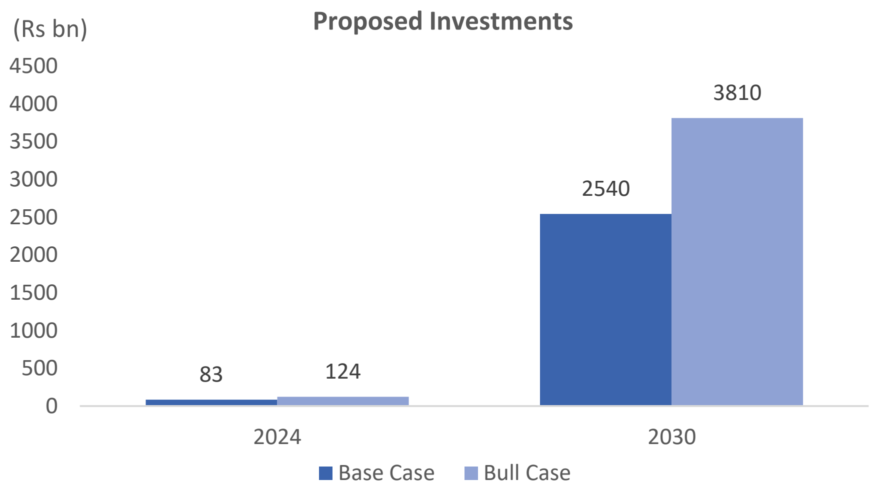
Infrastructure & Supply Chain
- Refuelling Stations
- Hydrogen Hubs
- Introduction in gas supply networks

Research & Development
- Applied Research (0-4 years)
- Long shot Research (upto 10 years)
- Analytical Studies

Regulations & Standards
- Testing Facilities
- Standards for performance, Safety regulations
- Strengthening Institutional Mechanism

Mission Implementation
- Standing Committee
- Expert Group
- Secretariat





Source - Draft National Hydrogen Energy Mission Document, IEA, PhillipCapital India Research

Hydrogen - 101

Evolution of Hydrogen

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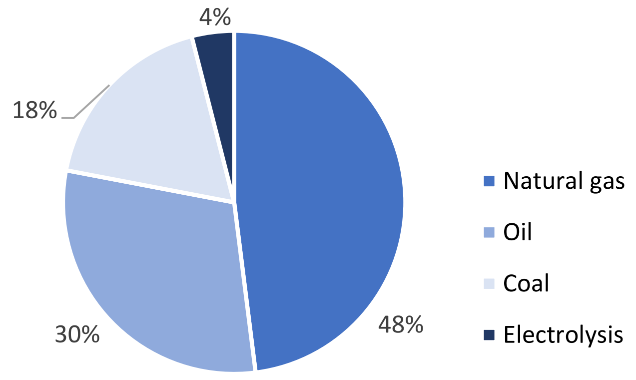
- **1766**: Hydrogen's ability to combine with oxygen- first noted by Henry Cavendish
- **1800**: Nicholson and Carlisle created the first electrolyzer
- **1839**: A Welsh scientist, William Grove invented the first simple hydrogen fuel cell
- **1885**: Daimler and Benz came together to work on electric cars
- **1950**: Francis Bacon made advancements in the Grove's technology
- **1960**: Pratt and Whitney licensed Bacon's fuel cell patents in the 1960s and developed the technology for use by NASA
- **1970**: Companies after the oil crisis based their business models on hydrogen fuel using Grove's Paper and Bacon's patent information for conducting research
- **1990**: A research team at Ballard Power Systems discovered a way to increase the power density of hydrogen, from 200 to 1,500 watts/litre
- **1999**: Reduction of poisoning effect of carbon monoxide in electrolysis
- **2003**: President Bush introduced the Hydrogen Fuel Initiative to boost the development of hydrogen fuel cell, delivery and storage technologies
- **2013**: The first commercial 2 MW power to gas (P2G) installation in Falkenhagen, Germany became active
- **2016**: H21- A collaborative gas industry programme focused on demonstrating UK gas network to carry 100% hydrogen
- **2018**: HES Energy Systems initiated its plans for Element One, a hydrogen-electric passenger aircraft
- **2020**: Fukushima Hydrogen Energy Research Field demonstration project -20 MW of solar power generation facilities on a 180,000m^2 site

Sources of Hydrogen; Potential uses of Hydrogen will increase in the future

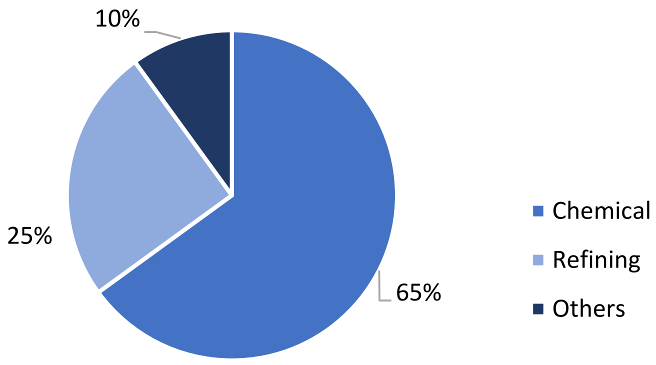
H_2 production in 2020
73.3 Mn tn

Expected Total Addressable market by 2030
$ 300bn

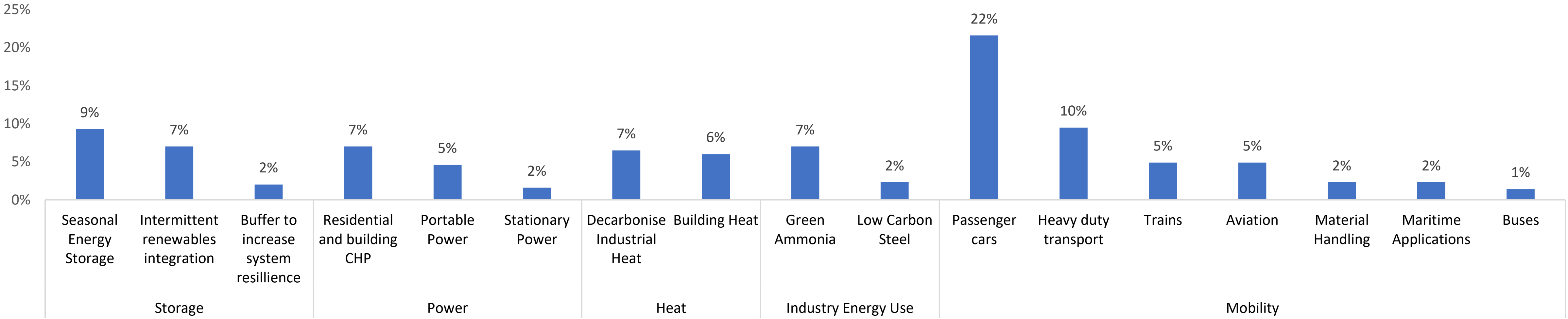
Global Hydrogen Demand 2020



Global Hydrogen Sources 2020

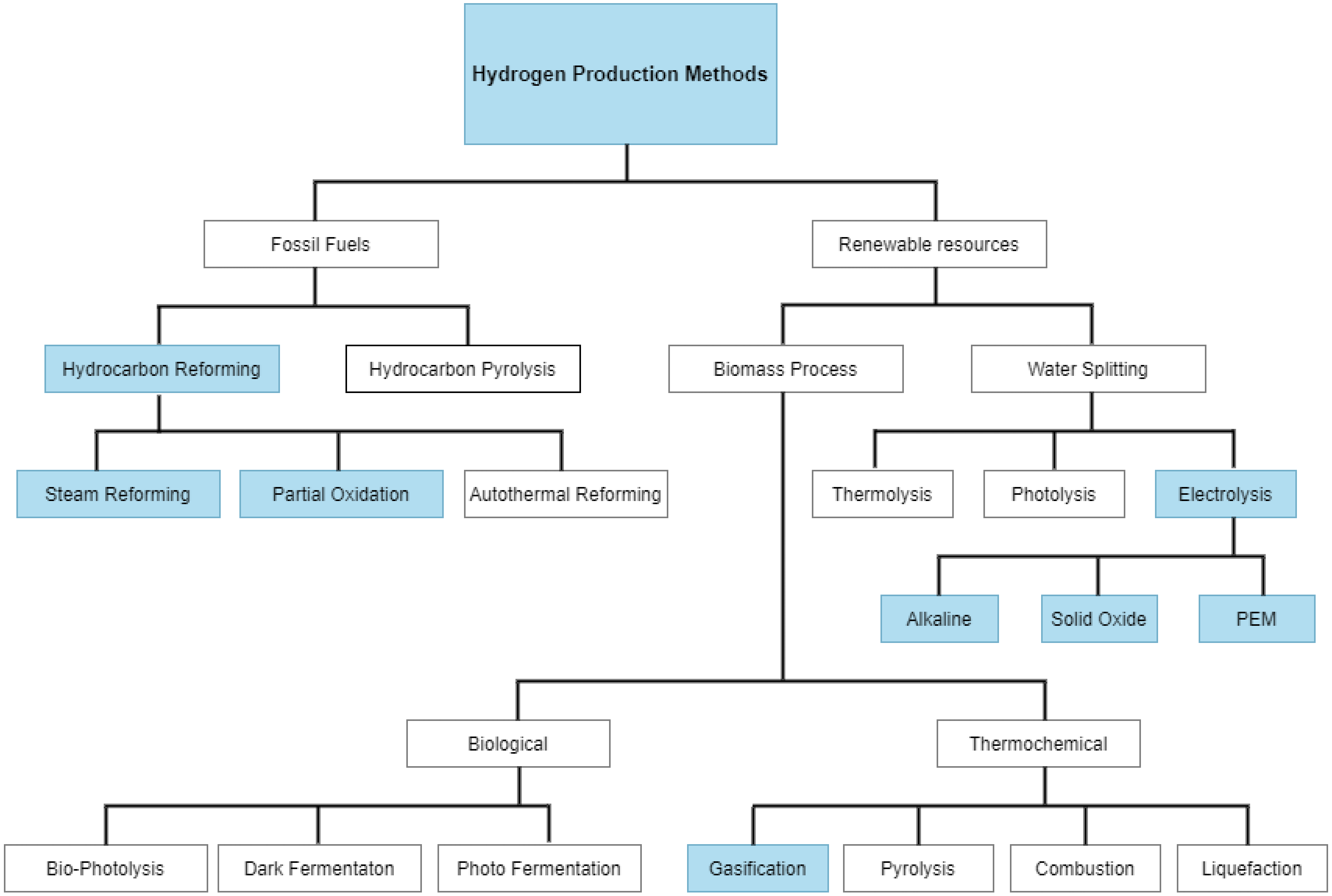


Future potential uses of Hydrogen by 2040

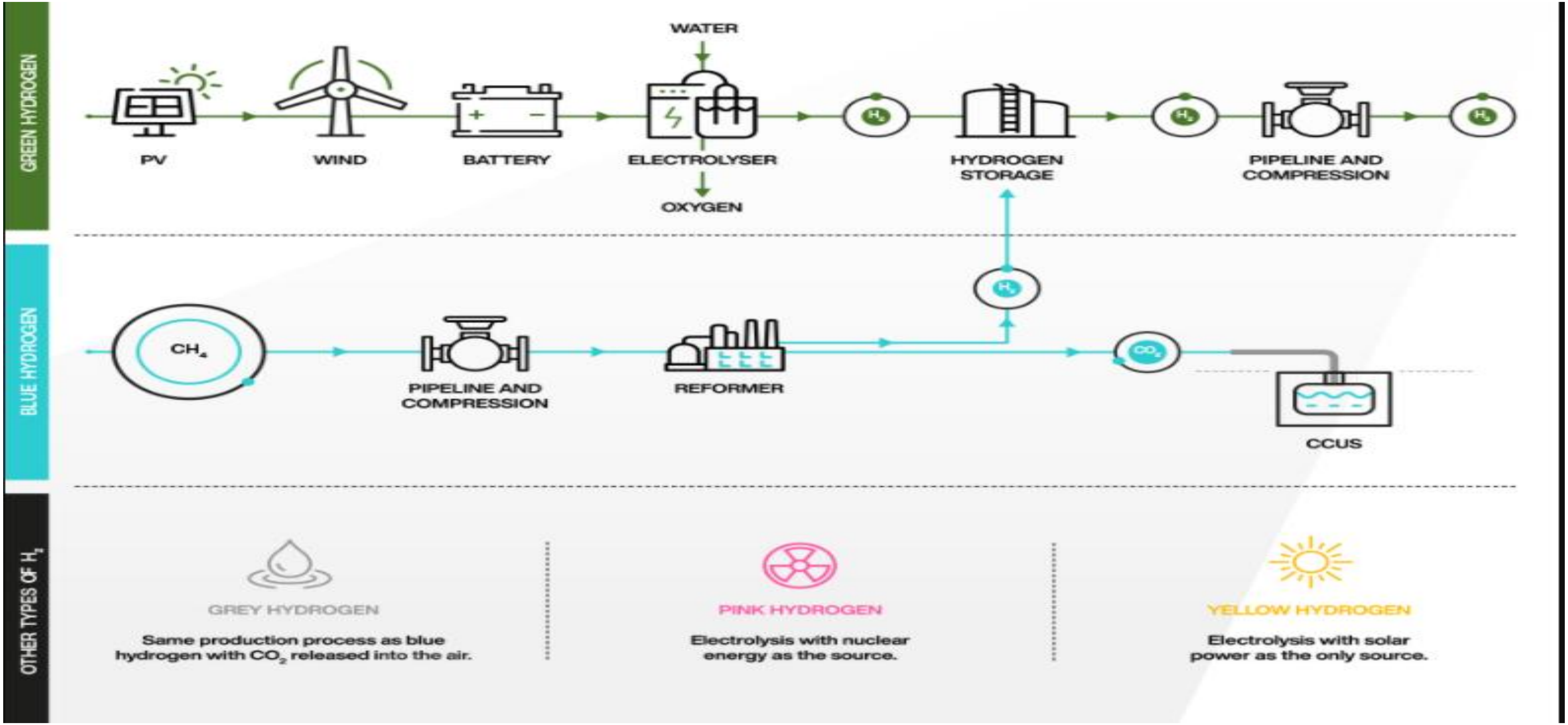


Source – IRENA, S&P Platts, Bloom Energy

Methods of producing Hydrogen



Colours of Hydrogen



Source - Petrofac

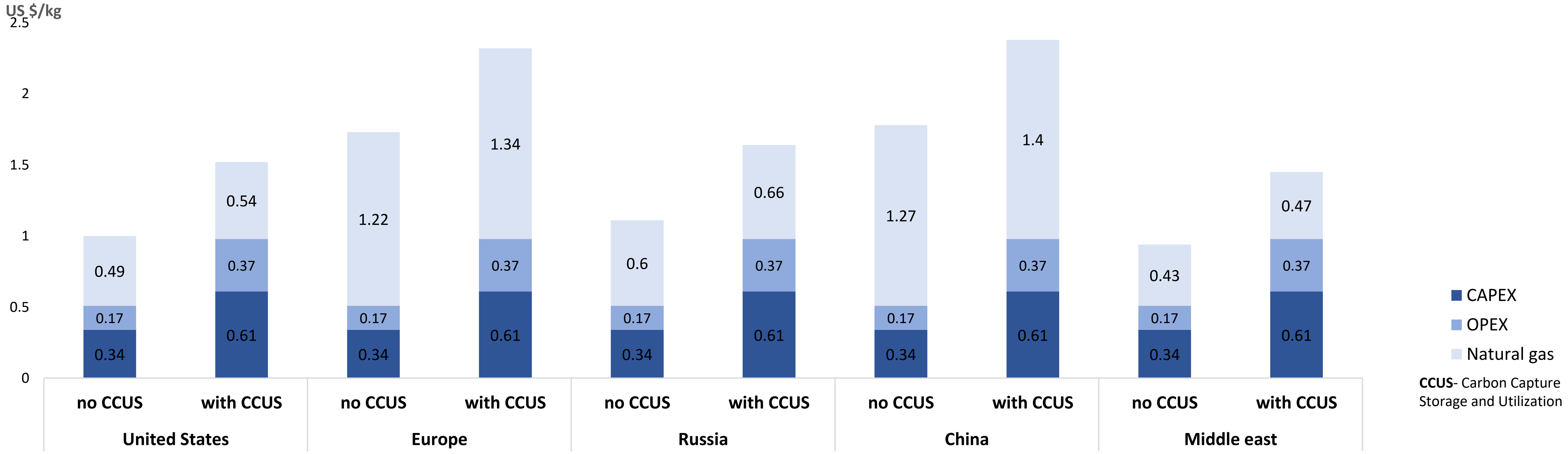
Comparison of different processes to produce Hydrogen

Hydrogen production Method	Method overview	Advantages	Disadvantages	Efficiency %	Cost [$/kg]
Steam Reforming	Synthesis gas, a mixture of hydrogen, carbon monoxide, and a small amount of carbon dioxide, is created by reacting natural gas with high-temperature steam. The carbon monoxide is reacted with water to produce additional hydrogen.	Developed technology & Existing infrastructure	Produced CO, CO2 Unstable supply	**74–85**	**2.27**
Partial Oxidation	The methane and other hydrocarbons in natural gas react with a limited amount of oxygen (typically from air) that is not enough to completely oxidize the hydrocarbons to carbon dioxide and water.	Established technology	Along with H_2 Production, produced heavy oils and petroleum coke	**60–75**	**1.48**
Gasification	A synthesis gas is created by reacting coal or biomass with high-temperature steam and oxygen in a pressurized gasifier, which is converted into gaseous components. The resulting synthesis gas contains hydrogen and carbon monoxide, which is reacted with steam to separate the hydrogen.	Abundant, cheap feedstock and neutral CO2.	Fluctuating H_2 yields because of feedstock impurities, seasonal availability and formation of tar.	**30–40**	**1.77–2.05**
Electrolysis	An electric current splits water into hydrogen and oxygen. If the electricity is produced by renewable sources, such as solar or wind, the resulting hydrogen will be considered renewable	Established technology Zero emission Existing infrastructure O2 as byproduct	Storage and Transportation problem	**60–80**	**10.3**

Source - ScienceDirect

Production cost comparison

Production Cost of Grey and Blue Hydrogen in USD/kg of H_2 in 2018



Method of production	Production costs USD/kg
Natural gas	0.9-3.2
Natural gas with CCUS	1.5-2.9
Coal	1.2-2.2
Renewables	3-7.5

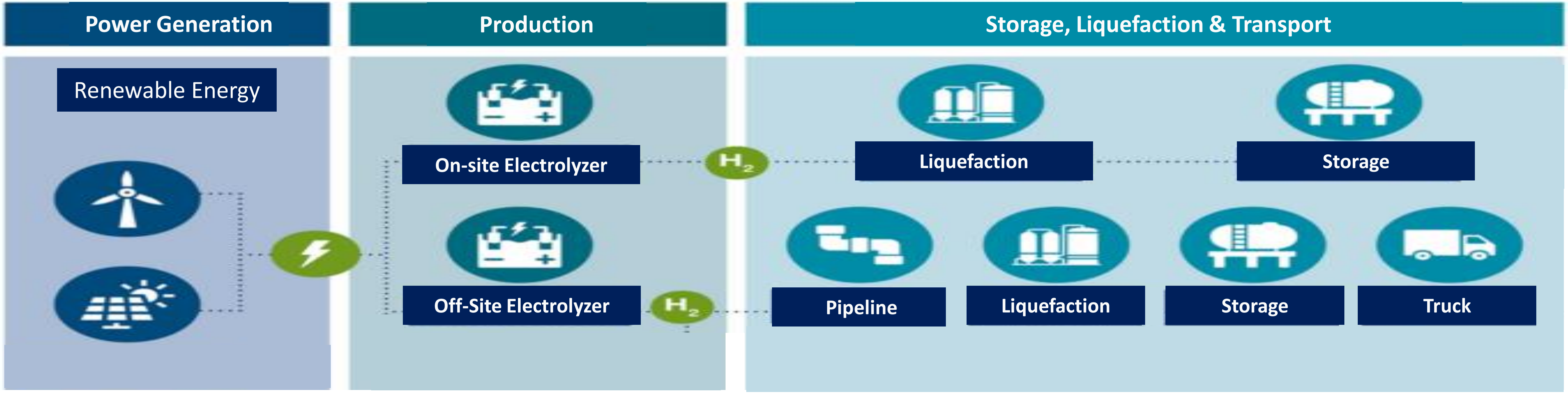
Transition from Grey and Blue Hydrogen to Green Hydrogen

- Cost of grey and blue hydrogen is expected to rise by 82%/59% by 2040 respectively due to increase in Natural Gas prices and CCUS technologies used in Blue Hydrogen are expensive and limited.
- Green hydrogen could cost below $2/kg from $10/kg currently in most geographies by 2050 as capex on renewables, electrolyzers decline and cost of distribution and storage reduce.
- Eventual cost of decarbonizing hydrogen production would be very small and potentially even negative.

Source – IEA, PhillipCapital India Research

Internals of a Green Hydrogen unit

Key modules in a green hydrogen unit



For Green H_2, renewable energy is used for electrolysis. 1Kg of H_2 requires 39kWh of electricity (at 100% efficiency).

Key Players

Global: Nextera Energy, Enel, Iberdrola, Orsted, Brookfield Renewable Partners

India: NTPC, Tata Power, Renew Power, Azure Power, Adani Green

H_2 is produced in an Electrolyzer by passing electric current into water. 1MW Electrolyzer produces 450kg H_2/day.

Key Players

Global: Plug Power, Bloom Energy, Ballard Power, ITM Power, Cummins, Siemens Energy

India: Thermax, MTAR, Reliance Industries, Carborundum Universal, Sainergy

H_2 produced is stored in tanks, transported by sea, rail or trucks and distributed at fueling stations.

Key Players

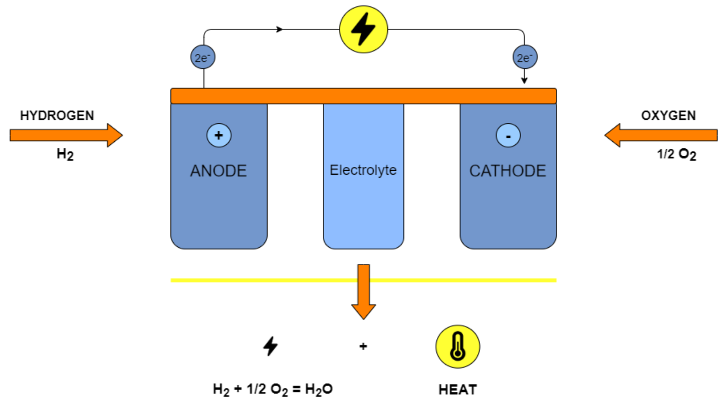
Global: Linde, Air Liquide, NPROXX, Air Products, Praxair

India: Elgi-Sauer (Compression), INOX Air Products

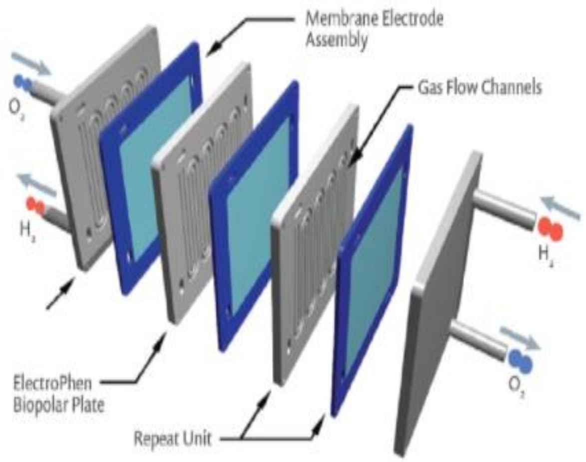
Source – PhillipCapital India Research

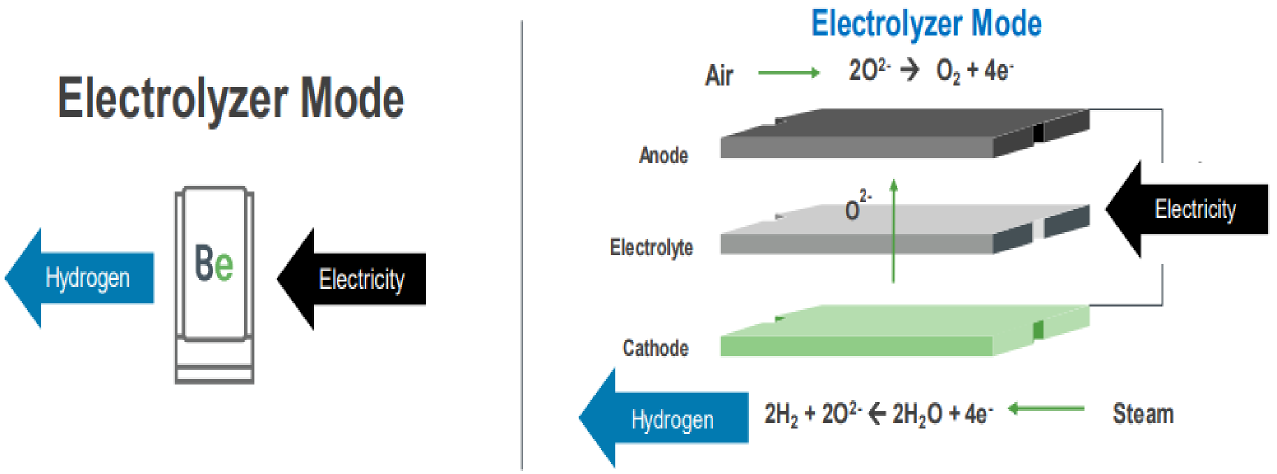
Electrolyzer and Fuel Cell Operation

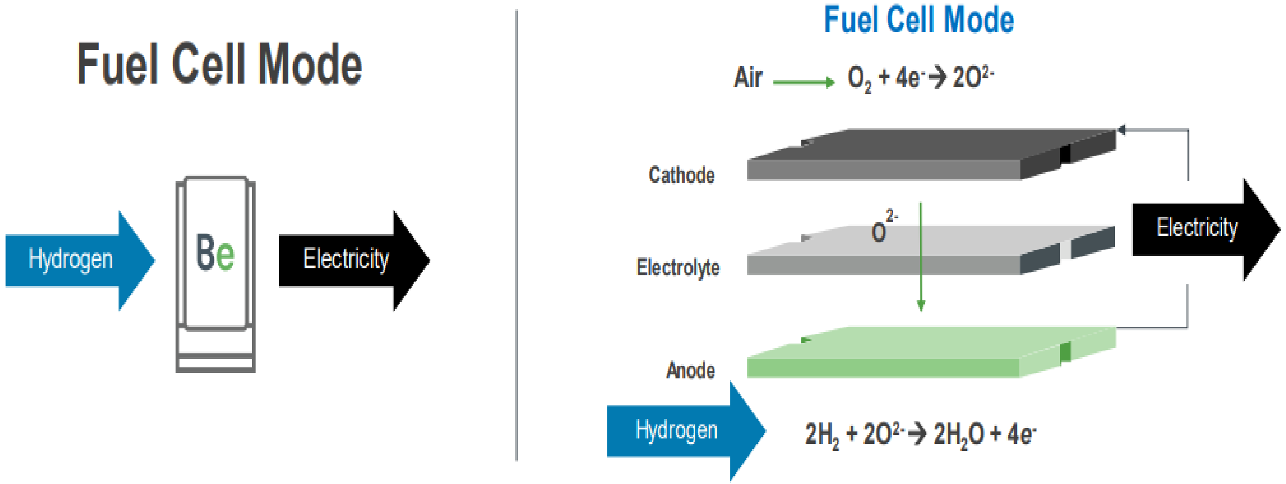
Electrolysis Process



Fuel cells stack







Source – IEEE, Bloom Energy, PhillipCapital India Research

Electrolyzer

A 1 MW electrolyzer has the capacity to support energy storage, hydrogen fuelling station and Industrial needs

Product Specification (System)	
Specification	**Rating**
INPUT	
Electrical Input	480VAC, 60Hz (USA) / 400 VAC, 50Hz (EU)
BALANCE OF PLANT	
Water Consumption (DI)	10kg/kg hydrogen produced
PHYSICAL	
Dimensions (W*H*L)	8'x9'6"x40' container
Weight	35 tons
Ambient Temperature	-20°C to +40°C
PERFORMANCE	
Hydrogen Production	200Nm3/hr / 18kg/hr
Hydrogen Purity	99.999%
Hydrogen pressure	40 bar
Start-up time	30 seconds (warm start) / < 5mintues (cold start)
Average efficiency at stack- level	49.9 kWh / kg

Source- Plug Power

Different types of fuel cells

Technology	Proton Exchange Membrane	Alkaline Fuel Cell	Phosphoric Acid Fuel Cell	Solid Oxide Fuel Cell	Molten Carbonate Fuel Cell
Electrolyte Materials	PEM Membrane- Nafion, Flemion etc	KOH, NaOH, H_2SO_4	Phosphoric acid soaked in a porous matrix or imbibed in a polymer membrane	ZrO_2 stabilised by Y_2O_3, MgO or CaO etc	Molten lithium, sodium, and/or potassium carbonates, soaked in a porous matrix
Catalyst Materials	Platinum	Nickel/Silver	Platinum	$LaMnO_3$/$LaCoO_3$	Nickel
Operating temp in celsius	50-100	90-100	150-200	650-1000	600-700
Advantages	• Quick start • Works at room temperature • Air as oxidant • High energy conversion efficiency, high power density	• Quick start • Works at room temperature	• Insensitive to CO2 • Better tolerance to Carbon monoxide	• Air as oxidant • High energy efficiency	• Air as oxidant • High energy efficiency
Weaknesses	• Special requirements for components- expensive polymer electrolyte membrane, porous electrodes, and current collectors. • Sensitive to CO Reactants need to be humidified	• Need pure oxygen as oxidant • Efforts needed to reduce resistances like- electrochemical reaction resistance, bubble resistance, etc	• Sensitive to CO and sulfur. • Slow start. Acid has corrosive effects	• High operating temperature	• High operating temperature
Applications	Vehicle Power Portable power	Aerospace Military	Distributed generation	Large distributed generation Portable power	Large distributed generation

Hydrogen Fuelling Station

A typical Hydrogen fueling stations consists of:

- **Bulk Storage Tank:** Cryogenic storage that holds 15,000-18,000 gallons of liquid hydrogen at -423°F (-253°C).
- **Compression Pumps:** Compress liquid hydrogen to gaseous hydrogen at 7,000 psi.
- **Gaseous Storage Tubes:** Holds approximately 120kg of gaseous hydrogen.
- **Average capex to set up a hydrogen fueling station with a capacity of 200-1000kgs/day is $0.9-1.8mn** (Source: IEA)

Source – Plug Power

Hydrogen handling- transportation and storage

Transportation method	Long-distance transportation		Short-distance distribution			Storage			
	Pipeline	Tankers	Pipeline	Trucks	Trains	Tank	Pipeline	Can	Cavern
Physical Transformation									
Compression	✓	✓	✓	✓	✓	✓	✓		✓
Liquefaction		✓		✓	✓	✓			
Chemical combination									
Ammonia	✓	✓	✓	✓	✓	✓	✓		
LOHC		✓		✓	✓	✓			
Hydrides		✓		✓	✓			✓	
Scale	-2,000 km	>3,000 km	<500 km	<500 km	<1,000 km	Small to mid-scale	Small to mid-scale	Small-scale	Large-scale

For a 3,000 km journey, transporting gaseous hydrogen through a pipeline is about $2/kg compared to about $1.5/kg transported by ship

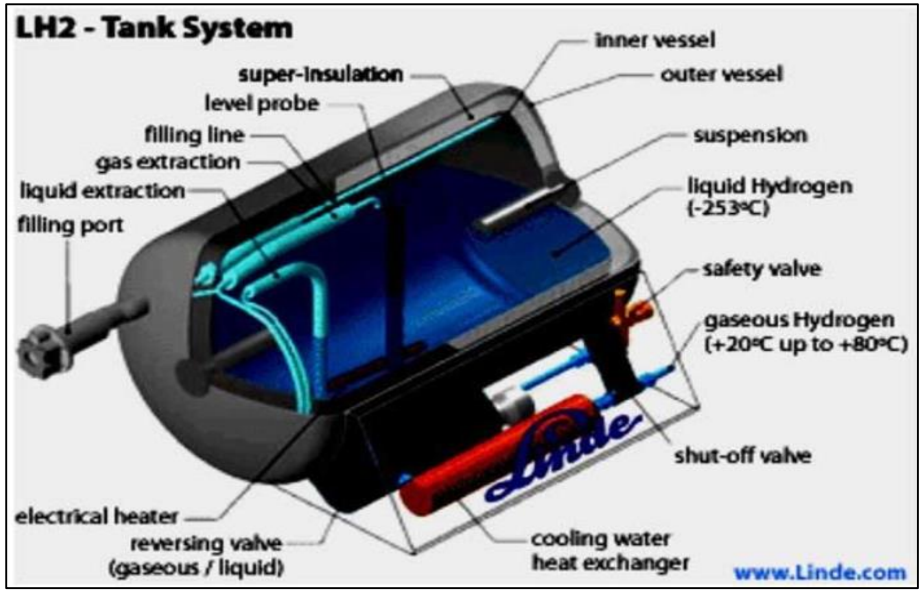
For a 500 km journey, transporting compressed gaseous hydrogen by trucks costs about $2/km versus about 40¢ to 80¢/km for pipelines

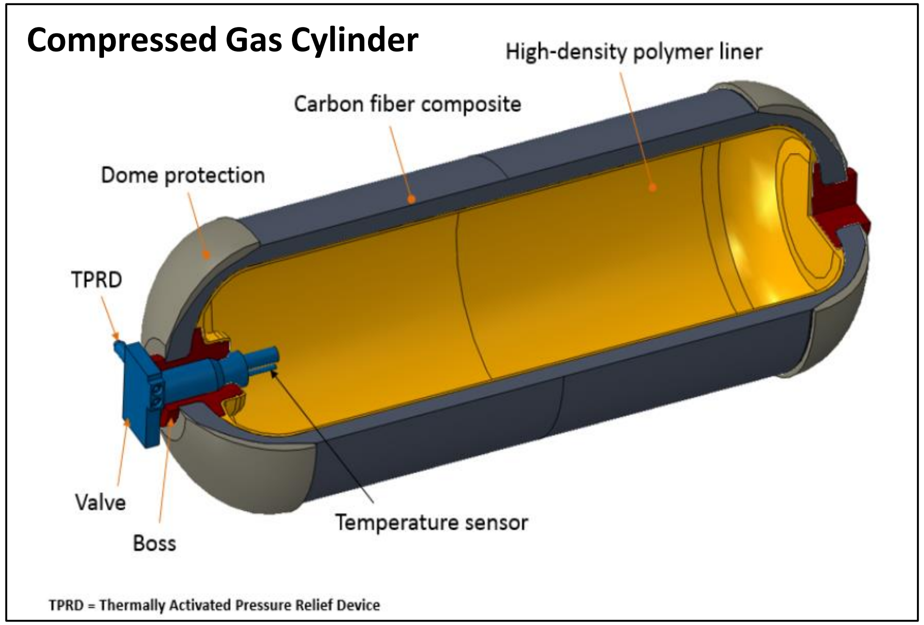
- LOHC is liquefied organic hydrogen carrier

Source – IEA, Kearney Energy Transition Institute, PhillipCapital India Research

Hydrogen storage benefits and barriers

Hydrogen storage technology	Benefits	Barriers
Compressed gas cylinders:	Well understood up to pressures of 200 bars; generally available; can be low cost	Only relatively small amounts of Hydrogen are stored at 200 bar; fuel storage energy densities at high pressure (700bar) are comparable to liquid hydrogen, but still lower than that for gasoline and diesel; high pressure storage still under development
Liquid tanks:	Well-understood technology; good storage density possible	Very low temperatures require super insulation; cost can be high; some hydrogen is lost through evaporation; energy intensity of liquid hydrogen production; energy stored still not comparable to liquid fossil fuels
Metal hydrides:	Some technology available; solid-state storage; can be made into different shapes; thermal effects can be used in subsystems; very safe	Heavy; can degrade with time; currently expensive; filling requires cooling-circuit
Chemical hydrides:	Well known reversible hydride formation reactions e.g. NaBH; compact	Challenges in the logistics of handling of waste products and in infrastructure requirements
Carbon structures:	May allow high storage density; light; may be cheap	Not fully understood or developed; early promise remains unfulfilled





Cost competitiveness of Hydrogen and use cases

What does Green Hydrogen cost today?

Assumptions:

- Electrolyzer cost (CAPEX) US$ 1mn/MW
- Annual OPEX is 1.5% of CAPEX
- Electrolysis requires ~50kWh to produce 1kg of Hydrogen
- Renewable energy cost per MWh - 50 to 115 USD
- Low temperature electrolyzer cost USD/kWe = 1300
- Hydrogen produced by a 1MW electrolyzer in a day = 450 Kg
- Electrolyzer stack life – 75,000 hours
- Distribution costs are currently c.60% of the outlay

		2020	
Particulars	**Solar**	**Wind onshore**	**Wind offshore**
Renewable energy cost in US- LCOE (USD/MWh)	50	35	115
Renewable energy cost in US- LCOE (USD/kWh)	0.05	0.035	0.115
Total renewable energy cost to produce 1kg H_2	2.5	1.8	5.5
Low temperature electrolyzer cost (USD/kWe		1,300	
Electrolyzer life		75,000	
PEM Electrolyzer cost to produce 1 kg Hydrogen	0.87	0.87	0.87
Pre distribution cost of 1 kg H_2	**3.37**	**2.62**	**6.62**
Distribution costs per kg of H_2	2.02	1.57	3.97
Total Cost ($/kg)	**5.4**	**4.2**	**10.6**

Source – IEA, Hydrogen Council, HydrogenOne Capital, PhillipCapital India Research

Lowering renewable energy, CAPEX and distribution costs to achieve H_2 cost of $ 2-3/kg

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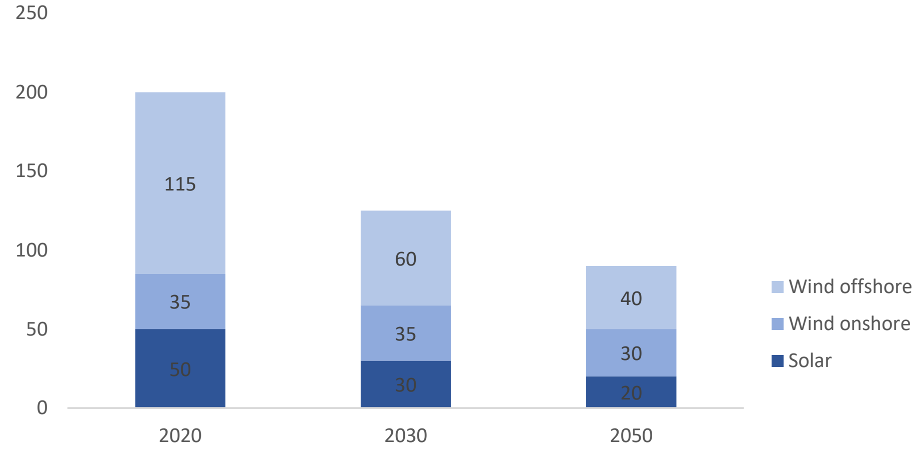
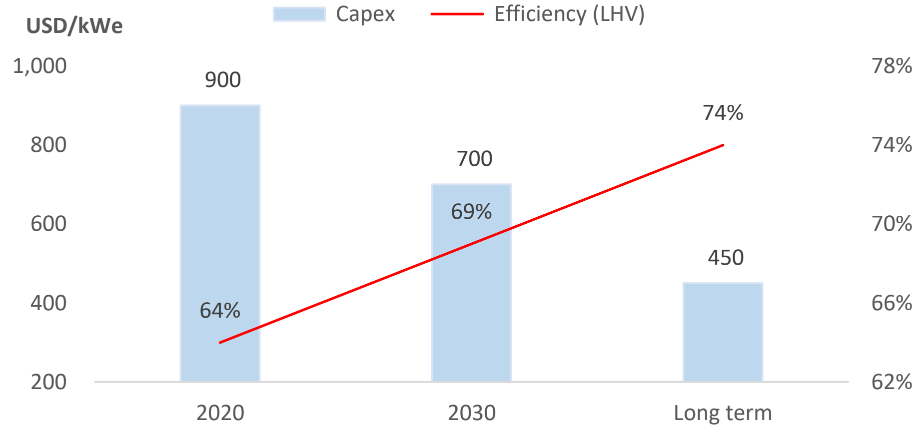
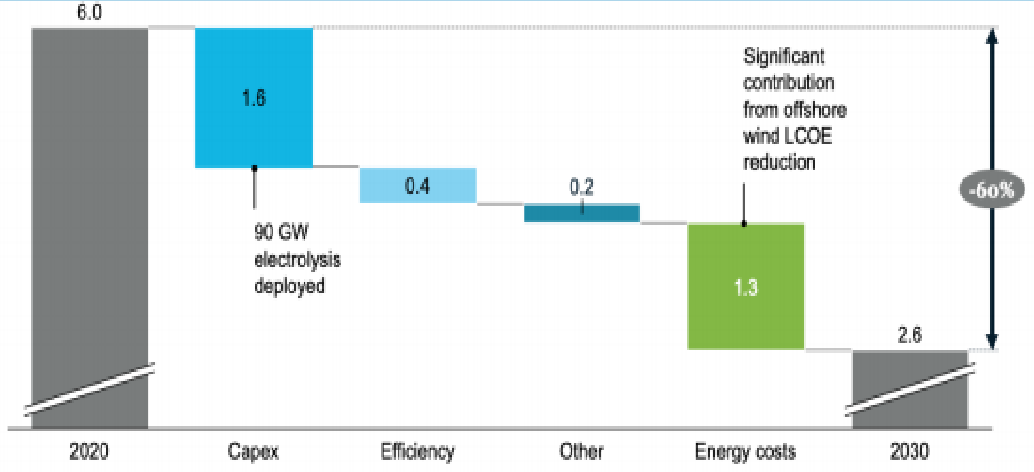
Renewable energy cost in US- LCOE in USD/MWh



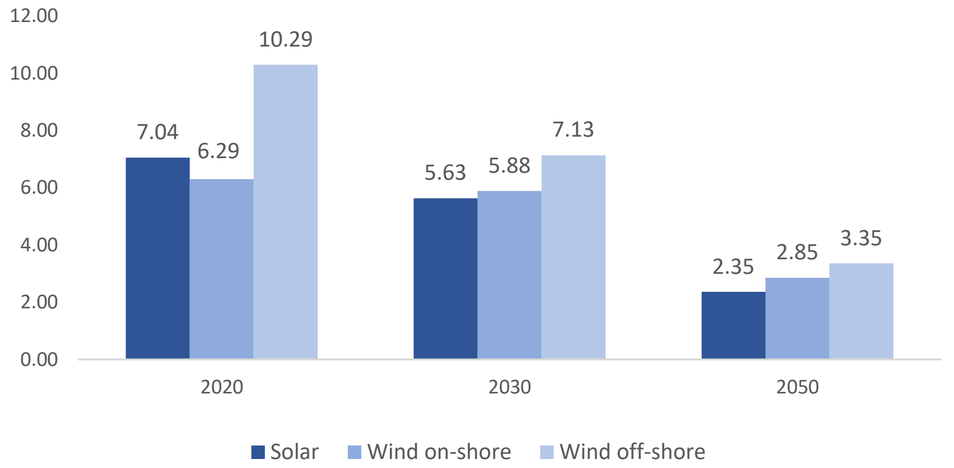
Water electrolysis Capex and Efficiency



By 2030 Costs (USD/kg) reduce to…

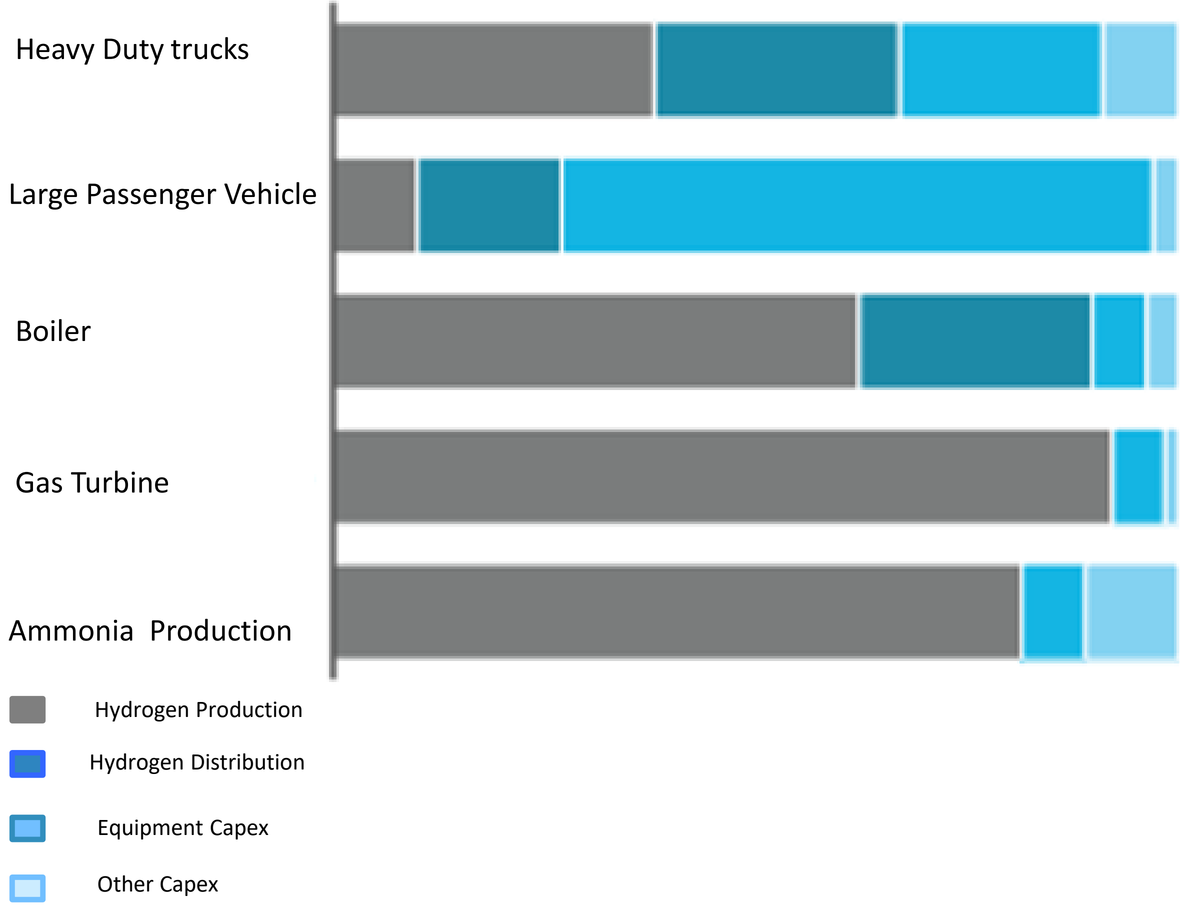


Future Costs of Green Hydrogen USD/kg



Source – IEA, HydrogenOne Capital, Hydrogen Council, PhillipCapital India Research

Drivers of Hydrogen cost competitiveness in different sectors



Cost breakdown of Hydrogen applications (Percentage of total cost 2020)	**Cost drop 2020-30 in %**	**Cost reduction levers to reach target**
Heavy Duty trucks	-50%	Scale up of full supply chain Industrialization of fuel cell and hydrogen tank manufacturing
Large Passenger Vehicle	-45%	Industrialization of fuel cell and hydrogen tank manufacturing Scale up and utilization of HRS
Boiler	-45%	Lower cost hydrogen from renewables Higher pipeline network utilization due to scale up of demand
Gas Turbine	-35%	Scale up of system size and manufacturing of Electrolyzers for green hydrogen production
Ammonia Production	-45%	

Assuming 50/50 blend of low carbon and average renewable hydrogen

Source – Hydrogen Council

Cost competitiveness analysis- Hydrogen vs Diesel generators

Without policy support the fuel cell becomes cost competitive in 10 years

	Typical Fuel cell 5 kW system in Integrated power Cabinet with fuel storage	Diesel Generator 20 kW with ATS and fuel storage
Capital Cost	**USD**	**USD**
Hardware	35920	20000
Permitting Installation	13000	17500
Total first cost	**48920**	**37500**
Operational Costs		
Annual Maintenance/ materials	300	1400
Annual fuel & delivery	223	500
Total Annual OPEX	**523**	**1900**
Cost comparison in 2 years	**49443**	**39400**
Cost comparison in 5 years	51535	47000
Cost comparison in 10 years	**54150**	**56500**

Federal tax credit considered as 30% of the installed cost of the fuel cell

With policy support the fuel cell becomes cost competitive within 2 years

	Typical Fuel cell 5 kW system in Integrated power Cabinet with fuel storage	Diesel Generator 20 kW with ATS and fuel storage
Capital Cost	**USD**	**USD**
Hardware	35920	20000
Permitting Installation	13000	17500
Incentives- Federal tax credit	**14676**	**0**
Total first cost	**34244**	**37500**
Operational Costs		
Annual Maintenance/ materials	300	1400
Annual fuel & delivery	223	500
Total Annual OPEX	**523**	**1900**
Cost comparison in 2 years	**34767**	**39400**
Cost comparison in 5 years	36859	47000
Cost comparison in 10 years	**39474**	**56500**

Source - Plugpower

Hydrogen PEV's vs Battery operated vehicles

Battery EVs	
Pros	**Cons**
Has momentum	A fledgling industry
Basis for a charging infrastructure is widely available	Refueling network sparse, expensive to implement
Model pipeline and segment coverage are growing	OEM offer is either low volume, or absent altogether
Affordability is improving steadily	Cost is greater than BEV (partly due to low volume)
Better on-board efficiency, fewer steps to produce fuel	FCEV packaging currently less optimal than BEV
All OEMs will offer a BEV portfolio in the medium term	More losses on-board, and from hydrogen production
Hydrogen Fuel Cell EVs	
Pros	**Cons**
Range & charge time not suitable for all usage cycles	Quick to refuel, range comparable to ICE
Current cost of using an FCEV is high	Technology is proven and available, though immature
Driver re-education is required, benefits hard to sell	Specific energy capacity of H_2 far greater than battery
No guarantee of a battery breakthrough	Lower environmental impact from production process
Battery raw material supply may not be sustainable	Rare and/or exotic material requirement is lower
BEV batteries are very difficult to recycle at EOL	FC stacks are refurbish-able and up to 95% recyclable

Conclusion- Hydrogen FCEVs are better equipped for long distances and battery EVs for short distances

Source – Copenhagen Centre on Energy Efficiency

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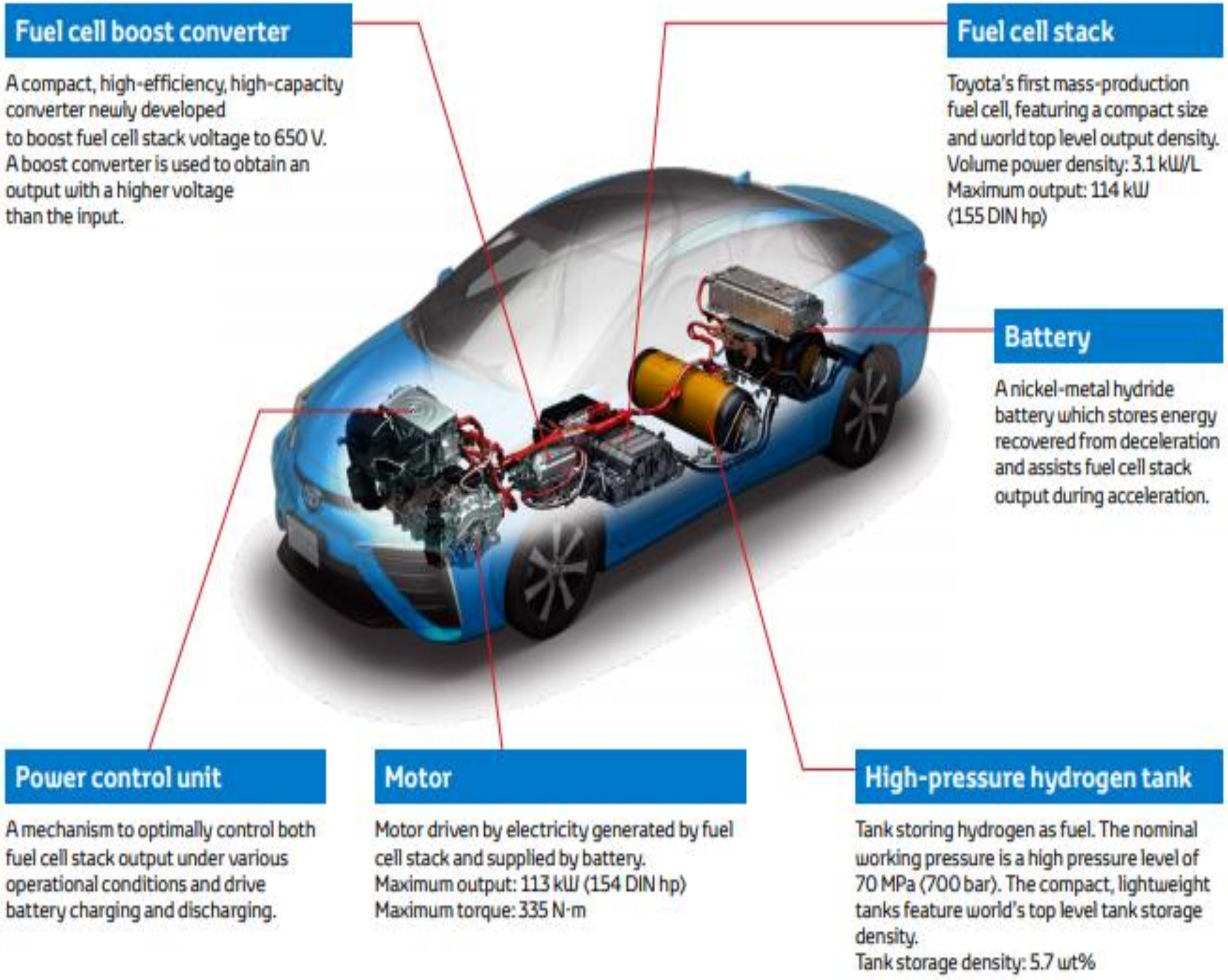
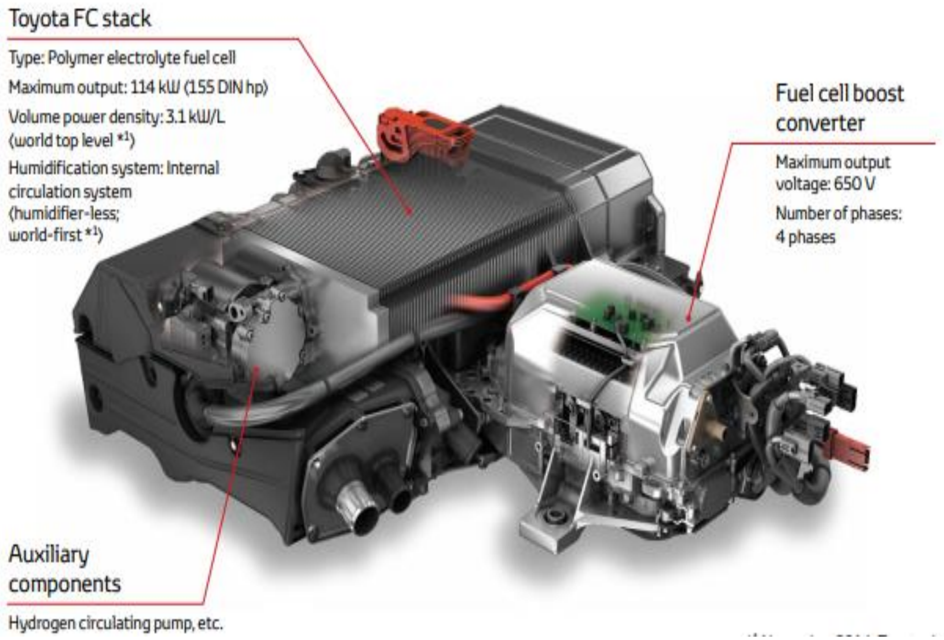
Fuel cell electric car



Fuel Cell Electric Vehicle Specifications- Toyota Mirai

Vehicle	Cruising range	Approx 550 km Estimated
	Maximum speed	178 km/hr
Fuel Cell Stack	Volume power density	3.1 kW/L
	Maximum output	114 Kw
High pressure hydrogen tank	No of tanks	2
	Nominal working pressure	700 bar
	Tank storage density	5.7 wt%
	Maximum output	113 Kw
	Maximum torque	335 Nm
Refuelling time		3 mins



Source - Toyota

Industrial use of Hydrogen fuel- Forklifts for material handling

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- On-demand hydrogen production for industrial users including electric turbine cooling, hydrogenation for food manufacturers, float glass processing and semiconductor fabrication.
- US company Power Plug has commercialized hydrogen powered forklift trucks.
- The forklifts use a nickel-aluminium alloy hydrogen storage material called Hy-Stor 208 in their fuel tanks.
- The forklifts can be refuelled in 15 minutes, a fraction of the time recharging a battery forklift takes.

Plug Power's GENDRIVE Fuel Cell for Material Handling Equipment

Product Specifications	(1400)	
Nominal Voltage (VDC)	36	48
Operating Temperature (Deg F)	22 to 104	
Fuelling		
Hydrogen Storage (Kg)	0.7	
Pressure	350 bar	
Fill Time	< 3 minutes	

Source – Plug Power

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Key participants in the Hydrogen ecosystem

Major players (global) in the Hydrogen value chain

Manufacturers	Products and Services
United Hydrogen Inc	Hydrogen generation and storage
Giner ELX (Plug Power)	Grid-level energy storage and on-site hydrogen generation for fuel cell vehicle refueling stations
Hygen	Decentralised Fuelling Infrastructure Construction
Apex Clean Energy	Development construction and operation of Renewable energy and energy storage/distribution services
Hydrogenics Corporation (Cummins)	PEM fuel cell designer and maker
AFC Energy	Electrolyzers, fuel cells, invertors, Fuel storage
Advanced Plastics	Fuel Cell Plates
De Nora	Electrodes
Areva H_2 Gen	Electrolyzers
Meher Compression Customised solutions	Compressors
Sauer Compressors	Compressors
Hydrogenious LOHC Technologies	Distribution Infrastructure
Kustec	Hydrogen Cooling
Wystrach	Mobile Hydrogen Filling station, storage infrastructure

Plug Power – Not Rated

Headquarters: USA

- Founded in 1997, Plug Power is a leading provider of clean hydrogen and zero emission fuel cell solutions that are both cost effective and reliable
- Products offered for e-mobility, material handling and stationary power
- The company is a leader in the forklift field.
- It is building 5 green Hydrogen plants in the USA expected to be operational by 2024
- The company now has a 95% market share for hydrogen fuel cells in the transportation industry.

Financials (USD mn)	2016	2017	2018	2019	2020
Revenue	86	100	175	230	363
EBITDA	-46	-92	-54	-4	-83
PAT	-57	-127	-78	-84	-140
R&D	21	29	34	15	28
R&D/Sales(%)	25	29	19	7	8
Debt	19	79	234	290	-932
Debt/Equity (%)	20	106	681	221	-64
OCF	-30	-60	-58	-53	-155
OCF/EBITDA	NA	NA	NA	NA	NA
NWC	-2	-21	-29	40	68
NWC % Sales	-2	-21	-17	17	19

Source – Company, Bloomberg, PhillipCapital India Research

Ballard Power – Not Rated

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BALLARD

Headquarters: Canada

- Founded in 1979, Ballard is a leading provider of clean energy and fuel cell solutions
- Products offered include PEM fuel cells for marine industry, for heavy-duty motive, portable power, material handling, engineering services
- Ballard modules power the U.K.'s first fully sized hydrogen demonstrator refurbished train
- Ballard modules powers Ultra heavy duty mining truck for Anglo, the world's largest platinum group metals mining company

Financials (USD mn)	2016	2017	2018	2019	2020
Revenue	85	121	97	106	104
EBITDA	-11	1	-15	-17	-32
PAT	-21	-8	-27	-39	-51
R&D	20	25	27	25	36
R&D/Sales(%)	23	21	28	24	34
Debt	-65	-53	-187	-128	-748
Debt/Equity(%)	-54	-45	-66	-51	-83
OCF	-4	-10	-32	-14	-43
OCF/EBITDA	NA	NA	NA	NA	NA
NWC	-8	3	22	17	39
NWC % Sales	-9	3	22	16	37

Source - Company, Bloomberg, PhillipCapital India Research

Bloomenergy – Not Rated

Headquarters: USA

- Bloomenergy was established in 2001.
- The company has developed a distributed, on-site electric power solution that is redefining the $2.4 trillion electric power market.
- Products offered include Solid Oxide Fuel Cells, Electrolyzers, Microgrids, clean and affordable power generation systems
- The company is actively pursuing partnerships building on momentum with hydrogen-to-power (SK partnership) and shipping (Samsung HI partnership)

Financials (USD mn)	2016	2017	2018	2019	2020
Revenue	209	376	633	785	794
EBITDA	-196	-111	-110	-81	-19
PAT	-280	-263	-274	-304	-158
R&D	47	51	89	104	84
R&D/Sales	22	14	14	13	11
Debt	638	734	416	434	194
Debt/Equity (%)	-2	-1	1047	-3	137
OCF	-283	-67	-92	164	-99
OCF/EBITDA	NA	NA	NA	NA	NA
NWC	-26	45	186	-304	-65
NWC % Sales	-12	12	29	-39	-8

Source - Company, Bloomberg, PhillipCapital India Research

Fuel Cell Energy – Not Rated

Headquarters: USA

- Founded in 1969, Fuel Cell Energy designs, manufactures, operates and services Direct Fuel Cell power plants that run on natural gas and biogas
- The company is a global leader in delivering clean, efficient and affordable fuel cell solutions configured for the supply, recovery and storage of energy.
- U.S. Department of Energy recently awarded Fuel Cell Energy an additional $8 Million in funding for its differentiated Solid Oxide Platform

Financials (USD mn)	2016	2017	2018	2019	2020
Revenue	108	96	89	61	71
EBITDA	-41	-35	-36	-34	-16
PAT	-51	-54	-47	-78	-89
R&D	21	20	23	14	5
R&D/Sales(%)	19	21	26	23	7
Debt	2	43	50	103	33
Debt/Equity (%)	1	23	28	76	13
OCF	-47	-72	16	-31	-37
OCF/EBITDA	NA	NA	NA	NA	NA
NWC	66	56	31	12	25
NWC % Sales	61	59	35	20	36

Source - Company, Bloomberg, PhillipCapital India Research

Cummins Inc – Not Rated

Headquarters: USA

- Cummins Inc. was founded in 1919. Its products range from diesel, natural gas, electric and hybrid powertrains and powertrain-related components including filtration, aftertreatment, turbochargers, fuel systems, controls systems, air handling systems, automated transmissions, electric power generation systems, batteries, electrified power systems, hydrogen generation and fuel cell products.
- Cummins established alternative energy as a commercial entity in 2017 and gained new capabilities through inorganic acquisitions such as Hydrogenics, Johnson Matthey Battery systems, Brammo, Efficient drives etc enabling it to be leading player in hydrogen and fuel cell technology.
- CMI partnered Iberdrola to announce one of the world's largest electrolyzer plants for the production of green hydrogen to be located in Castilla-La Mancha, Spain

Financials (USD mn)	2016	2017	2018	2019	2020
Revenue	17509	20428	23771	23571	19811
EBITDA	2549	2906	3782	3634	3087
PAT	1394	999	2141	2260	1789
R&D	637	754	902	1001	906
R&D/Sales(%)	4	4	4	4	5
Debt	476	439	951	1398	755
Debt/Equity (%)	7	5	12	17	8
OCF	1939	2277	2378	3181	2722
OCF/EBITDA	1	1	1	1	1
NWC	2262	1882	2131	1998	2161
NWC % Sales	13	9	9	8	11

Source - Company, Bloomberg, PhillipCapital India Research

Siemens Energy – Not Rated

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SIEMENS energy

Headquarters: Germany

- Siemens Energy was founded in 2020 by the spin off of the former Gas and Power division of Siemens group. It also has 67% stake in Siemens Gamesa
- Siemens Energy has a footprint across Power Generation and Transmission, Oil and Gas, Industrials, Hydrogen and Renewable Energy Technologies
- It has been in the forefront of technological innovations both in Conventional and Renewable Energy. It has recently announced that it will provide two turbines to Omaha Public Power District’s Plant in Nebraska. The turbines have the ability to run on 30% hydrogen and biodiesel.

Financials (INR mn)	**2017**	**2018**	**2019**	**2020**
Revenue	33,238	33,360	32,484	30,756
EBITDA	2,833	2,068	1,913	1,764
PAT	1,005	651	178	-1,799
R&D	1,227	1,273	1,129	1,103
R&D/Sales(%)	3.7	3.8	3.5	3.6
Debt	(483)	(449)	(691)	(1,981)
Debt/Equity (x)	(3.6)	(3.6)	(4.8)	(11.0)
OCF	534	755	1,642	1,637
OCF/EBITDA	0.2	0.4	0.9	0.9
NWC	2,139	-476	-1,277	-5,032
NWC % Sales	6.4	(1.4)	(3.9)	(16.4)

Source - Company, Bloomberg, PhillipCapital India Research

ITM Power – Not Rated

Headquarters: UK

- ITM Power was founded in 2001
- ITM Power designs and manufactures products which generate hydrogen gas, based on Proton Exchange Membrane (PEM) technology.
- Its product portfolio consists of electrolysers ranging from 600kW to 100 MW. It also builds owns and operates hydrogen refueling stations through its wholly owned subsidiary, ITM Motive. It currently operates and owns 7 hydrogen refueling stations

Financials (USD mn)	**2016**	**2017**	**2018**	**2019**	**2020**
Revenue	3	3	4	6	4
EBITDA	(5)	(4)	(6)	(10)	(26)
PAT	(6)	(5)	(8)	(12)	(37)
R&D	3	3	2	3	3
R&D/Sales(%)	101	84	55	51	70
Debt	(5)	(4)	(28)	(7)	(42)
Debt/Equity (%)	(29)	(23)	(57)	(20)	(60)
OCF	(11)	(7)	(11)	(15)	(15)
OCF/EBITDA	NA	NA	NA	NA	NA
NWC	7	7	14	19	8
NWC % Sales	253	214	325	319	196

Source - Company, Bloomberg, PhillipCapital India Research

Thermax - SELL

THERMAX

Headquarters: India

- Thermax was established in 1966
- Thermax operates in 3 segments – Energy, Environment and Chemicals. The group has 15 manufacturing facilities – 10 in India, 2 in Denmark and one each in Poland, Germany and Indonesia.
- The company's product portfolio includes Heating, Cooling, Powergen, Renewable energy, Air Pollution Control, Water, Chemicals, Waste Management product and solutions. It is also developing Hydrogen fuel cells and Solar films

Financials (INR mn)	2016	2017	2018	2019	2020	2021
Revenue	51,450	44,831	44,649	59,732	57,313	47,913
EBITDA	4,291	4,330	4,009	4,574	4,062	3,552
PAT	2,823	2,970	2,322	3,244	2,825	2,460
R&D	227	196.1	226.2	318.6	298.5	NA
R&D/Sales(%)	0.4	0.4	0.5	0.5	0.5	NA
Debt	(10,292)	(9,520)	(13,430)	(10,124)	(11,599)	(18,275)
Debt/Equity (x)	(0.4)	(0.4)	(0.5)	(0.3)	(0.4)	(0.6)
OCF	4,234	4,924	7,107	716	4,568	8,633
OCF/EBITDA	1.0	1.1	1.8	0.2	1.1	2.4
NWC	2,717	3,191	148	4,377	3,780	(565)
NWC % Sales	5	7	0	7	7	-1

Source - Company, Bloomberg, PhillipCapital India Research

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MTAR Technologies – Not Rated

Headquarters: India

- MTAR was promoted in 1970 by technocrats with the intent to manufacture precision engineered products for agencies such as ISRO, NPCIL and DRDO that were looking to localise mission critical technologies.
- Presently, MTAR has a portfolio of 29 products catering to Clean Energy (3), Nuclear (14), Defence and Space (6 each) that it manufactures out of seven plants.
- MTAR is currently engaged in new product development by entering into sheet metal fabrication, roller screws and large and medium sized gears.
- Most of the products manufactured by MTAR are import substitutes hence , it has limited competition

Financials (INR mn)	2016	2017	2018	2019	2020	2021
Revenue	815	1,007	1,566	1,837	2,138	2,464
EBITDA	121	(113)	319	537	580	831
PAT	2	(187)	54	400	315	462
Debt	187	194	107	88	54	(1,794)
Debt/Equity (x)	0.1	0.1	0.1	0.0	0.0	(0.4)
OCF	330	124	170	515	634	203
OCF/EBITDA	2.7	-1.1	0.5	1.0	1.1	0.2
NWC	848	610	753	760	689	1,324
NWC % Sales	104	61	48	41	32	54

Source - Company, Bloomberg, PhillipCapital India Research

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