Asian Insights Sparx

Hydrogen Energy

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The next green energy revolution?

- Green hydrogen will be one of the key tools for policymakers globally to meet net zero targets
- Expensive for now, but things could change rapidly over the next decade, as our experience with renewable energy has shown
- Green hydrogen is not a competitor to renewables, rather it is complementary and synergistic to the growth of wind and solar power
- Apart from cost reductions, hydrogen economy needs bigger scale deployments and investments to bridge the gap in storage and transmission

Meeting the clean hydrogen cost target of US$1-2/kg by 2030 will be critical. This will mean reducing costs by about 50-80% in a decade, which is a stiff target but given the experience the world has had with renewable energy, where costs have fallen much faster than expected, this is not an improbable target. The cost reduction strategies will involve increasing scale, reducing the capital costs of the electrolyser system (production), improving the energy efficiency for converting electricity to hydrogen and lengthening the operational life of the electrolyser cell stacks, among others.

Worth looking at some pioneering business models. We do not have active coverage on the emerging players in the sector as business models are still evolving and not profitable at this stage. Some of the interesting new age names to note in this space include Plug Power, FuelCell Energy, Bloom Energy and Ballard Power (US), ITM Power, Ceres Power, NEL ASA (Europe), Doosan Fuel Cells, Hyosung Advanced Materials, S-Fuelcell (Korea) and Beijing SinoHytec (China).

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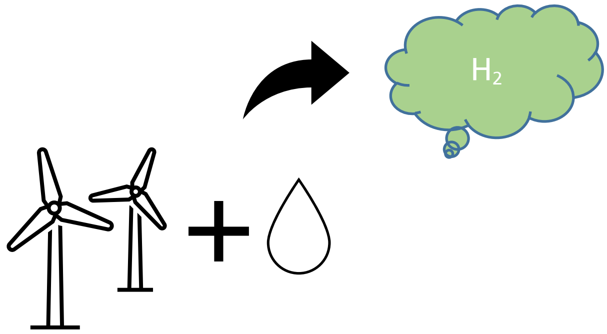
What is green hydrogen?



Green hydrogen is a high-value zero emissions energy source produced by the electrolysis of water using low-cost renewable electricity

Source: DBS Bank

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SUMMARY HIGHLIGHTS

Focus should be on green hydrogen in future. Green hydrogen or emission free hydrogen that is produced using renewable energy sources is being increasingly viewed as an important means to achieve net zero carbon goals globally. Currently, grey hydrogen accounts for 95% of global hydrogen production, but this type of hydrogen is not carbon-emission free. Of course, it will not be easy to transition to green hydrogen overnight, as it costs about 3-5x grey hydrogen, and costs need to reduce over the next decade to make green hydrogen production and use more feasible. In the meantime, we may see blue hydrogen emerging as an interim solution, as it uses carbon capture technologies to store the CO_2 emissions involved in grey hydrogen, but this is not the ideal solution.

Many advantages of hydrogen. As it is a renewable energy source, there is adequate supply available. However, it needs separation, as it is always part of another compound, such as water or methane. Hydrogen is also environment friendly, produces no emissions during operations and has high energy density. This improves productivity, as hydrogen-powered equipment can operate for longer times.

But many challenges as well. The key challenge today is that green hydrogen is very expensive, as it involves significant capital expenditure in electrolysis. Hence, there is no mass production yet and without scale, costs are difficult to reduce. Further, storage and transportation including liquefaction and regasification is both expensive and difficult, as it is a very light gas, highly flammable and is very risky if it is not handled appropriately.

Hydrogen production will be complementary and synergistic to renewable energy in future. Hydrogen production via electrolysis may offer opportunities for synergy with dynamic and intermittent power generation, which is characteristic of some renewable energy technologies. For example, although the cost of wind power has continued to drop, the inherent variability of wind is an impediment to the effective use of wind power. Hydrogen fuel and electric power generation could be integrated at a wind farm, allowing flexibility to shift production to best match resource availability with market needs. Also, in times of excess electricity production from wind farms, instead of curtailing the electricity, it is possible to use this excess electricity to produce hydrogen through electrolysis and store for later.

Meeting the clean hydrogen cost target of US$1-2/kg by 2030 will be critical. This will mean reducing the cost by about 50-80% in a decade, which is a stiff target but given the experience the world has had with renewable energy sources, where costs have fallen much faster than expected, this is not an improbable target. The cost reduction strategies will involve reducing the capital costs of the electrolyser system over time, improving the energy efficiency for converting electricity to hydrogen over a wide range of operating conditions and lengthening the operational life of the electrolyser cell stacks, among others.

Hydrogen fuel can be used in a variety of applications. The most common use case for green hydrogen fuel will be in areas where it is difficult for renewable energy to reach directly; hence, the (long-range) transport sector stands out, as green hydrogen can be delivered through fuel cells. Hydrogen is also gaining popularity as backup energy source for critical infrastructure like servers and data centers. It could also be used to replace part of the fuel mix for high emission heavy industries like steel and refining to reduce carbon compliance costs in future.

Europe is the most mature market. An estimated US$500bn worth of hydrogen projects are planned globally to 2030, of which 30% can be considered mature. Europe remains the centre of hydrogen development, accounting for more than 50% of announced projects. In Asia, South Korea and Japan could be considered first movers but China could emerge as a hydrogen powerhouse in Asia, to reach its ambitious climate targets by 2050. Over in India, Reliance Industries has committed to set up "giga-factories" to produce electrolysers and fuel cells for the green hydrogen economy and aims to aggressively push towards lowering the cost of hydrogen to US$1/kg by 2030.

Pioneering business models to note. Hydrogen players can be involved in the electrolyser space on the production side, transport and storage infrastructure including hydrogen refuelling stations and in the development of fuel cells and related components on the application side. Some of the interesting new age names to note in this space include Plug Power, FuelCell Energy, Bloom Energy and Ballard Power (US), ITM Power, Ceres Power, NEL ASA (Europe), Doosan Fuel Cells, Hyosung Advanced Materials, S-Fuelcell (Korea) and Beijing SinoHytec (China). Other bigger more established names like Linde, Cummins and a number of Japanese and Korean conglomerates are also developing their hydrogen businesses actively.

INTRODUCTION – HYDROGEN ECONOMY

Hydrogen is a potentially clean fuel that produces water when consumed in a fuel cell. It is abundant in supply and is light, storable, and energy-dense and produces no direct emissions of pollutants or greenhouse gases.

Hydrogen can be produced using a variety of domestic resources, such as natural gas, biomass, nuclear power, and renewable power like solar and wind. The most common form of hydrogen production currently is by steam reforming hydrocarbons; this process is expected to be replaced with more renewable sources in future. At present, c.95% of hydrogen is produced from steam reforming or natural gas, and hence not really clean.

Steam reforming process is most widespread now. The steam reforming process is a high-temperature process in which steam reacts with a hydrocarbon fuel to produce hydrogen. Hydrocarbon fuels such as natural gas, diesel, gasified coal etc. can be reformed to produce hydrogen.

Transition to green hydrogen economy has begun. Green hydrogen or emission free hydrogen that is produced using renewable energy sources is being increasingly viewed as an important means to achieve net zero carbon goals globally. Hydrogen's discrete characteristics make it an attractive fuel option for long-range transportation and electricity generation. Given the various investment plans by governments worldwide and global private companies on hydrogen production and infrastructure, we believe that a transition to the hydrogen economy has already begun.

Challenges abound though. However, hydrogen comes with some complications such as heavy infrastructure requirements, storage issues and high flammability, which makes it a fuel option to look at with caution.

In this report, we will look at some of the key characteristics of hydrogen as an energy source of the future and the challenges faced, along with national policies and strategies enacted by major players in the industry.

Hydrogen economy overview

Source: Australian Hydrogen Council, DBS Bank

DIFFERENT TYPES OF HYDROGEN

Focus should be on green hydrogen in future. Currently, grey hydrogen accounts for 95% of global hydrogen production, but this type of hydrogen is not carbon-emission free. Given that this production method utilises fossil fuels like natural gas, it does not serve the purpose of reducing carbon emissions and transitioning to net zero emissions over the next 30 years, which many countries have pledged to. Of course, it will not be easy to transition to green hydrogen overnight, as it costs about 3-5x grey hydrogen, and costs need to reduce over the next decade to make green hydrogen production and use more feasible. In the meantime, we can maybe see blue hydrogen emerging as an interim solution, as it uses carbon capture technologies to store the CO_2 emissions, but it is not the ideal solution.

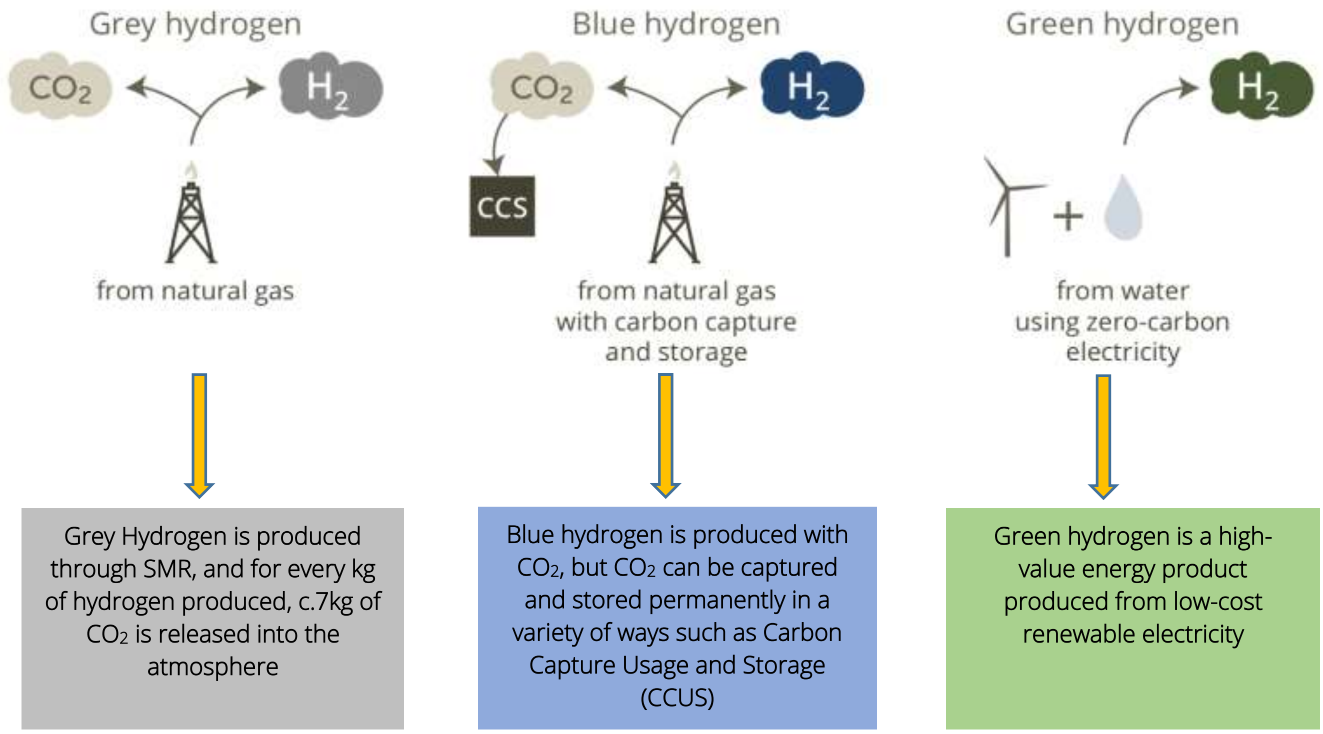
Hydrogen types

Grey hydrogen	The most common type accounting for roughly 95% of hydrogen produced in the world currently. It is produced using fossil fuels such as natural gas. Natural gas is split into Hydrogen and CO_2 using Steam Methane Reforming (SMR) or Auto Thermal Reforming (ATR) and the CO_2 is captured and released into the atmosphere.
Brown hydrogen	Another common type of hydrogen generated from hydrocarbon-rich feed stock such as coal fossil fuels or methane gas. Production is normally through coal gasification. However, production of this hydrogen is harmful to environment, as exorbitant amounts of CO_2 are emitted to the atmosphere.
Blue hydrogen	Generated using non-renewable energy sources like nuclear and meets the low-carbon threshold. This mitigates the environmental impact to the earth as the process of splitting natural gas is the same as grey hydrogen; however, CO_2 is captured and stored. The capturing is done through a process called Carbon Capture Usage and Storage (CCUS).
Green hydrogen	Generated using renewable energy sources such as solar or wind. Production of green hydrogen is performed by splitting water by electrolysis. This is the cleanest and currently the most expensive hydrogen option, as it produces hydrogen and oxygen, where hydrogen can be used and oxygen released into the atmosphere with no negative impact to the environment.
Pink hydrogen	The production process is the same as green hydrogen through electrolysis as mentioned above, but it uses nuclear energy as its power source.
Yellow hydrogen	This is also produced using electrolysis as discussed above; however, it is achieved only through solar power unlike green hydrogen, which can be produced using solar and wind power. It can thus be considered a subset of green hydrogen.

Source: DBS Bank

Type of hydrogen currently produced depends on access to resources. Blue hydrogen is produced in markets where there is adequate and cheap natural gas with plenty of space for carbon storage. This is the best choice for markets such as the Middle East, Russia, and US Gulf Coast. On the other hand, in markets where there is abundant and cheap renewable energy and where carbon pricing is high with little natural gas, green hydrogen would be better produced. Green hydrogen is best favoured in markets such as Australasia, Europe, and Latin America.

Hydrogen types - visualisation



Source: Environmental Defense Canada, DBS Bank

BENEFITS AND DRAWBACKS OF HYDROGEN FUEL

Advantages of using hydrogen fuel

No supply issues	Being a renewable energy source, there is adequate supply available. However, it needs separation, as it is always part of another compound, such as water or methane.
Environment friendly	Hydrogen is not harmful to the environment when burnt, as no destructive by-products are released to the atmosphere.
High energy density	Hydrogen's high energy density improves productivity, as hydrogen-powered equipment can operate for longer times.
No emissions	During operation, hydrogen does not produce any CO_2 emissions compared to combustion engines, which can even emit small amounts of poisonous carbon monoxide.
Enhances energy security	Countries dependent on fossil fuels can increasingly transition to renewables + hydrogen economy and secure better bargaining power in relation to fossil fuel suppliers.

Source: DBS Bank

Disadvantages of using hydrogen fuel

Expensive to produce	Hydrogen is very expensive, as it involves significant capital expenditure, whether it is produced through SMR or electrolysis. Hence, many countries do not commit to mass production. However, there is a lot of research being done to discover ways in which it can be produced economically.
Higher safety requirements	Hydrogen usage is dangerous, as it is highly flammable and is very risky if it is not handled appropriately. Also, hydrogen is odourless, which makes it difficult to identify possible leakages. Furthermore, it does not produce significant heat radiation, making it a lot less visible than flames from other fuels due to lack of soot.
Difficult to transport	As hydrogen is a much lighter gas than gasoline, it cannot be easily stored or transported. It can be stored in the form of gas in high-pressure tanks or as liquid in cryogenic temperatures. However, both methods would lead to a loss of energy.

Source: DBS Bank

GREEN HYDROGEN THROUGH ELECTROLYSIS CAN BE KEY TO NET ZERO TARGETS GLOBALLY

Hydrogen produced via electrolysis can result in zero greenhouse gas emissions, depending on the source of the electricity used. The source of the required electricity—including its cost and efficiency, as well as emissions resulting from electricity generation—must be considered when evaluating the benefits and economic viability of hydrogen production via electrolysis.

If renewable energy is used to split the water molecules and produce hydrogen, this will be emission-free. Hydrogen production via electrolysis is being pursued for renewable (wind, solar, hydro, geothermal) and nuclear energy options. These hydrogen production pathways result in virtually zero greenhouse gas and criteria pollutant emissions; however, the production cost needs to be decreased significantly to be competitive with more mature carbon-based pathways such as natural gas reforming.

Currently, most of the hydrogen produced is brown, but that is not the way forward. Hydrogen produced from steam reforming processes via hydrocarbons, even with carbon capture in place, is not emission-free, even though the costs of production are much lower. Using the national grid for providing the electricity required for electrolysis is not ideal either, because of the greenhouse gases released and the amount of fuel required due to the low efficiency of the electricity generation process.

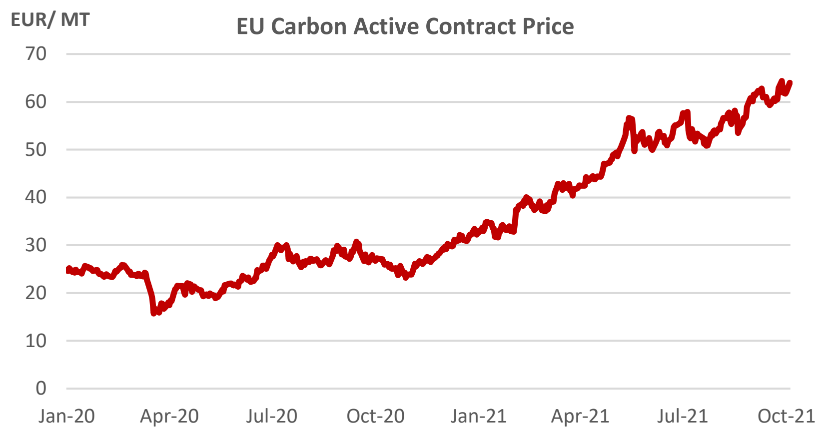
Electricity generation using renewable or nuclear energy technologies, either separate from the grid, or as a growing portion of the grid mix, is a possible option to overcome these limitations for hydrogen production via electrolysis. Since the current grid in most parts of the world is still majority dependent on fossil fuels, using this electricity to fuel the electrolysers will not result in emission free hydrogen fuel. Thus, to achieve green hydrogen, production can either be clubbed with off-grid renewables (including nuclear) or in certain extreme cases where the existing grid is already largely supplied by renewable energy sources, green hydrogen production can be achieved on grid.

Hydrogen production will be complementary and synergistic to renewable energy in future. Hydrogen production via electrolysis may offer opportunities for synergy with dynamic and intermittent power generation, which is characteristic of some renewable energy technologies. For example, although the cost of wind power has continued to drop, the inherent variability of wind is an impediment to the effective use of wind power. Hydrogen fuel and electric power generation could be integrated at a wind farm, allowing flexibility to shift production to best match resource availability with system operational needs and market factors. Also, in times of excess electricity production from wind farms, instead of curtailing the electricity as is commonly done, it is possible to use this excess electricity to produce hydrogen through electrolysis.

Meeting the clean hydrogen cost target of US$1/kg by 2030 (and interim target of US$2/kg by 2025) will be critical. Electrolysis is the leading hydrogen production pathway to achieve this, but this will mean reducing the cost by about 80% in a decade. This is a stiff target but given the experience the world has had with renewable energy sources, whose levelised cost of energy (LCOE) are less than conventional sources of energy much earlier than expected in 70% of the world, this is not an improbable target. The cost reduction strategies will involve reducing the capital costs of the electrolyser system over time, improving the energy efficiency for converting electricity to hydrogen over a wide range of operating conditions and lengthening the operational life of the electrolyser cell stacks, among others.

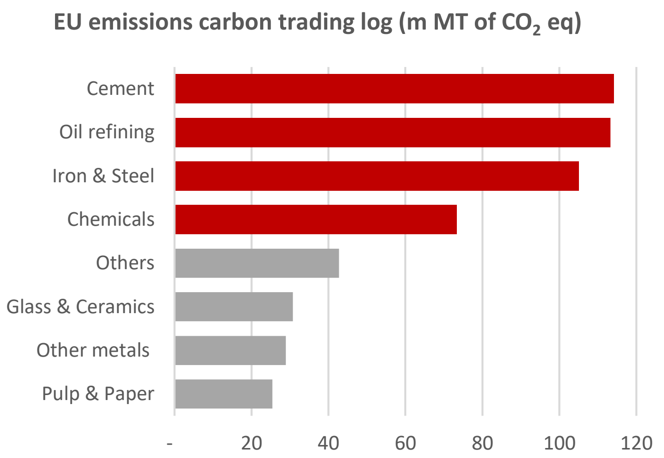
The high cost of carbon compliance, especially in Europe could see the adoption of hydrogen fuel by highly polluting industries sooner than later. Carbon compliance prices in Europe have shot up over the last year, from EUR24/MT at the start of 2021 to more than EUR63/MT currently, owing to the need to meet emission targets, in line with the EU's pledge to curb carbon emissions by 55% by 2030. In fact, the EU could look to tighten carbon emission norms even further, so the price of these mandatory carbon credits could see further upside. This will result in cost inflation for emission-intensive heavy industries like steel, power utilities, cement, oil refiners and airlines. To avoid this, we believe some of these industries will look to ramp up investments in wind, solar, green hydrogen and other clean technologies. The steel industry, in particular, will be keen to look at the option of introducing green hydrogen in the fuel mix, if green hydrogen prices fall to US$2/kg or lower.

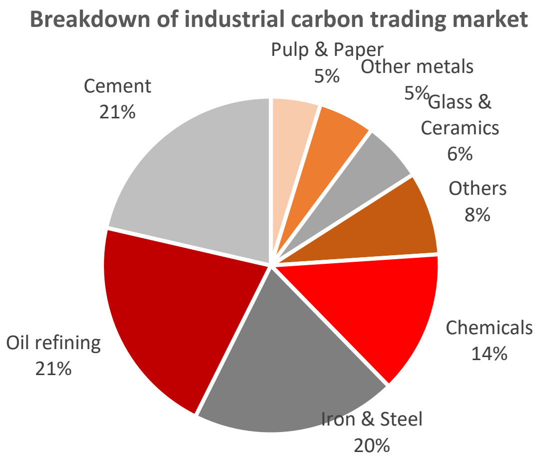
Carbon prices in Europe reaching record high levels as pressure to meet emission targets grows



Source: Bloomberg Finance L.P., DBS Bank

Cement, oil refining, steel and other industries will be keen to stem rising input costs as carbon prices grow





Source: Bloomberg Finance L.P., DBS Bank

APPLICATIONS OF HYDROGEN FUEL

Hydrogen fuel is used in a variety of verticals such as renewables industry, automakers, oil and gas companies, electricity and gas utilities, big cities, and major technology firms. The most common use case for hydrogen fuel will be in areas where it is difficult for renewable energy to reach directly; hence, the transport sector stands out, as green hydrogen can be delivered through fuel cells. Following are some examples of hydrogen fuel applications in future:

Potential applications of hydrogen fuel

Port and warehouse logistics	Companies with large warehouses and distribution are looking into clean trucks and forklifts powered by hydrogen fuel cells.
Long-range logistics	Since fuel cells have the range and power to fuel up long-haul trucking and local distribution. As discussed later in this report, major companies like Toyota and Hyundai are already building hydrogen powered semi-trucks and vans.
Buses	Many cities are already experimenting use of hydrogen-powered buses for public transportation.
Trains	Germany has already introduced a hydrogen-based train (Coradia iLint), and, in the next few years, we can expect to see more in other major countries.
Personal mobility	Hydrogen fuel cell electric vehicles (FCEV) will be a key application of hydrogen fuel in future. Toyota, Hyundai, and Honda including other major automakers have already introduced fuel cell vehicles and are continuously working on strategies to improve these.
Aviation	Some experimental projects like Pathfinder and Helios prototypes have explored application of hydrogen fuels in aerospace. Given the longer range of hydrogen, it presents a more feasible option for long distance aviation than normal battery fuelled engines.
Shipping	Hydrogen is the leading low-carbon fuel alternative being studied for the global maritime industry, which accounts for roughly 1/4th of all emissions from the global transportation sector. Fuel cell technology can be retrofitted in most ships. Hydrogen-powered ferries and smaller shipping vessels have been piloted in the United States, Belgium, France, and Norway. Maersk, MSC, and CMA-CGM are currently investing in carbon-neutral shipping technology development.
Backup power generation	Hydrogen becomes a useful application for Uninterruptible Power Supply (UPS) systems as especially hospitals and data centres are looking into hydrogen to meet this purpose. In 2020, Microsoft tested hydrogen fuel cells as a backup power source at one of its US data centres, which powered part of the facility for nearly two days.
Decarbonising industrial emissions	As companies in highly polluting industries like cement, steel, oil refining and others look to decarbonise operations to meet emissions reduction/net zero goals - whether voluntarily or mandatorily – use of hydrogen as part of the fuel consumption instead of fossil fuels will help reduce Scope 2 emissions.
Gas grid blending	Potential for 20% hydrogen blending into natural gas networks for building heating and for natural gas-fired power plants to produce electricity.

Source: DBS Bank

BREAKOUT 1: WHAT IS A FUEL CELL?

A fuel cell uses the chemical energy of hydrogen or other fuels to cleanly and efficiently produce electricity. If hydrogen is the fuel, the only products are electricity, water, and heat. Fuel cells are unique in terms of the variety of their potential applications; they can use a wide range of fuels and feedstocks and can provide power for systems as large as a utility power station and as small as a laptop.

Fuel cells can be used in a wide range of applications
- Power for transportation
- Power for industrial/commercial/residential buildings
- Long-term energy storage for the grid in reversible systems

Advantages of fuel cells
- Fuel cells can operate at higher efficiencies than combustion engines and can convert the chemical energy in the fuel directly to electrical energy with efficiencies capable of exceeding 60%
- Fuel cells have lower or zero emissions compared to combustion engines
- Hydrogen fuel cells emit only water, addressing critical climate challenges, as there are no carbon dioxide emissions
- There also are no air pollutants that create smog and cause health problems at the point of operation
- Fuel cells are quiet during operation, as they have few moving parts

How do fuel cells work?

A fuel cell consists of two electrodes—a negative electrode (or anode) and a positive electrode (or cathode)—sandwiched around an electrolyte. A fuel, such as hydrogen, is fed to the anode, and air is fed to the cathode. In a hydrogen fuel cell, a catalyst at the anode separates hydrogen molecules into protons and electrons, which take different paths to the cathode. The electrons go through an external circuit, creating a flow of electricity. The protons migrate through the electrolyte to the cathode, where they unite with oxygen and the electrons to produce water and heat.

Difference between fuel cells and batteries
- Fuel cells work like batteries, but they do not run down or need recharging
- They produce electricity and heat as long as fuel is supplied

Parts of a fuel cell

Polymer electrolyte membrane (PEM) fuel cells are the current focus of research for fuel cell vehicle applications. PEM fuel cells are made from several layers of different materials. The main parts of a PEM fuel cell include the membrane electrode assembly and supporting hardware.

The heart of a PEM fuel cell is the membrane electrode assembly (MEA), which includes the membrane, the catalyst layers, and gas diffusion layers (GDLs). The hardware includes gaskets and bipolar plates. More details in table below.

Components of a fuel cell/ fuel cell stack

Membrane Electrode Assembly (MEA)	
Polymer Electrolyte Membrane or Proton Exchange Membrane (PEM)	This is made from specially treated material and looks something like an ordinary kitchen plastic wrap and conducts only positively charged ions and blocks the electrons. The PEM is the key to the fuel cell technology; it must permit only the necessary ions to pass between the anode and cathode. Other substances passing through the electrolyte would disrupt the chemical reaction. For transportation applications, the membrane is very thin—in some cases, under 20 microns.
Catalyst Layers	A layer of catalyst is added on both sides of the membrane—the anode layer on one side and the cathode layer on the other. Conventional catalyst layers include nanometre-sized particles of platinum dispersed on a high-surface-area carbon support. On the anode side, the platinum catalyst enables hydrogen molecules to be split into protons and electrons. On the cathode side, the platinum catalyst enables oxygen reduction by reacting with the protons generated by the anode, producing water.
Gas Diffusion Layers (GDLs)	The GDLs sit outside the catalyst layers and facilitate transport of reactants into the catalyst layer, as well as removal of product water. Gases diffuse rapidly through the pores in the GDL.
Hardware	
Bipolar Plates	Each individual MEA produces less than 1 V under typical operating conditions, but most applications require higher voltages. Therefore, multiple MEAs are usually connected in series by stacking them on top of each other to provide a usable output voltage. Each cell in the stack is sandwiched between two bipolar plates to separate it from neighbouring cells. These plates, which may be made of metal, carbon, or composites, provide electrical conduction between cells, as well as providing physical strength to the stack.
Gaskets	Each MEA in a fuel cell stack is sandwiched between two bipolar plates, but gaskets must be added around the edges of the MEA to make a gas-tight seal. These gaskets are usually made of a rubbery polymer.

Source: Office of Energy Efficiency & Renewable Energy, United States of America (energy.gov)

Types of fuel cells

Type	Features	Applications
Polymer Electrolyte Membrane (PEM) Fuel Cells	- Use a solid polymer as an electrolyte and porous carbon electrodes containing a platinum or platinum alloy catalyst - Typically fuelled with pure hydrogen supplied from storage tanks or reformers - Operate at relatively low temperatures, around 80°C, which allows them to start quickly and results in better durability - However, it requires that a noble-metal catalyst (typically platinum) be used to separate the hydrogen's electrons and protons, adding to system costs - The platinum catalyst is also extremely sensitive to carbon monoxide poisoning, making it necessary to employ an additional reactor to reduce carbon monoxide in the fuel gas if the hydrogen is derived from a hydrocarbon fuel. This reactor also adds costs	Suitable for use in vehicle applications, such as cars, buses, and heavy-duty trucks
Direct Methanol Fuel Cells (DMFCs)	- Powered by pure methanol, which is usually mixed with water and fed directly to the fuel cell anode, instead of reforming methanol and feeding hydrogen - Direct methanol fuel cells do not have many of the fuel storage problems typical of some fuel cell systems because methanol has a higher energy density than hydrogen - Ethanol is also easier to transport and supply to the public using our current infrastructure because it is a liquid like gasoline	DMFCs are often used to provide power for portable fuel cell applications such as cell phones or laptops
Alkaline Fuel Cells (AFCs) and Alkaline Membrane Fuel Cells (AMFCs)	- AFCs use a solution of potassium hydroxide in water as the electrolyte and can use a variety of non-precious metals as a catalyst at the anode and cathode - These fuel cells are closely related to conventional PEM fuel cells, except that they use an alkaline membrane instead of an acid membrane - The high performance of AFCs is due to the rate at which electro-chemical reactions take place in the cell. They have also demonstrated efficiencies above 60% in space applications - A key challenge for this fuel cell type is that it is susceptible to poisoning by carbon dioxide due to carbonate formation with even very small amount of CO_2 in the air, dramatically affecting performance and durability - Alkaline membrane fuel cells (AMFCs) have lower susceptibility to CO_2 poisoning than liquid-electrolyte AFCs do, but performance and durability of the AMFCs still lag that of PEMFCs	AFCs were the first type widely used in the US space programme to produce electrical energy and water on-board spacecraft AMFCs are being considered for applications in the W to kW scale

Source: Office of Energy Efficiency & Renewable Energy, United States of America (energy.gov)

Types of fuel cells (continued)

Type	Features	Applications
Phosphoric Acid Fuel Cells (PAFCs)	- Use liquid phosphoric acid as an electrolyte and porous carbon electrodes containing a platinum catalyst - Considered the "first generation" of modern fuel cells. It is one of the most mature cell types and the first to be used commercially - PAFCs are more tolerant of impurities in fossil fuels that have been reformed into hydrogen than PEM cells - PAFCs are more than 85% efficient when used for the co-generation of electricity and heat but they are less efficient at generating electricity alone (37-42%), only slightly more than that of combustion-based power plants (33%) - PAFCs are also less powerful than other fuel cells, given the same weight and volume. As a result, these fuel cells are typically large and heavy - PAFCs are also expensive. They require much higher loadings of expensive platinum catalyst than other types of fuel cells do, which raises the cost	Typically used for stationary power generation, but some PAFCs have been used to power large vehicles such as city buses
Molten carbonate fuel cells (MCFCs)	- High-temperature fuel cells that use an electrolyte composed of a molten carbonate salt mixture suspended in a porous, chemically inert ceramic lithium aluminium oxide matrix - Because they operate at high temperatures of 650°C, non-precious metals can be used as catalysts at the anode and cathode, reducing costs - Molten carbonate fuel cells, when coupled with a turbine, can reach efficiencies approaching 65%. When the waste heat is captured and used, overall fuel efficiencies can be over 85% - Unlike alkaline, phosphoric acid, and PEM fuel cells, MCFCs do not require an external reformer to convert fuels such as natural gas and biogas to hydrogen. At the high temperatures at which MCFCs operate, methane and other light hydrocarbons in these fuels are converted to hydrogen within the fuel cell itself by a process called internal reforming, which also reduces cost - The primary disadvantage of current MCFC technology is durability. The high temperatures at which these cells operate and the corrosive electrolyte used accelerate component breakdown and corrosion, decreasing cell life - Scientists are currently exploring corrosion-resistant materials for components as well as fuel cell designs that double cell life from the current 40,000 hours (c.5 years) without decreasing performance	Currently being developed for natural gas and coal-based power plants for electrical utility, industrial, and military applications

Source: Office of Energy Efficiency & Renewable Energy, United States of America (energy.gov)

Types of fuel cells (continued)

Type	Features	Applications
Solid oxide fuel cells (SOFCs)	- Solid oxide fuel cells (SOFCs) use a hard, non-porous ceramic compound as the electrolyte - SOFCs are around 60% efficient at converting fuel to electricity. In applications designed to capture and utilise the system's waste heat (co-generation), overall fuel use efficiencies could top 85% - Operate at very high temperatures—as high as 1,000°C (1,830°F). High-temperature operation removes the need for precious-metal catalyst, thereby reducing costs - Also allows SOFCs to reform fuels internally, which enables the use of a variety of fuels and reduces the cost associated with adding a reformer to the system - It is the most sulfur-resistant fuel cell type; they can tolerate several orders of magnitude more sulfur than other cell types can - They are not poisoned by carbon monoxide, which can even be used as fuel. This property allows SOFCs to use natural gas, biogas, and gases made from coal - High-temperature operation has disadvantages. It results in a slow start-up and requires significant thermal shielding to retain heat and protect personnel, which may be acceptable for utility applications but not for transportation - The high operating temperatures also place stringent durability requirements on materials. The development of low-cost materials with high durability at cell operating temperatures is the key technical challenge facing this technology	Utility applications
Reversible fuel cells	- Produce electricity from hydrogen and oxygen and generate heat and water as byproducts, just like other fuel cells - However, reversible fuel cell systems can also use electricity from solar power, wind power, or other sources to split water into oxygen and hydrogen fuel through a process called electrolysis - Reversible fuel cells can provide power when needed, but during times of high-power production from other technologies (such as when high winds lead to an excess of available wind power), reversible fuel cells can store the excess energy in the form of hydrogen	Energy storage for intermittent renewable energy technologies.

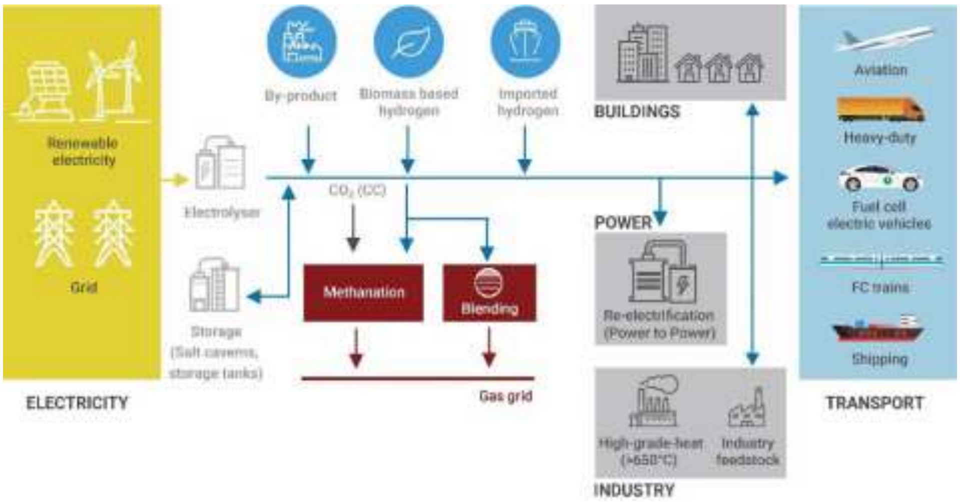
Source: Office of Energy Efficiency & Renewable Energy, United States of America (energy.gov)

Comparison of fuel cell types

Type	Electrolyte	Operating Temperature	Efficiency	Advantages	Challenges	Stack Size	Applications
PEM	Perfluorosulfonic acid	<120°C	60% with direct hydrogen; 40% with reformed fuel	Lower corrosion Low temperature Quick start-up	Expensive catalysts Sensitive to fuel impurities	<1 kW–100 kW	Backup power, Portable power, Distributed generation Transportation, Specialty vehicles
AFC	Aqueous potassium hydroxide soaked in a porous matrix or alkaline polymer membrane	<100°C	60%	Lower cost components Low temperature Quick start-up	Sensitive to CO_2 in fuel and air Electrolyte management and conductivity (polymer)	1–100 kW	Military Space Backup power Transportation
PAFC	Phosphoric acid soaked in a porous matrix or imbibed in a polymer membrane	150°–200°C	40%	Suitable for Combined Heat and Power Increased tolerance to fuel impurities	Expensive catalysts Long start-up time Sulfur sensitivity	5–400 kW, 100 kW module (liquid PAFC) <10 kW (polymer membrane)	Distributed generation
MCFC	Molten lithium, sodium, and/or potassium carbonates, soaked in a porous matrix	600°–700°C	50%	High efficiency Fuel flexibility Suitable for CHP and Hybrid/gas turbine cycle	Corrosion and breakdown of cell components Long start-up time Low power density	300 kW–3 MW, 300 kW module	Electric utility Distributed generation
SOFC	Yttria stabilised zirconia	500°–1,000°C	60%	High efficiency Fuel flexibility Solid electrolyte Suitable for CHP and Hybrid/gas turbine cycle	Corrosion and breakdown of cell components Long start-up time Limited number of shutdowns	1 kW–2 MW	Auxiliary power Electric utility Distributed generation

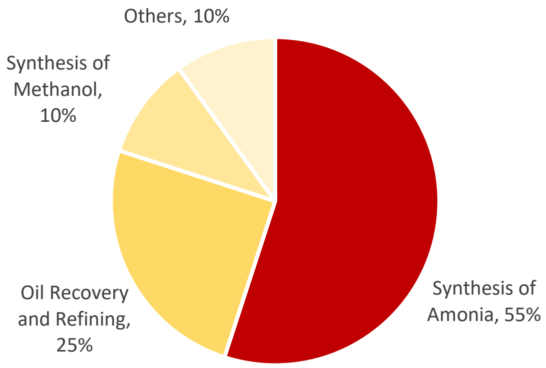
Source: Office of Energy Efficiency & Renewable Energy, United States of America (energy.gov)

Visualising the hydrogen value chain in future – from production to utilisation



Source: IRENA

Breakdown of current global consumption of hydrogen – as of 2020



Source: MDPI, DBS Bank

Fuel Cell applications recap

Nature of Application	Portable devices like laptops and computers	Buildings/ Back up Power	Transportation	Power Generation
Power requirements	<50W	1-10kW	8-200kW	>100kW
Fuel Cell Type Used	PEM DMFC	PEM SOFC	PEM SOFC	 SOFC MCFC PAFC

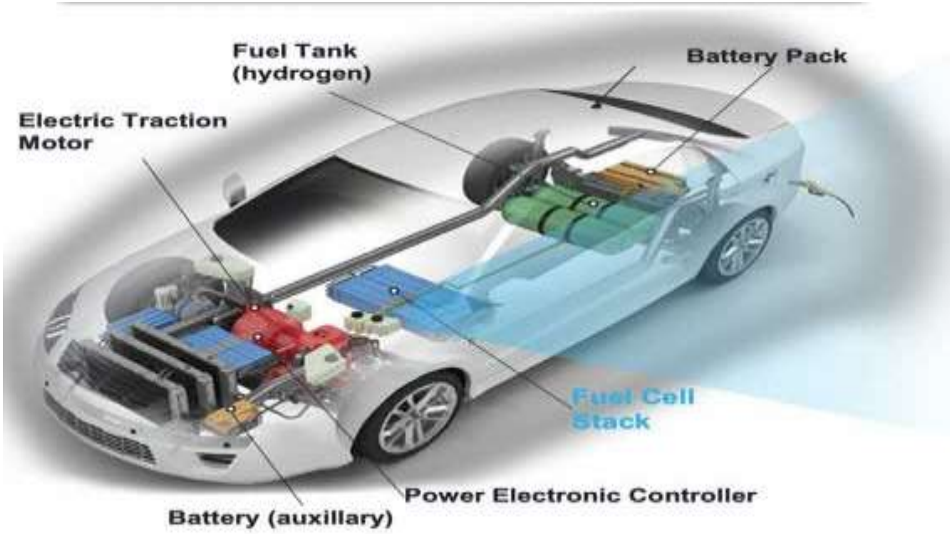
Source: DBS Bank

Who manufactures fuel cells?

Technology	PEMFC	AFC	DMFC	MCFC	SOFC	PAFC
Key Companies	Plug Power S-Fuelcell Hyundai Toyota SFC Energy	AFC Energy	SFC Energy Gaoncell	FuelCell Energy	Bloom Energy STX Heavy Kyocera Aisin	Doosan Fuel Cell

Source: DBS Bank

Fuel Cell Electric Vehicle (FCEV) is a key future application of hydrogen fuel delivered via fuel cells



Source: Nanofilm (Sydrogen) corporate presentation

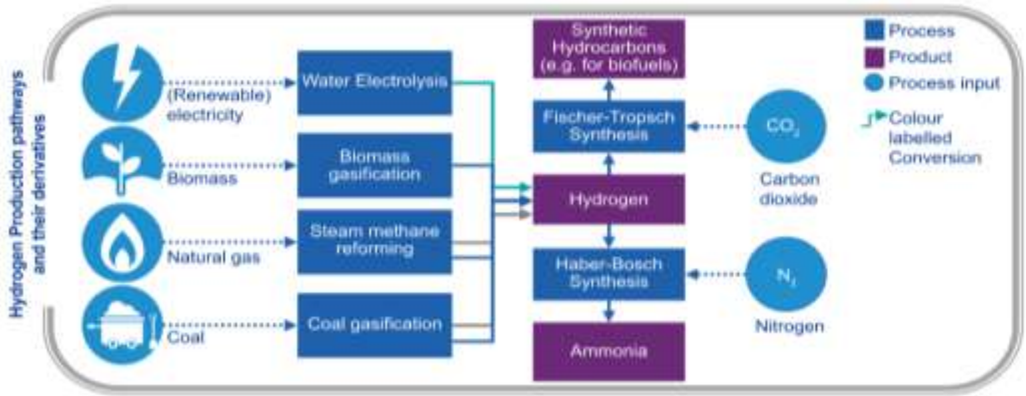
PRODUCTION PROCESS OF HYDROGEN

Current methods of producing hydrogen fuel

Natural Gas Reforming (Steam Methane Reforming) / Gasification	Natural gas reforming process involves creation of synthetic gas by reacting natural gas with high-temperature steam. It creates a mixture of hydrogen, carbon monoxide and some carbon dioxide. This is the most common form of hydrogen production currently, being the cheapest and most efficient. Gasification is a process where synthetic gas is created by reacting coal or biomass with high-temperature steam and oxygen in a pressurised gasifier. This synthetic gas contains hydrogen and carbon monoxide, which is reacted with steam to separate the hydrogen. Grey and brown hydrogen are created through this process.
Electrolysis	This is the process of splitting water into hydrogen and oxygen using electricity. An electrolyser is used for this process and it can be a small-sized appliance to a large-scale central production facility. Hydrogen produced through electrolysis is considered renewable, resulting in zero greenhouse gas emissions, if it is produced using renewable sources like solar and wind. Green hydrogen is produced through this process. This and the above processes are the most common methods of hydrogen production.
Renewable Liquid Reforming	Hydrogen is produced using renewable liquid fuels, such as ethanol, which are reacted with high temperature steam. This process is not commonly used.

Source: DBS Bank

Visualising current methods of producing hydrogen fuel – inputs, process and products



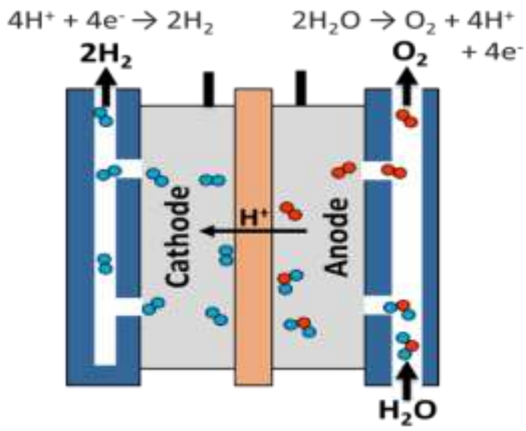
Source: KPMG Global

BREAKOUT 2: WHAT IS AN ELECTROLYSER?

Electrolysis is the process of using electricity to split water into hydrogen and oxygen. This reaction takes place in a unit called an electrolyser. Electrolysers can range in size from small, appliance-size equipment that is well-suited for small-scale distributed hydrogen production to large-scale, central production facilities that could be tied directly to renewable or other non-greenhouse-gas-emitting forms of electricity production.

How does it work? Like fuel cells, as we have seen before, electrolysers consist of an anode and a cathode separated by an electrolyte. Different electrolysers function in different ways, mainly due to the different type of electrolyte material involved and the ionic species it conducts.

Splitting water into oxygen and hydrogen



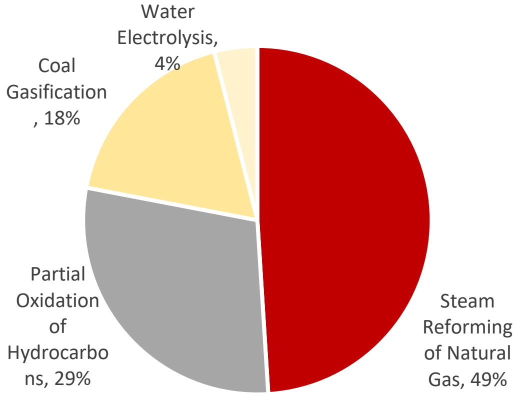
Source: energy.gov

Types of electrolysers

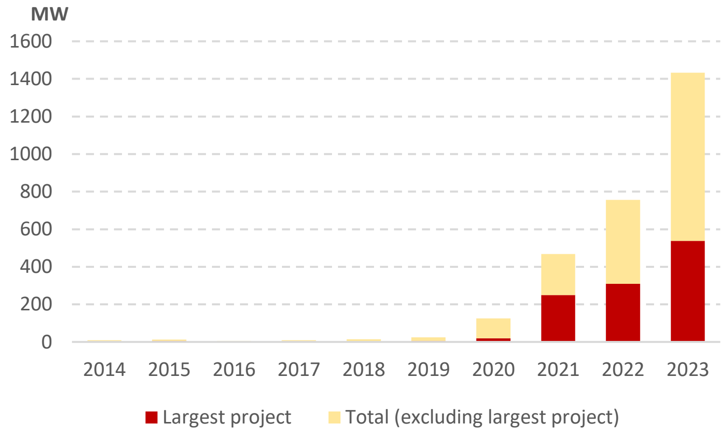
Polymer Electrolyte Membrane (PEM) Electrolyser	The electrolyte is a solid speciality plastic material. Water reacts at the anode to form oxygen and positively charged hydrogen ions (protons). The electrons flow through an external circuit and the hydrogen ions selectively move across the PEM to the cathode. At the cathode, hydrogen ions combine with electrons from the external circuit to form hydrogen gas.
Alkaline Electrolyser	Alkaline electrolysers operate via transport of hydroxide ions (OH-) through the electrolyte from the cathode to the anode with hydrogen being generated on the cathode side.
Solid Oxide Electrolysers	Slightly different method to above two. Uses solid ceramic material as the electrolyte. Solid oxide electrolysers must operate at temperatures high enough for the solid oxide membranes to function properly (about 700°–800°C, compared to PEM electrolysers, which operate at 70°–90°C, and commercial alkaline electrolysers, which typically operate at less than 100°C). This method can effectively use heat available at these elevated temperatures to decrease the amount of electrical energy needed to produce hydrogen from water.

Source: energy.gov

Breakdown of current methods of producing hydrogen fuel – only 4% is currently electrolysis based but more electrolysis capacity is becoming operational globally in next 3 years

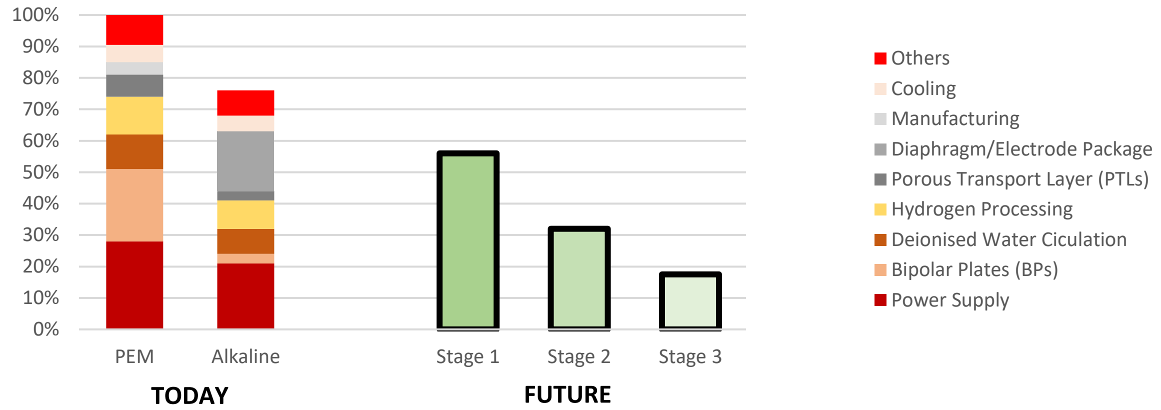


Source: MDPI, DBS Bank



Source: International Energy Agency, DBS Bank

Water electrolysis system cost breakdown today and expected potential cost reduction by stage in future



- Stage 1 assumptions – Expansion in market size, module size expansion to 30MW and economies of scale
- Stage 2 assumptions – Module size expansion between 20 to 100MW and 1GW-level system introduction
- Stage 3 assumptions – Module size at 100MW or bigger

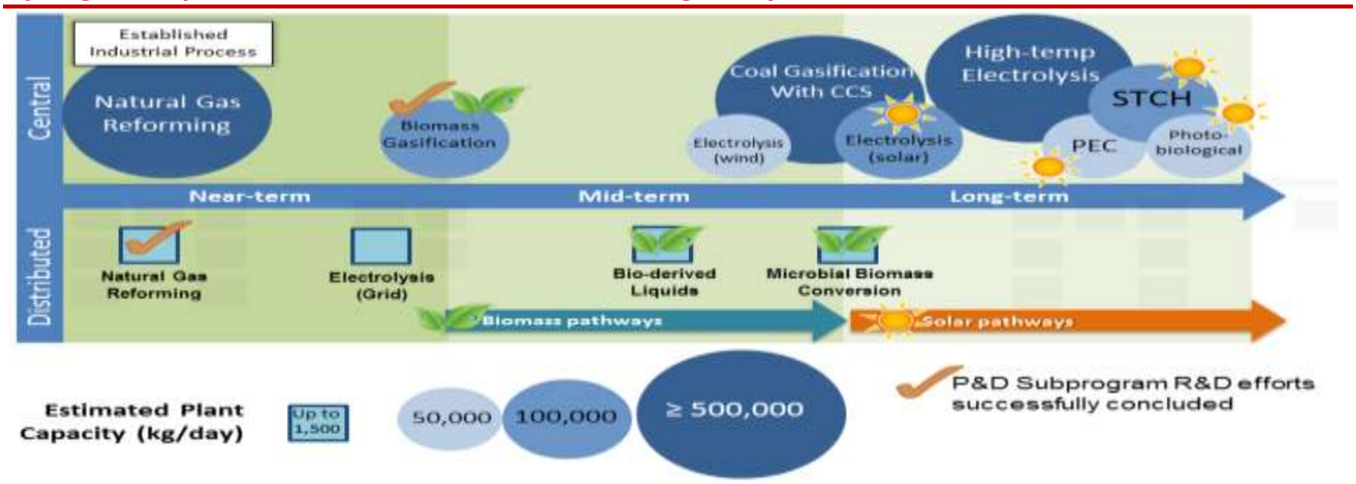
Source: IRENA, DBS Bank

Methods of producing hydrogen fuel under development

High-temperature water splitting	This process involves the use of heat (500-2,000 degrees Celsius) to drive a series of chemical reactions that produce hydrogen. When solar power or the waste heat of nuclear power is used for the heating process, this leads to near-zero greenhouse gas emissions when producing hydrogen.
Photobiological water splitting	This process uses microorganisms (green microalgae or cyanobacteria) and sunlight to convert water or organic matter into hydrogen. Despite this process being in the early phase of research, it is expected to bring about a sustainable hydrogen production method in the future.
Photoelectrochemical (PEC) water splitting	Another environment-friendly method of hydrogen production, where hydrogen is produced from water, using sunlight and specialised semiconductors (photoelectrochemical materials), where light energy is used to directly separate water molecules into hydrogen and oxygen. This method is considered sustainable and cost-effective, as it is a promising solar-to-hydrogen pathway for hydrogen production.

Source: DBS Bank

Hydrogen fuel production methods in near-term and long-term possibilities



Source: U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, DBS Bank

HYDROGEN TRANSPORTATION AND STORAGE

Delivery of hydrogen is a challenge because it is the lightest element. Mass of one gallon of gasoline is about c.2.57kg, whereas mass of one gallon of hydrogen is around 0.00075 kg. Large amounts of hydrogen can be delivered as compressed gas or liquefied.

Hydrogen used in fuel cells vehicles are dispensed the same as gasoline for conventional vehicles. On the other hand, hydrogen used in portable or stationary applications can be delivered by truck to a storage facility or in cylinders or cartridges just like battery.

The biggest challenges to hydrogen delivery are as follows:

- Reducing delivery cost
- Increasing energy efficiency
- Maintaining hydrogen purity
- Minimising leakage
- Building a national hydrogen delivery infrastructure

Recent developments in hydrogen transportation. In Europe, 12 European gas transmission system operators have revealed plans for a 39,700 km European Hydrogen Backbone (EHB) in April 2021, to be completed by 2040 in view of bringing upon a cost-effective, long-distance clean hydrogen transportation. Transportation using the EHB is expected to cost around EUR0.11 to EUR0.21 per kg of hydrogen, leading to a cost-effective form of hydrogen transportation.

View of a liquid hydrogen truck

Source: Liquid Hydrogen Truck, DBS Bank

Methods of transporting hydrogen fuel

Pipeline	Currently hydrogen is delivered from the point of production to point of use through pipelines on land, as it is the least expensive way to transport large volumes of hydrogen. These hydrogen pipelines are located near large petroleum refineries and chemical plants. Due to the distinct characteristics of hydrogen, manufacturing of new pipelines involves high capital costs and various challenges in terms of the materials and compressor design used.
High-Pressure Tube Trailers	Compressed hydrogen gas can be transported through truck, railcar, ship, or barge in high-pressure tube trailers but is an expensive way and used mainly for short distance transportation.
Liquified Hydrogen Tankers	Cryogenic liquefication is a process where hydrogen is cooled to a temperature that makes it a liquid, and it can be transported in liquid form. This method of transportation is efficient as hydrogen can be transported over long distances by truck, railcar, ship, or barge since it can hold a much larger mass compared to a gaseous tube trailer. However, this liquified hydrogen could evaporate from its containment vessels if it is not used at an adequately hight rate at the time of consumption.
Ammonia and Liquid Organic Hydrogen Carriers (LOHC)	Hydrogen can also be stored and transported in other forms for easier storage and transportation and converted back using carbon-free chemical reactions. More details in the following pages.

Source: DBS Bank

BREAKOUT 3 - HYDROGEN TRANSPORTATION VIA AMMONIA AND LOHC

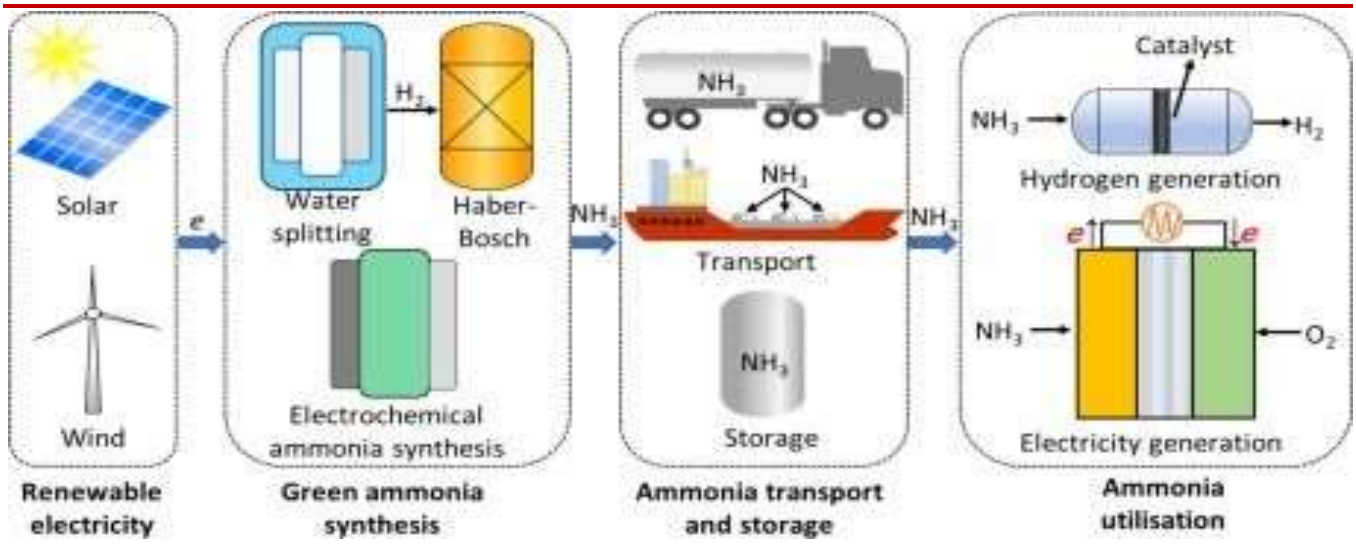
Ammonia is considered the most favourable choice of hydrogen transportation due to its high storage density. Ammonia is easier to liquefy, as it liquefies at -33°C and contains 1.7 times more hydrogen per cubic metre compared to liquified hydrogen. Green hydrogen can be converted into green ammonia and then stored and transported more easily than liquid hydrogen, and then reconverted back to hydrogen and nitrogen in a carbon-free process by using a suitable catalyst, as shown in the graphic below. Ammonia can be directly used as a fuel for ships or in power plants or can be reconverted into hydrogen at the site of use.

The International Energy Agency (IEA) has referred to ammonia as an inexpensive storage and transportation solution compared to liquefied hydrogen and liquefied organic hydrogen carriers (LOHC), when it comes to hydrogen delivery via pipelines or vessels. YARA International, a leading ammonia manufacturer in Europe, and Engie, a French energy company, are developing a green ammonia production process in Australia, a country abound with renewable energy sources.

Gas-based 'blue' ammonia with carbon capture may comprise most hydrogen transportation in the near term although as it has a much lower production cost compared to renewable ammonia or green ammonia. Green ammonia's high cost is mainly due to the high capital cost incurred in constructing an electrolyser plant for hydrogen production.

Liquefied organic hydrogen carriers are also being piloted. LOHC is an organic compound that can absorb and release hydrogen through a chemical reaction and is an alternative to liquid hydrogen and ammonia as a hydrogen carrier. Recently, SembCorp Industries of Singapore signed an MOU with Chiyoda Corporation and Mitsubishi Corporation of Japan to explore and implement a commercial-scale supply chain to deliver low-carbon hydrogen into Singapore, using Chiyoda's proven SPERA Hydrogen™ technology to release hydrogen from Methylcyclohexane (MCH), which is a type of liquid organic hydrogen carrier (LOHC). MCH is a liquid produced from toluene and hydrogen, which can be in a liquid state from -130°C to 100°C, therefore, can be handled as a liquid under ambient temperature and pressure.

Green ammonia value chain



Source: Science Direct, DBS Bank

CHALLENGES OF HYDROGEN FUEL STORAGE

Why hydrogen fuel infrastructure is difficult and needs to be developed over time

Weight & volume	Transportation of hydrogen fuel is cumbersome due to the weight and volume of hydrogen storage systems, as there is an inadequate vehicle range compared to conventional petroleum vehicles
Durability	Generally, the durability of hydrogen storage system is inadequate. Materials and components are needed to increase the lifetime of hydrogen storage systems.
Efficiency	One of the main challenges for hydrogen storage is energy efficiency, as the energy required to get hydrogen in and out is an issue for reversible solid-state materials. The key objective is to achieve materials and components that allow hydrogen storage systems with a lifetime of 1,500 cycles.
Refuelling time	Refuelling times for hydrogen storage systems take too long and there is a need to develop hydrogen storage systems with refuelling times of less than three minutes over the lifetime of the system.
Cost	Hydrogen storage systems are very costly compared to conventional storage systems for petroleum fuels. Low-cost materials and components are needed, together with low-cost, high-volume manufacturing methods.
High Flammability	Because of the presence of oxygen, hydrogen can quickly catch fire and can sometimes even lead to an explosion. Ignition energy required for hydrogen is only 1/10th to that of gasoline. Also, hydrogen lacks smell compared to gasoline, which leads to installation of sensors to detect leakages.
Low density	Hydrogen is less dense than gasoline; hence, it is compressed to a liquid state and stored at low temperatures. Because of this low density, hydrogen must be stored and transported under high pressure.

Source: DBS Bank

THE HIGH COST OF HYDROGEN AND HOW IT WILL DROP IN FUTURE

Green hydrogen is much more expensive than conventional hydrogen and fossil fuels. According to the European's Commission's July 2020 hydrogen strategy, green hydrogen costs the most at around US$4/kg to US$9/kg, compared to blue hydrogen at US$3.3/kg, and fossil-based grey hydrogen at around US$2.5/kg. Blue hydrogen production is cheaper than green hydrogen as long as there is availability of oil and gas deposits or salt caverns for Carbon Capture and Storage systems (CCS).

Compared to fossil fuels like natural gas, US$1.0/kg cost of hydrogen roughly corresponds to natural gas price of around US$7.5/mmbtu and oil price of US$45-50/bbl. Thus, to make green hydrogen production from renewables a viable alternative to conventional fuels, the cost of production of green hydrogen must drop by at least 50% to USD2.0-2.5/kg by 2030. Higher prices of carbon offsets for fossil fuels would also be required to make green hydrogen a serious alternative to fossil fuels.

Price comparison in different countries as at Aug 2020

USA	Conventional hydrogen in the US Gulf Coast costs around USD1.25/kg compared to USD2/kg in California. On the other hand, green hydrogen using PEM electrolysis would be around USD2.8/kg in Gulf Coast and USD4.0/kg in California.
Netherlands	Conventional hydrogen costs around USD1.7/kg, where blue hydrogen costs around USD1.9/kg and green hydrogen using PEM electrolysis around USD4.3/kg.
Japan	Conventional hydrogen costs around USD2.7/kg and green hydrogen using PEM electrolysis costs around USD5.3/kg.

Source: DBS Bank

Electricity price makes the biggest chunk of variable cost of electrolyser. The largest single cost component of producing green hydrogen is the cost of the renewable energy needed to power the electrolyser unit. Low cost of electricity is thus necessary to produce green hydrogen viably, but green hydrogen cost can thus never be less than renewable energy prices. Thus, hydrogen needs to be produced at optimal locations with easy access to renewable energy sources, while also solving the problem of curtailing and grid access for renewables.

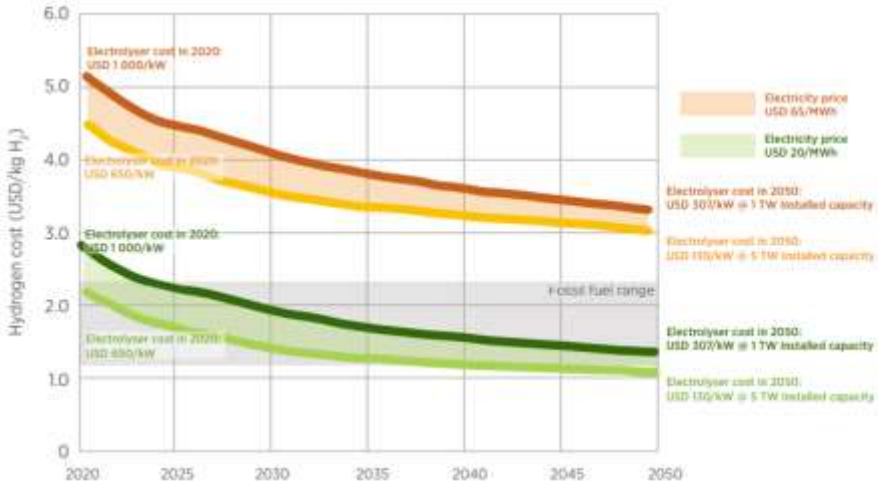
Lower cost of renewables will lower the cost of green hydrogen in the future. Cost declines for wind and solar resources could lead to large deployments in the electric power systems, with solar or wind production costs of USD20-30/MWh. The green hydrogen production cost is expected to decrease to US$2.0/kg with the access to low-cost renewable electricity.

Reduction in electrolyser costs is also necessary. Electrolysis is the second largest cost component of green hydrogen production, and reduction in investment costs for electrolysis plants will be the key to achieving lower hydrogen costs in future. Improvements in electrolyser design and construction and economies of scale will lead to lower electrolyser costs. Scale is important as companies can operate electrolysers at low capacity for high efficiency, but this increases capital cost, and very high capacity is needed to apportion capital costs.

The following three factors are expected to bring about material drop in the green hydrogen production cost in the near term:

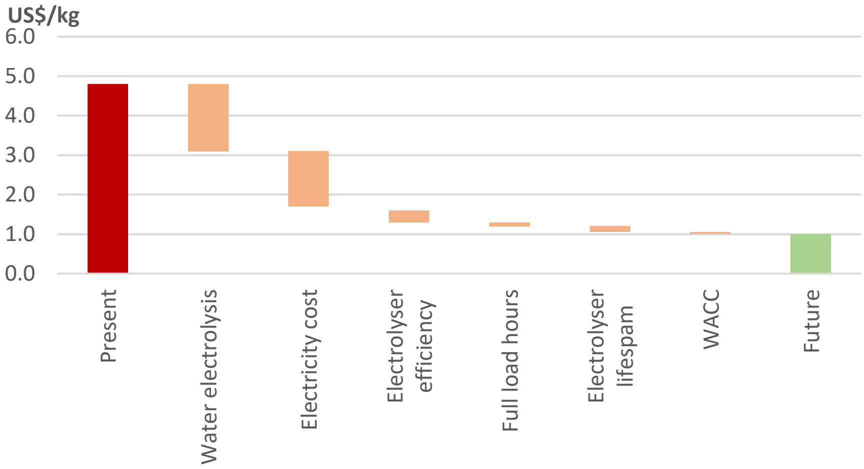
- Levelised cost of renewable power comprises 60% of green hydrogen costs, so a reduction of USD10/MWh will bring down the hydrogen cost by USD0.4-0.5/kg
- A reduction in electrolyser capital cost of USD250/kW is expected to reduce costs by another USD0.3-0.4/kg
- An increase in capacity utilisation to 50% from 40% is expected to reduce hydrogen costs by a further USD0.2-0.3/kg

Expected trend in green hydrogen production costs



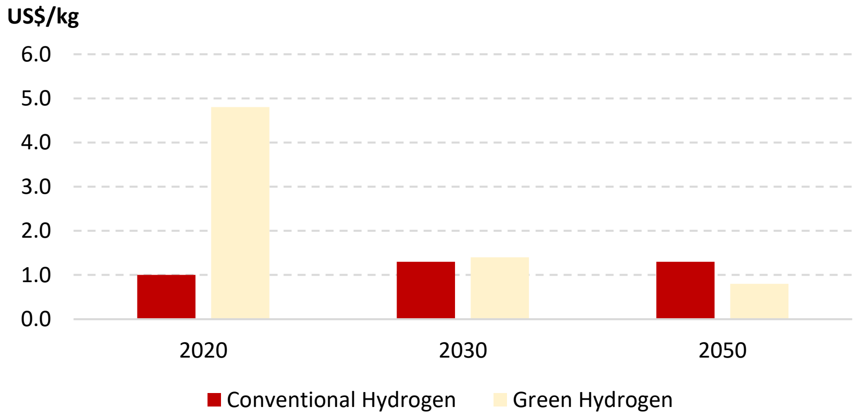
Source: IRENA

Factors that will enable decline in green hydrogen production cost in future



Source: International Renewable Energy Agency (IRENA), DBS Bank

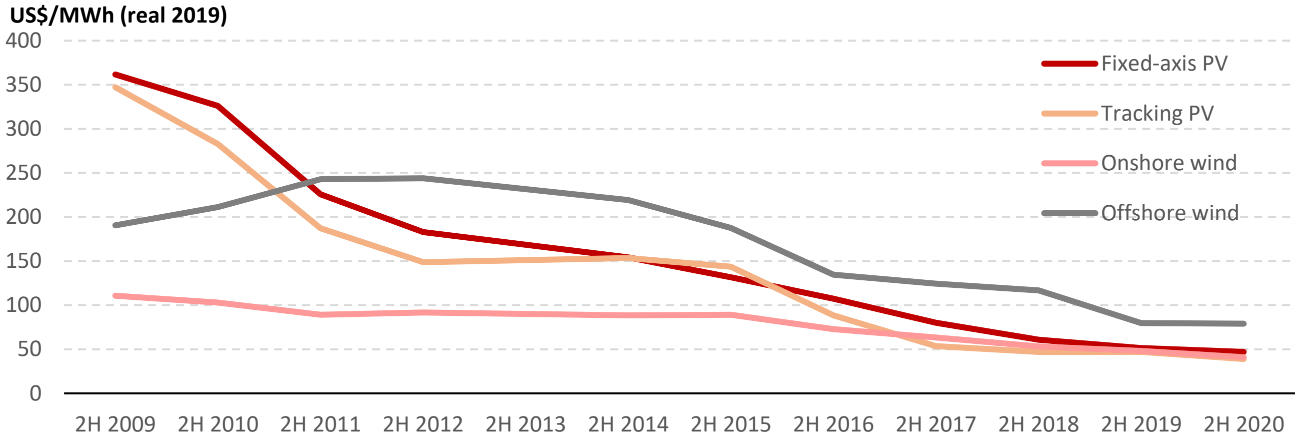
Expected convergence in costs of conventional vs. green hydrogen in future



Source: Bloomberg New Energy Finance, DBS Bank

Learnings from renewables leads to optimism. The LCOE of solar PV has fallen by close to 85% over the past decade, while that of onshore and offshore wind have fallen by over 60% during the same time. This implies learning rates of around 18% for solar and 9% for wind. According to IRENA, several studies have shown that learning rates for electrolysers and fuel cells could be similar to solar PV and reach values between 16-21%. Thus, electrolysers could have similar cost decreases as solar PV with large-scale deployment, and it is possible that electrolyser costs could decrease by 40-50% over the next decade, depending on capacity deployed.

LCOE trends of solar and wind over time



Source: Bloomberg New Energy Finance, DBS Bank

NATIONAL POLICIES ON HYDROGEN FUEL – GLOBAL VIEW

- **US$500BN WORTH OF PROJECTS PLANNED, LED BY EUROPE**
- **10 MILLION TONS P.A. OF LOW-CARBON HYDROGEN PRODUCTION BY 2030**
- **3.5-4.5 MILLION FCEVS ON THE ROAD BY 2030, LED BY ASIA**
- **10,000+ REFUELLING STATIONS BY 2030**

US$500bn worth of hydrogen projects planned globally to 2030. According to insights from the Hydrogen Council, a global CEO-led initiative promoting the use of hydrogen in the clean energy transition, a total of 359 projects have been committed to globally by July 2021. The total investment value of the projects and along the whole value chain is estimated to be around $500 billion through 2030.

Of the total investment, $150 billion, or 30%, can be considered "mature" – meaning that the investment is either in a planning stage, has passed a final investment decision, or already under construction, commissioned, or operational. If all the above investments come to fruition, total low-carbon hydrogen capacity will come to around 10mtpa by 2030, according to the Hydrogen Council, with around 70% of this green (renewables powered) and the remaining 30% blue in nature (fossil fuels generated with carbon capture in place).

This increase in activity comes on the heel of stricter carbon targets globally. 90 countries, representing 80% of the world's GDP, are now committed to net zero targets. Hydrogen is a crucial element in most strategies to achieve net zero standing, and more countries are developing hydrogen plans. In fact, over 30 countries have created such strategies on a national level, and 6 are drafting them. Countries with concrete hydrogen strategies have allocated US$76 billion of government funding. Europe remains the centre of hydrogen development, accounting for more than 50% of announced projects and estimated investments of US$130 billion. Europe has committed to plans of adding capacity of 6GW electrolysis by 2024 and 40GW electrolysis by 2030 for hydrogen production.

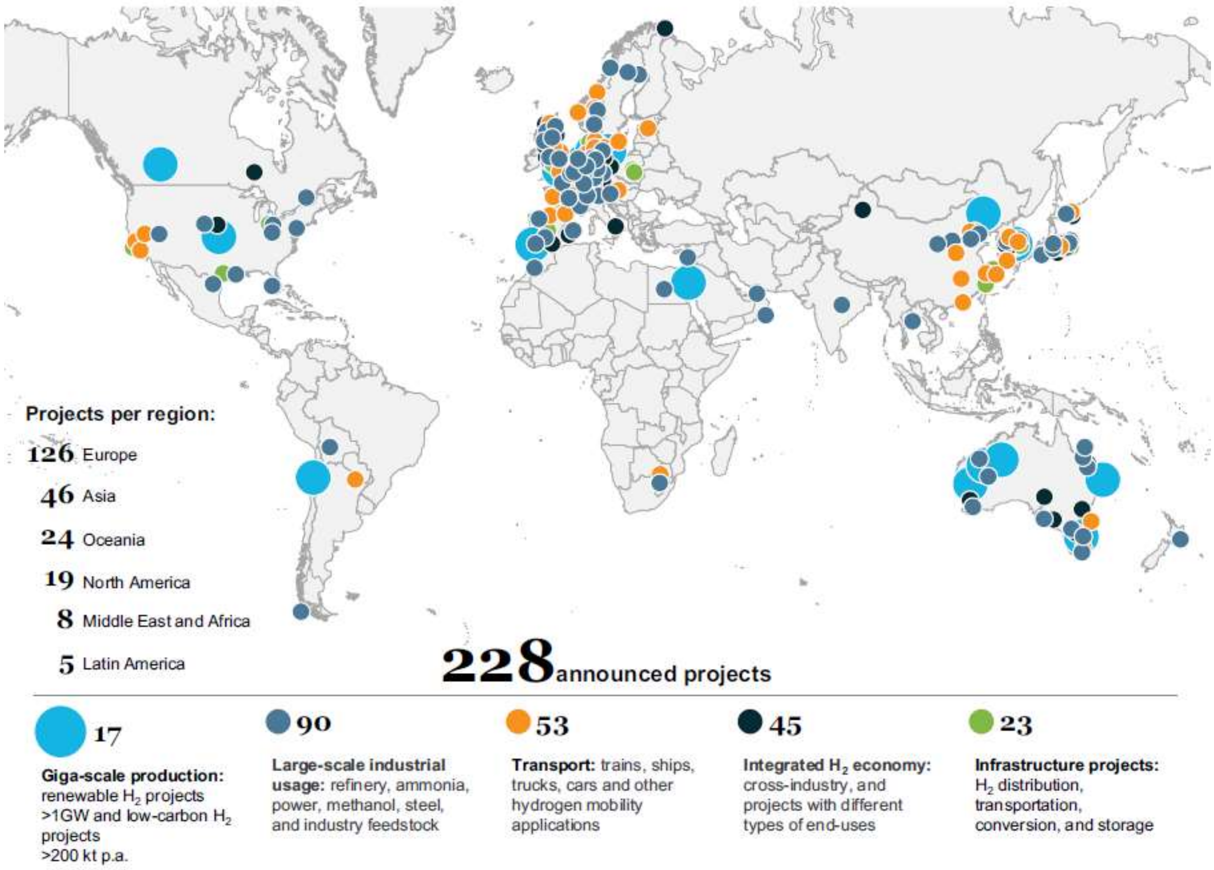
China could emerge as a hydrogen powerhouse in Asia. China is expecting hydrogen to comprise 10% of the energy share by 2050 to reach its ambitious climate targets: Net zero by 2060 and "peak carbon" in key sectors by 2030. 53 large-scale projects have been publicly announced in China, and investments worth US$17 billion can be considered mature. The Chinese government has made US$20 billion of public funding available to hydrogen projects. 50% of China's announced projects are linked to transport applications, key to its energy transition plan.

Snapshot of country level plans for hydrogen

Country	Targets
Americas	
USA	15 states mandating 30% of trucks to be ZEV by 2030
Chile	Targets 30GW electrolysis by 2030
Europe	
Portugal	Pledged investments worth Euro 7bn by 2030
Spain	Aims to install 4GW electrolysers by 2030
United Kingdom	Target to produce 5GW low-carbon hydrogen capacity by 2030
France	Pledged Euro 7bn investment and 6.5GW electrolyser capacity by 2030
Germany	Pledged Euro 9bn investment and 5.0GW electrolyser capacity by 2030
Holland	Targets 3-4GW electrolyser capacity by 2030
Denmark	Targets to install 5GW wind power to partially produce green Hydrogen
Asia-Pacific	
China	Targets 1mn FCEV by 2030
Japan	Targets 800k FCEV by 2030
South Korea	Targets 80k FCEV by 2022 and 1.8m FCEV by 2030
Australia	Working on national strategy

Source: DBS Bank

Planned hydrogen projects globally as of early 2021



Source: Hydrogen Council

Europe leads globally in the number of announced hydrogen projects, with Australia, Japan, Korea, China, and the USA following as additional hubs. In expected major demand centres like Korea, Japan, and Europe, the focus is on industrial usage and transport application projects. While Japan and Korea are strong in road transport applications, green ammonia, LH2, and LOHC projects, Europe champions multiple integrated hydrogen economy projects. These latter initiatives often feature close cross-industry and policy cooperation (e.g., the Hydrogen Valley in the Northern Netherlands).

NATIONAL POLICIES ON HYDROGEN FUEL – USA

The Department of Energy US announced a Hydrogen Program Plan in November 2020. The plan involves the advancement of affordable production, transport, storage, and use of hydrogen across different sectors of the economy.

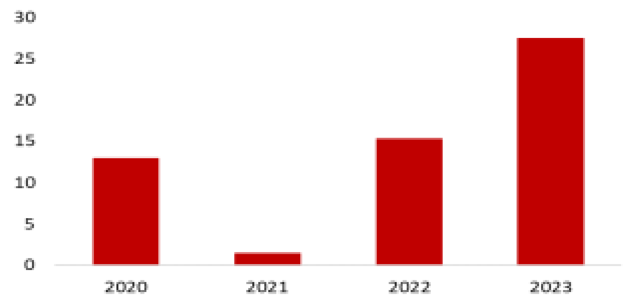
The main goals are to reduce production cost to US$ 2/kg and delivering for transportation applications to US$ 2/kg. A further goal is to achieve electrolyser costs of US$ 300/kW and the high temperature fuel system cost to US$ 900/kW. There are also plans to promote further education among the workforce on hydrogen technologies.

Current US President Joe Biden recently made an announcement of plans to reduce emissions to 52% by 2030 compared to its 2005 levels. He stressed on the importance of hydrogen as one of the main solutions to provide decarbonisation and clean power.

Hydrogen energy and fuel cell technologies are being commercialised in the US and abroad. US is a home to several hydrogen components and system manufacturers as well as large multinational hydrogen companies with liquid and compressed hydrogen production and distribution network.

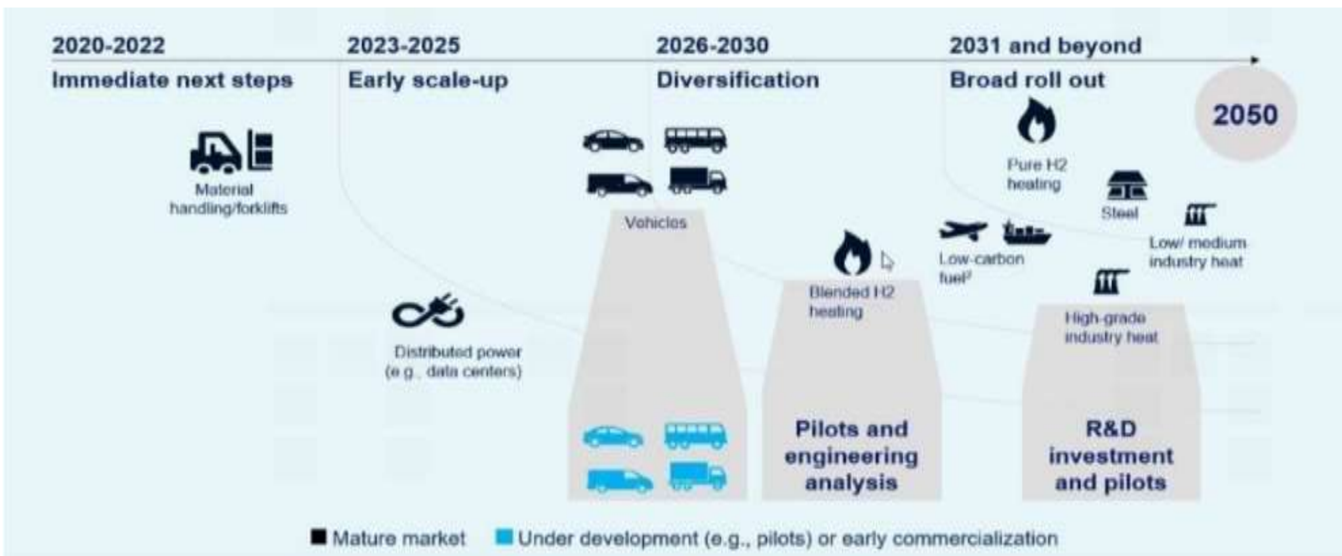
Hydrogen infrastructure will be based on each State or Region's own policies as per the US hydrogen economy road map. The West Coast, especially in California, is expected to accelerate plans on hydrogen as it has progressive policies on reducing transportation emissions. California, being the third-largest gas consumer in the US for industry, has set up plans to replace fossil fuels with green hydrogen, which are produced using electrolysis. In May 2021, the Green Hydrogen Coalition and the Los Angeles Department of Water and Power launched a collaboration to develop the USA's very first green hydrogen hub in the Los Angeles area.

Green hydrogen projects in the US



Source: S&P Global Platts Hydrogen Production Database, DBS Bank

Planned development of hydrogen economy in the US over next decade and beyond



Source: US Hydrogen Road Map

NATIONAL POLICIES ON HYDROGEN FUEL – EUROPE

The European commission launched the EU Hydrogen Strategy in July 2020 and it is split into three phases. According to phase one (2020-24), there are plans to install 6GW of renewable hydrogen electrolysers in the EU by 2024, compared to the current 1GW installed.

European step-wise development of hydrogen ecosystem

Source: EU Hydrogen Strategy

This will be followed by phase two (2024-30), which involves the installation of 40GW of renewable hydrogen electrolysers in the EU by 2030 and the production of up to 10m tonnes of renewable hydrogen in the EU.

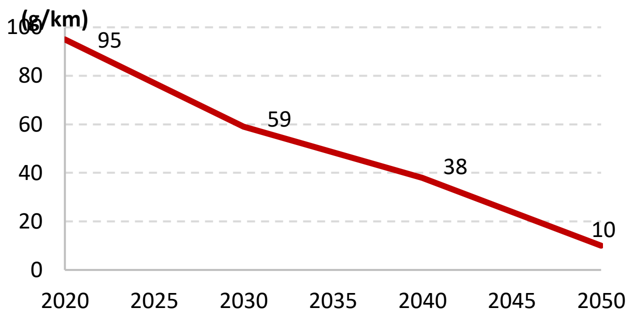
Phase three (from 2030 onwards and towards 2050): During this phase, a full reach of hydrogen among multiple sectors is expected with the maturity of renewable hydrogen technologies. During this phase, renewable electricity production is expected to drastically increase as a quarter of it is expected to be used for renewable hydrogen production by 2050.

The majority of electrolyser projects globally are planned in Europe currently. According to Aurora energy research, a total of 213.5GW of electrolyser projects are planned by companies globally, out of which 85% are projects in Europe. Excluding early-stage projects, there is a pipeline of over 9GW in Germany, 6GW in Netherlands, and 4GW in the UK, scheduled to be operational by 2030.

The EU-Hydrogen strategy is mainly focusing on green hydrogen, but it also looks at low-carbon ones such as blue hydrogen, focusing on an investment of EUR3-18bn for low-carbon hydrogen, compared with EUR180-470bn for green hydrogen.

North-West Europe has a well-developed hydrogen industry and is expected to play a key role in governments' aims to reduce greenhouse gas emissions. To accelerate the hydrogen market expansion, the carbon emission target set by the European Governments should align with the EU Green Deal or UK Climate Change Act.

Europe carbon emission targets for new passenger cars – hydrogen powered fuel cell cars could play a key role



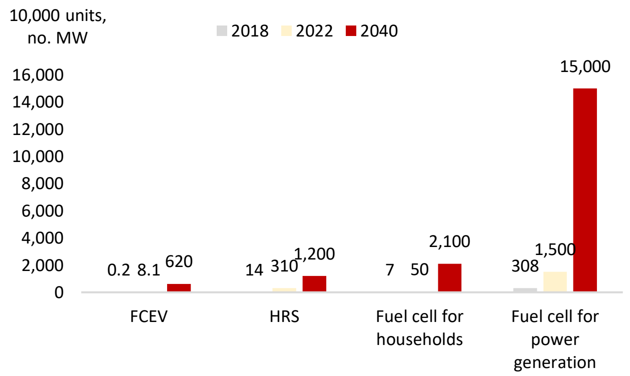
Source: EU, DBS Bank

By improving the policies, hydrogen demand is expected to develop by a third and low-carbon hydrogen could meet more than half of dedicated production. At present, the North-West Europe area generates 5% of global hydrogen demand and 60% of European demand.

NATIONAL POLICIES ON HYDROGEN FUEL – SOUTH KOREA

In Korea, the hydrogen economy roadmap was announced by the government in Jan 2019, which sets out its plan until 2040. Korea is focusing on Fuel Cell Electric Vehicles (FCEVs) and fuel cells, as the country has great strength and track record in the automobiles and heavy industries segments. In Jul 2020, the Hydrogen Economic Committee was set up to establish government policies related to the growth of the hydrogen economy. The committee consists of experts from various ministries such as Trade and Industry and Energy and the private sector.

Installation targets - Korea



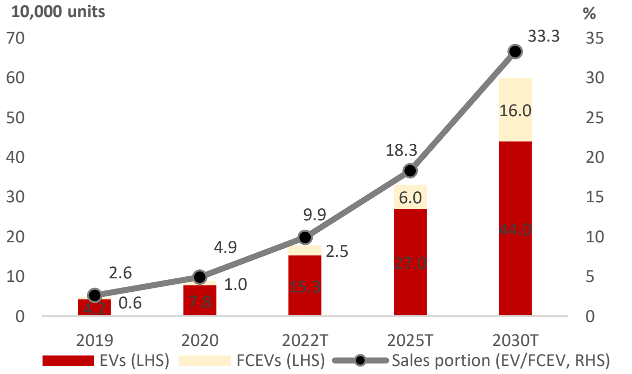
Source: Hydrogen Economy Roadmap, DBS Bank

Main goal involves the production of 5.9m fuel cell cars by 2040 with the installation of 1,200 hydrogen refuelling systems by that period. By 2030, the Korean government plans to expand the number of hydrogen cars to 850,000 and charging stations to 660. Furthermore, by providing subsidies, it plans to expand the scope of hydrogen vehicles into hydrogen-based large cargo trucks and long-distance buses.

The country also plans to increase the installed capacity of utility-scale to 15GW and homes and building fuel cell capacity to 2.1GW by 2040, which is expected to provide sufficient power to 940,000 households.

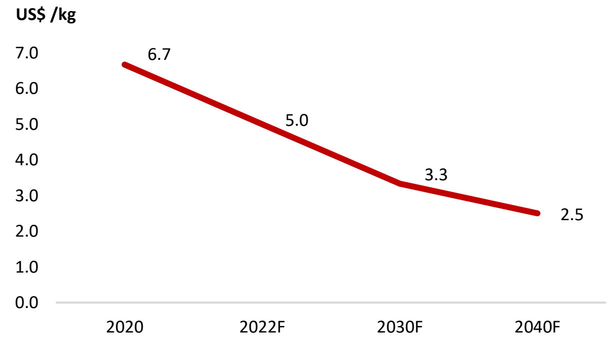
To improve the competitiveness of the hydrogen industry's ecosystem, the Korean government will foster 500 hydrogen-related companies by 2030 and 1,000 by 2040. Intensive support will be provided for companies involved in areas like hydrogen mobility, fuel cells, liquid hydrogen, hydrogen charging stations, and water electrolysis.

Annual EV and FCEV sales targets - Korea



Source: Ministry of Trade Industry and Energy Korea, DBS Bank

Hydrogen price target - Korea



Note: assumed USD-KRW x-rate of 1,200
Source: DBS Bank

The Korean government also plans to implement a bill of 'Hydrogen City Construction and Management' in 2021 for the regulation and financial support for hydrogen-powered city projects. **Currently there are three hydrogen model cities and one hydrogen R&D-oriented city in Korea.**

The Hydrogen Energy Portfolio Standard (HPS) is expected to be introduced in 2022, as, currently, fuel cell generation is in Renewable Portfolio Standard (RPS). The Korean government plans to exclude fuel cells from the RPS scheme to HPS scheme to improve the development of the fuel cell market. With the introduction of the HPS system, fuel cells are expected to stabilise. Furthermore, the hydrogen economic committee agreed to introduce systems for mandatory sales of green hydrogen and fuel cell installation for new large buildings.

SOUTH KOREA BOASTS OF AN ESTABLISHED HYDROGEN ECOSYSTEM ALREADY

Given Korea's commitment to the hydrogen industry, major business groups such as HMG, Hanwha, Hyosung, Doosan, POSCO, HHI, and KOGAS have launched their hydrogen strategies and plans. Major business groups in Korea are invested in the hydrogen economy not only from a business perspective, but as a means to reduce carbon emissions and achieve net zero targets by 2050. Based on investment plans, a total of KRW43tn has been estimated for the private sector's hydrogen investment, which includes KRW11tn for production of green/blue hydrogen, KRW8tn for liquefaction plant construction, storage and transportation infrastructure, KRW23tn for FCEVs, and KRW1tn for parts development.

Key strategies and business models of major business groups in Korea

Hyundai	• Presented its FCEV Vision 2030 plan and increased its electrification investment from KRW9.8tn to KRW10.8tn in its recent update of strategy 2025. • Hydrogen business investment is expanded from KRW0.6tn to KRW4.1tn • In early 2021, HMG signed a hydrogen business MOU with POSCO and SK Group. • Hyundai Mobis produces powertrain fuel-cell complete module and fuel processing system (components of FCEVs)
SK Group	• SK Group will invest KRW18.5tn for large-scale hydrogen liquefaction plant construction and the fuel cell business • SK E&C has established a joint venture with Bloom Energy in Korea to produce and distribute in the domestic market
Hanwha Group	• Hanwha Solutions is continuously developing alkaline electrolysis technology with a view to commercialisation by 2023 • Established electrolysis facilities and hydrogen refuelling stations in Kangwon-do in Dec 2020 • Hanwha Energy completed construction of 50MW hydrogen power plant in the Daesan Industrial Complex in Jul 2020 for KRW250bn • Has also established a joint venture with Doosan and Daesan Green Energy
Hyosung Group	• Hyosung Chemical has signed an MOU with Linde Korea, which is a company that develops technologies for hydrogen storage • Hyonsung Heavy Industries is engaged in Hydrogen Refuelling Stations (HRS) business for more than 10 years and is a leader in the domestic HRS market
Doosan Group	• Doosan Corp spun off Doosan Fuel Cell as a separate unit in Oct 2019 • Fuel Cell Power Business Unit produces Proton Exchange Membrane Fuel Cells (PEMFC) • Doosan Fuel Cell produces Phosphoric Acid Fuel Cell (PAFC) and also aims to secure Solid Oxide Fuel Cells (SOFC) with Ceres Power by 2023.
POSCO Group	• Announced plans in Dec 2020 to enter the hydrogen environment by setting up industrial gas/hydrogen business and low-carbon process research group. Currently, it has a capacity to produce 7,000 tons of hydrogen p.a. based on by-products and LNG (gray hydrogen) and aims to increase its overall production capacity to 5m tons by 2050 • POSCO International plans to enter green businesses such as FCEVs by establishing green materials business and mobility business

Source: Companies, DBS Bank

NATIONAL POLICIES ON HYDROGEN FUEL – JAPAN

The Japanese government announced its first policy roadmap in 2014 and then released the third strategic roadmap for hydrogen and fuel cells in March 2019. Japan is focusing on producing hydrogen at a lower cost using fossil fuels and utilising carbon capture storage technology (CCS), essentially blue hydrogen, rather than green hydrogen.

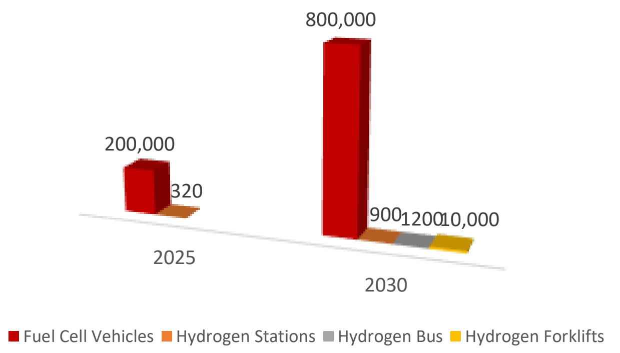
According to the roadmap, the Japanese government plans to procure around 300,000 tons of hydrogen annually and to reduce the cost of hydrogen to 30 yen/Nm3 per kg by 2030 to a further 20 yen/Nm3 in the later future. It has planned a budget of JPY 70bn for 2021, which includes funding for subsidies, hydrogen infrastructure and technologies.

Japan was the first country to adopt a 'Basic Hydrogen Strategy'. The Japanese hydrogen market is expected to grow to JPY 408.5 bn by 2030. The number of fuelling stations are expected to increase to 581 by 2025 from 111 in 2020.

Japan plans to establish and commercialise a liquified hydrogen supply chain by 2030 and plans to develop and commercialize an organic hydride supply chain after 2025.

To reduce the cost of hydrogen from renewable energy, Japan plans to commercialise the power-to-gas technology by 2032, which will enable the storage of renewable energy electricity. This technology is expected to reduce the cost of hydrogen to as low as that of imported hydrogen.

Japan's hydrogen fuel mobility plans



Source: Agency for Natural Resources and Energy, DBS Bank

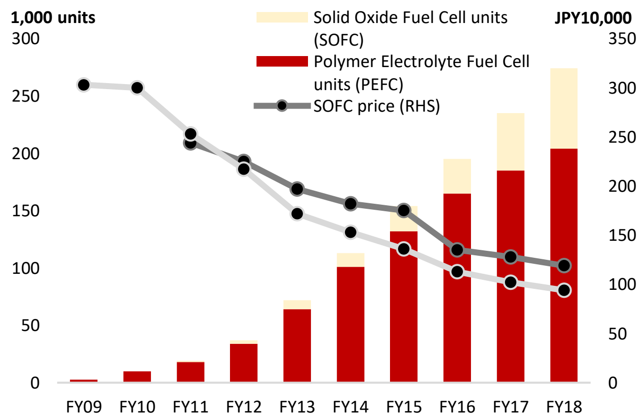
Toyota has been the leader for the creation of Fuel Cell Vehicles (FCEV), while companies like Panasonic and Kyocera are developing and distributing household fuel cells.

In Jan 2020, the Japan Bank for International Cooperation (JBIC) allocated more government funding for hydrogen projects to be undertaken in developed countries by designating hydrogen as an 'essential resource'.

Furthermore, the government also planned to showcase its hydrogen technology at the 2020 Olympic and Paralympic games by using fuel cell vehicles and buses. However, since the postponement to 2021, it is expecting to demonstrate a scaled down version of hydrogen. Furthermore, Japan is planning on showcasing its hydrogen technology at the Expo 2025 in Osaka.

The Japanese government ended the Ene-Farm program (a subsidy for household fuel cells) in 2020, as the fuel cell market has entered a commercially viable stage. Tokyo Gas is one of the most active participants in the Ene-Farm drive and faced positive feedback overall with its supply of 140,000 installed residential fuel cells. This programme is considered as having been successful in increasing fuel cell installation at households.

Japan's household fuel cells installation



Source: Agency for Natural Resources and Energy, DBS Bank

NATIONAL POLICIES ON HYDROGEN FUEL – CHINA

China's hydrogen industry has rapidly grown in the recent past with the government providing aggressive policy support measures. In 2019, the development of the hydrogen industry has been a major point to note in government reports at major political meetings. The following is a summary of China's hydrogen policies:

Timeline of China's hydrogen plans

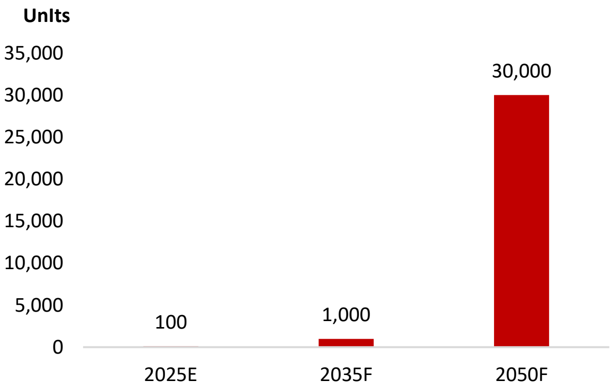
Date	Description
2016	Hydrogen was included in 15 key areas for action plan for energy/technology innovation
2020	White paper 'Energy in China's New Era' was disclosed and the need to establish guidance and policy measures for renewable energy sources, including hydrogen
2021	Inclusion of hydrogen as a major component of the 14th five-year plan (2021-2025) for National Economic and Social development and to announce the 'Ten cities, Thousand Vehicles' program for hydrogen vehicles as discussed below.

Source: DBS Bank

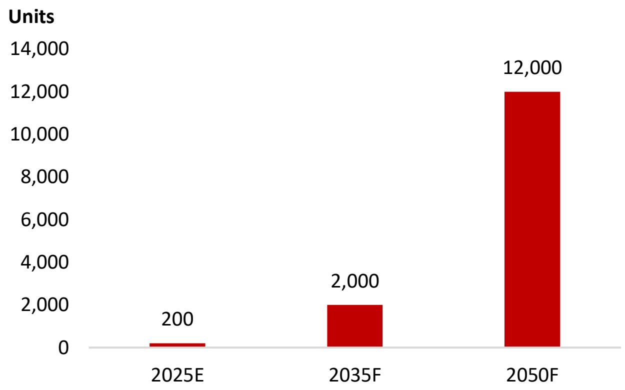
Currently, China is the largest hydrogen producer (one third of World's hydrogen production), producing more than 20 million tons of hydrogen annually, mostly through coal (brown hydrogen) and only around 3% from electrolysis. In March 2019, the government made plans to promote the construction of electric vehicle charging stations and hydrogen fuel cell refuelling stations. As at Jan 2020, China had 61 hydrogen refuelling stations.

Green hydrogen is the next frontier. China's White Paper 2020 focuses on the development of low-carbon, clean hydrogen supply to achieve the goal of carbon neutralisation. The Chinese government is to launch the 'Ten cities, Thousand vehicles' program where 10 cities will receive subsidies of up to RMB1.7bn to deploy 1000 hydrogen vehicles over the next five years. The Chinese government plans to light the torch with hydrogen and operate hydrogen-powered buses at the 2022 Beijing Winter Olympics to showcase the country's drive to lower carbon emissions.

China's hydrogen vehicle target



China's hydrogen refuelling stations target



Source: China's hydrogen energy and fuel cell industry, DBS Bank

NATIONAL POLICIES ON HYDROGEN FUEL – AUSTRALIA

Australia has abundant natural resources to produce clean hydrogen for its own use and to also supply globally. It is also considered the region's hydrogen export superpower. In December 2018, the Australian Government's Energy Council developed the National Hydrogen Strategy to set a vision for a safe and competitive hydrogen industry to benefit domestic and international players by 2030.

Some of the approaches of the National Hydrogen Strategy are as follows:

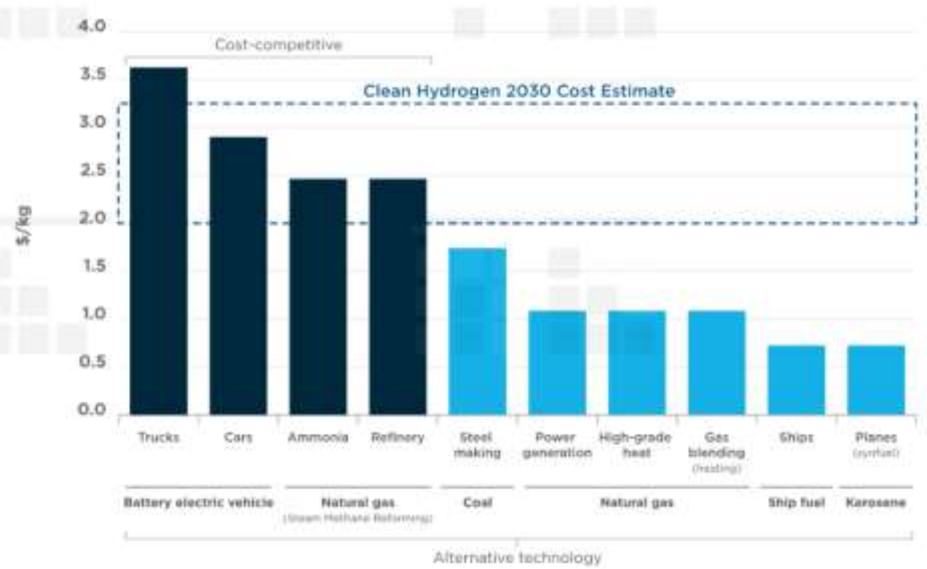
- **Partnering with international players to supply hydrogen by being a major hydrogen exporter.** According to Australian Renewable Energy Agency, the demand for hydrogen exported from Australia could be more than 3m tonnes each year by 2040, which could be worth more than AUD10 bn per annum by that time.
- **To create hydrogen hubs** to make the development on infrastructure more cost-effective, promote efficiencies from economies of scale and to enhance the use of hydrogen in transport, industry and to use hydrogen technologies into electricity systems. Planned budget of AUD275.5m towards hydrogen production for the development of four additional clean hydrogen hubs.
- **New job creation** and growth of clean hydrogen without compromising on safety.

Focus on producing cheap clean hydrogen. The Low Emissions Technology Statement in Australia focused on low emission technologies, mainly stressing on the use of hydrogen to reduce emission and produce cheap clean hydrogen (Under AUD2 per kg), which becomes competitive in applications such as producing ammonia, as a transport fuel, and for firming electricity. Given the drop in costs, clean hydrogen becomes more competitive and as shown below, the competitiveness in Australia is positive within the decade, especially for sectors such as transport and industrial.

Australia has also formed promising hydrogen partnerships with key countries such as Japan, Korea, Germany, and Singapore. Some major notable investments are the new hydrogen initiatives with Germany, increased efficiency of maritime operations with Singapore, exporting of clean liquefied hydrogen (Hydrogen Energy Supply Chain project) with Japan, etc.

Progress on creating infrastructure. In Feb 2021, the Australian government coordinated a National Hydrogen Infrastructure Assessment to observe the supply chain needs and to progress on upgrades or new infrastructure electricity and gas networks, water supply networks, refuelling stations, roads, and rail and ports.

Target breakeven cost of hydrogen against alternative technology - Australia



Source: Australia National Hydrogen Strategy, DBS Bank

NATIONAL POLICIES ON HYDROGEN FUEL – INDIA

In Nov 2019, the prime minister of India announced India's National Hydrogen Energy Mission (NHM), which focused on producing hydrogen from green power sources. India plans to produce 80% of its total hydrogen production in green hydrogen through renewable electricity and electrolysis by 2050. Appropriate capacity addition to renewable power generation and storage and transmission can make the production of green hydrogen in India cost-effective.

Given India's natural edge in green hydrogen production due to favourable geographic conditions and presence of abundant natural resources, the Indian government plans to expand gas pipeline infrastructure across the nation and has also introduced smart grids.

Enough renewable energy resources for green hydrogen. By 2030, the cost of producing green hydrogen is expected to drop by more than 50% to compete against costly hydrogen produced using fossil fuels. Furthermore, the Indian government targets 450GW of renewable capacity in 2030. The government is considering making it mandatory for industries like fertilisers and refineries which are currently using gray hydrogen to introduce green hydrogen into their fuel mix to cut down on emissions.

Indian state-owned refinery players plan to use hydrogen to make operations cleaner. In June 2021, Indian Oil Corporation announced its plan to build the country's first green hydrogen plant at its refinery in Mathura. This will enable the country's largest fuel retailer to use electricity generated from clean energy sources to produce green hydrogen and use it to replace part of the fossil fuels used to provide power in the refining process.

Private investments interest ramping up. India has recently seen collaboration deals with some international players aiming to set up production facilities in India, for example, the recent collaboration of Fusion Fuel Green with BGR Energy Systems with an agreement to develop green hydrogen projects in Tamil Nadu.

India's biggest oil & gas player Relance Industries plans foray into greener fuels including hydrogen. As part of his targets to make Reliance Industries a net zero carbon company by 2035, Chairman Mukesh Ambani has signalled his intentions to emerge as a serious player in the hydrogen economy and intends to push aggresively towards reducing the cost of hydrogen to below US$1/kg by 2030. Earlier in 2021,

Reliance Industries has announced big investments worth Rs 75,000 crore (US$10bn) in the clean energy business that will entail 3 parts – 1) Rs 60,000 crore (US$8bn) investment in four giga-factories that will manufacture and fully integrate all critical components for the business, 2) Rs 15,000 crore (US$2bn) infusion in building the value chain, partnerships and future technologies, including upstream and downstream industries; and 3) repurposing the company's engineering, project management and construction capabilities toward clean energy.

Reliance Industries' giga factories will focus on both production and application of hydrogen via electrolysers and fuel cells. The company has started work on a green energy giga complex over 5,000 acres in Jamnagar, Gujarat, close to its flagship refinery and petrochemicals complex. The four giga-factories mentioned above include: 1) an integrated solar photovoltaic (PV) module factory, 2) advanced energy storage battery factory, 3) an electrolyser factory for the production of green hydrogen and 4) a fuel cell factory that converts green hydrogen into electricity for downstream applications.

Reliance Industries is aiming at establishing 100GW worth of renewable energy capacity by 2030, and this can be partly configured towards the production of green hydrogen, thus creating an end-to-end green energy ecosystem in the country.

NATIONAL POLICIES ON HYDROGEN FUEL – SINGAPORE

The Singapore Energy Market Authority (EMA) has recognised the use of hydrogen as among the best solutions to meet emission targets, being an emerging low-carbon energy solution. Back in 2016, Singapore had signed the Paris agreement where it planned to reduce its toxic waste by 36% by 2030 compared to the 2005 levels.

Currently the hydrogen market in Singapore is still in its initial stages. Future opportunities are mostly seen in terms of experimental projects in collaboration with big hydrogen players in the market. In the near term, the key challenges for Singapore in the development of hydrogen include: i) lack of a global supply chain, ii) lack of infrastructure for the importing, storage, and transport of hydrogen and iii) high cost of producing and importing hydrogen. Furthermore, Singapore does not have adequate infrastructure or land to accommodate large-scale facilities for mass production of renewable energy powered green hydrogen.

Thus, focus will be on emerging as an R&D hub for low-carbon solutions including green hydrogen. Singapore can focus on the development of decarbonisation technologies, low-carbon hydrogen (green or blue), and CCUS by attracting companies to set up their R&D activities in Singapore.

Singapore is looking into continuous investments in the hydrogen applications space. In July 2021, Temasek (Singaporean Sovereign Wealth Fund) entered a JV named Sydrogen Energy with Nanofilm Technologies worth USD140m to develop cutting-edge components for fuel cells. Singapore is also the second-busiest container port in the world and a hub for global maritime trade; hence, it has several of its hydrogen initiatives focused on the maritime sector, including the construction of new build vessels and use of ammonia and methanol as marine fuel.

Singapore may look to import renewable energy to produce green hydrogen. Keppel Electric has recently signed an agreement with Electricite Du Laos (EDL) to explore opportunities to import renewable energy into Singapore. Under the framework exclusive agreement, EDL will export and Keppel will import up to 100 MW of renewable hydropower from Lao PDR to Singapore via Thailand and Malaysia using existing interconnectors under an import trial. We believe this could be a precursor to producing green hydrogen, delivered via methanol and ammonia to enable ship bunkering using green fuels in Singapore port.

Singapore can also provide desalination technology expertise. Many hydrogen projects in future may come up in locations without access to adequate water and given that hydrogen production involves water electrolysis, desalination may be an important aspect of a combined renewable power-desalination plant-hydrogen complex in future in areas like the Middle East. Given Singapore's long track record in desalination plants, this could open up more opportunities in future for Singapore companies to participate in the hydrogen economy.

MOUs signed in the hydrogen space in Singapore

March 2020	Five Singapore and two Japanese companies have acknowledged an MOU to learn and study the viability of importing and utilising hydrogen in Singapore, using technology developed by the Japanese companies to safely transport hydrogen.
June 2020	Implementation of hydrogen-powered tri-generation plant concept for data centres in Singapore through the MOU signed between Keppel Data Centers and Mitsubishi Heavy Industries.
March 2021	Keppel Offshore and Marine, Sumitomo and Maersk, Yara International, and Hong Kong's fleet management announced an MOU to execute a joint feasibility study targeting to be first movers in establishing a wide-ranging supply chain for provision of green ammonia ship-to-ship bunkering at the Port of Singapore.
October 2021	SembCorp Industries of Singapore, Chiyoda Corporation, and Mitsubishi Corporation of Japan have signed an MOU to explore the delivery of low-carbon hydrogen into Singapore, using Methylcyclohexane (MCH), which is a type of liquid organic hydrogen carrier (LOHC).

Source: Various press reports, companies, DBS Bank

WHAT ARE GLOBAL OIL MAJORS THINKING ABOUT HYDROGEN?

Oil & gas players need to invest in blue or green hydrogen to meet emission reduction goals. European legacy oil & gas players have made strong commitments in terms of reductions in emissions over the next few decades. Factoring in the risks to long-term oil demand from the eventual proliferation of electric and hybrid vehicles and continuing efficiency gains in ICE vehicles, these companies are increasingly investing a part of their annual capex in energy transition strategies, ranging from 15-20% for the European oil majors. US players have taken slower steps, but things are changing, with Chevron recently announcing increased capex in lower-carbon businesses through 2028. Asian oil majors, being mostly national oil companies, will likely leave the investments in renewable energy to other divisions or vehicles (electric utilities) of the government but they may invest in hydrogen fuel technologies as they already own some of the complementary infrastructure such as pipelines and refuelling stations.

International Oil Majors' Emissions Ambitions

Company	Emission targets (Scope 1 and 2)	Emission targets (Scope 3)
Shell	Net zero by 2050	Reduce net carbon intensity by 20% by 2030, 45% by 2035, and 100% by 2050. Global absolute net zero by 2050.
BP	Reduce emissions by 30-35% by 2030 (operations) and 35-40% (net equity ownership). Net zero by 2050	Reduce net carbon intensity by 50% by 2050. Global absolute net zero by 2050 from operated production (excluding Rosneft)
Total	Reduce emission by 40% by 2030. Net zero by 2050.	Reduce 20% emissions by 2030, 35% by 2040, 60% by 2050. Global absolute net zero by 2050.
Equinor	Net zero by 2030	Reduce net carbon intensity by 20% by 2030, 40% by 2035, and 100% by 2050. Global absolute net zero by 2050.
Eni	Net zero for upstream business by 2030. Net zero for group by 2040.	Reduce net carbon intensity by 15% by 2030, 40% by 2040, and 100% by 2050. Global absolute net zero by 2050.
Exxon	Reduce upstream GHG emission intensity by 15-20% by 2025 (from 2016 levels)	
Chevron	Reduce upstream oil GHG emission intensity by 5-10% by 2023 by 2023 and gas by 205% by 2023 (from 2016 levels)	

Source: Companies, DBS Bank

Shell plans to use green hydrogen fuel to partly power its refining operations in Europe. Shell has started up Europe's largest hydrogen electrolyser of its kind at its energy and chemicals park Rheinland, in Germany in July 2021. As part of the Refhyne consortium and with funding from the European Commission, the 10 megawatt PEM electrolyser uses renewable energy to initially produce up to 1,300 tonnes of green hydrogen a year. The plant will be operated by Shell and manufactured by ITM Power. The green hydrogen will initially be used to produce fuels with lower carbon-intensity at the refinery. As part of Shell's plans to become a net-zero-emissions energy business by 2050, it will transform five core refineries into integrated Energy and Chemicals Parks by 2030 by using more recycled and renewables feedstocks such as hydrogen.

Apart from this, Shell is developing green hydrogen production hubs in the Netherlands and Germany and launching refuelling stations for trucks. It has signed an agreement with Daimler Trucks to jointly drive the adoption of hydrogen-based fuel-cell trucks in Europe.

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BP and other oil majors have more exposure to blue hydrogen market. As part of its low-carbon energy strategy, BP plans to create leading position in hydrogen and CCUS, including a 10% market share of hydrogen in core markets. BP is also aiming for net zero emissions in its refinery business through green hydrogen. It has joined forces with Ørsted at the Lingen refinery in North West Germany and intends to build a wind-powered 50MW electrolyser by 2024 to produce green hydrogen and partly replace the grey hydrogen fuel that the refinery is currently consuming. In the UK, BP plans to transition the Teesside industrial area into a blue hydrogen powerhouse, aiming to produce 1GW of blue hydrogen, in two phases, starting in 2027, through carbon capture and storage.

Equinor is mainly involved in blue hydrogen projects, building on its position as a key natural gas supplier. Equinor has partnered with Engie to investigate the development of low-carbon hydrogen value chains in Belgium, the Netherlands, and France. Total has also been involved in grey hydrogen refuelling stations but is working towards using green hydrogen at its refineries in France. Eni will also be focusing on producing blue hydrogen as a key means of decarbonisation.

Among Asian NOCs, Sinopec has the most ambitious plans in the hydrogen space. Sinopec plans to spend Rmb30bn (US$4.6bn) on hydrogen energy by 2025, 1) to add hydrogen refuelling facility at up to 1,000 of its service stations in China with target of 200,000 tonnes of hydrogen refuelling capacity by 2025; and 2) to produce >1m tpa of green hydrogen (from renewable energy sources) between 2021 and 2025. The first green hydrogen plant in the city of Ordos in Inner Mongolia will come online in 2022 with initial production of 10k tpa hydrogen.

Hydrogen economy plans for oil supermajors

Company	Highlights
Shell	▪ Germany – Refhyne 10MW PEM electrolyser project started up with capacity of 1,300 tonnes of green hydrogen. Plans to expand electrolyser capacity to 100MW ▪ Netherlands – NortH2 project being planned along with consortium partners to produce more than 800,000 tonnes of green hydrogen by 2040, with electricity from 10GW offshore wind farm in North Sea ▪ Netherlands – proposed green hydrogen hub in Port of Rotterdam, with plans to build a 200MW electrolyser powered by offshore wind ▪ Netherlands – energy hub GZI Next will use solar energy to produce hydrogen ▪ China – 20MW electrolyser producing hydrogen from renewable energy in Hebei province to supply hydrogen refuelling stations in Zhangjiakou, one of the cities co-hosting the 2022 Beijing Winter Olympics
BP	▪ UK – blue hydrogen project planned in Teesside with 1GW capacity, starting 2027, capable of producing up to 260,000 tonnes of hydrogen ▪ Germany – joint venture with Ørsted at the Lingen refinery in North West Germany to build wind-powered 50MW electrolyser by 2024 to produce green hydrogen ▪ Australia – feasibility study of green hydrogen and ammonia project in Western Australia
Total	▪ France - Total and Engie have signed a cooperation agreement to build the Masshylia project, France's largest renewable hydrogen production site with a 40MW electrolyser to produce 5 tons of green hydrogen per day to meet the needs of the biofuel production process at Total's La Mède biorefinery ▪ Europe – operates 30 hydrogen refuelling stations
Equinor	▪ UK – target to produce 1.8GW of blue hydrogen production in UK, along with partners by 2030 in the Humber region ▪ Germany – working on providing blue hydrogen to German steelworks by 2027 ▪ Netherlands – part of the above-mentioned NortH2 project, led by Shell
Eni	▪ Italy – Eni and Enel have joined forces to develop 10MW electrolyser pilots for green hydrogen near two of Eni's refineries ▪ Italy – collaboration between Cassa Depositi e Prestiti (CDP), Eni, and Snam to promote green hydrogen use including use of hydrogen in rail transport
ExxonMobil	▪ Leader in global carbon capture capacity, will play a role in blue hydrogen
Chevron	▪ Aim to grow hydrogen (blue/green) production to 150,000 tonnes per year by 2028, among other energy transition goals

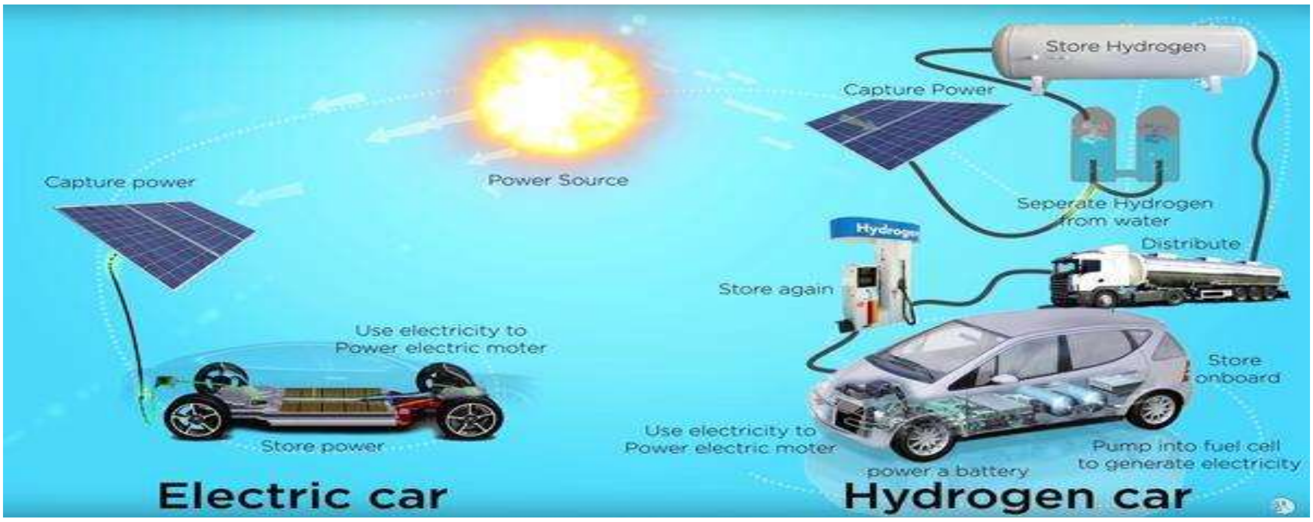
Source: Companies, DBS Bank

HYDROGEN IN AUTOMOBILE VALUE CHAIN – EVOLUTION OF HYDROGEN FUEL CELL VEHICLES VIS A VIS ELECTRIC VEHICLES

There are continuous arguments as to whether battery electric vehicles or hydrogen fuel cell vehicles are better for the environment. Battery electric vehicles have gained popularity in recent years with the reduction of pollution. Tesla's sales of battery electric cars, with the recent introduction of EVs to customers on a tighter budget showcases acceptance of customers on battery EVs apart from the traditional fuel-based vehicles.

Hydrogen fuel cell vehicles still in infancy. On the other hand, hydrogen fuel cell vehicles are still at its early stage with continuous research on the usage of fuel cells to convert the most abundant element in the universe into electric energy. Due to the heavy cost of producing hydrogen vehicles, mass adoption cannot be expected anytime soon, but it is much argued that the technology is more environment-friendly than battery electric vehicles.

On the face of it, the hydrogen fuel cell electric vehicle (FCEV) ecosystem looks much more complicated than conventional battery electric vehicles (BEV)



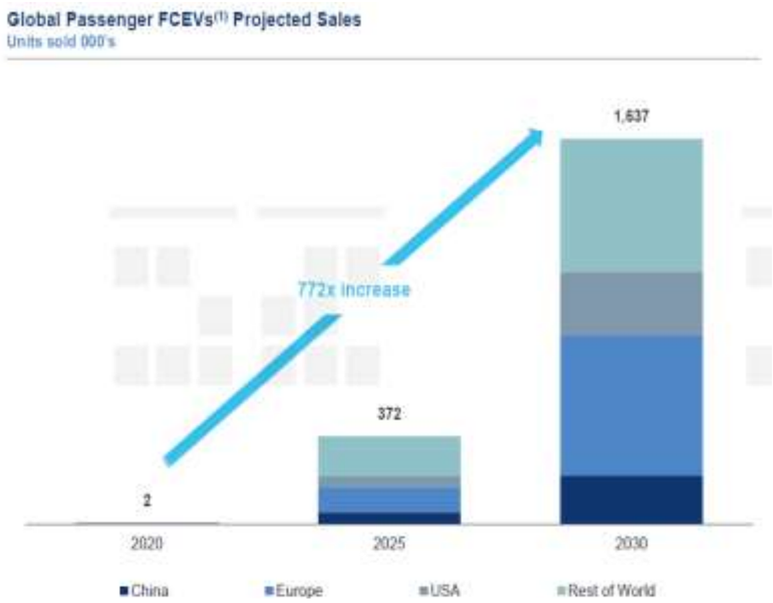
Source: InsideEVs

Advantages and disadvantages of FCEVs vs BEVs

Metrics	Battery electric vehicles	Hydrogen fuel cell vehicles
Range	Range comes with the price paid for the vehicles, as the expensive battery electric vehicles have higher ranges compared to the budget ones. Furthermore, electric charging can take an hour at minimum.	Hydrogen fuel cell vehicles seem to have the upper hand despite being in early stages, as these have higher ranges than the battery electric vehicles. Furthermore, it takes less time to fill up (5 minutes usually).
Emissions	Even though no gases are emitted from the vehicle exhausts, the manufacturing of batteries is a very energy-intensive process. E.g.: To produce a 100kWh battery, it emits around 20 tonnes of CO_2 and will deliver 124g/km of CO_2.	A hydrogen fuel cell vehicle produces around 120g/km of CO_2 over its lifetime including manufacturing. However, this amount can be drastically reduced if hydrogen was produced using renewable sources.
Ownership cost	Not the cheapest, but vehicles ranging from the expensive ones to the budget-friendly ones are available. However, cost of charging is economical, especially if it is through home power supply. E.g.: In the UK, roadside chargers cost around GBP35, whereas through home power, supply is much cheaper at GBP12.	Hydrogen fuel cell vehicles are expensive to purchase as well as the cost of filling up hydrogen is very expensive compared to battery electric vehicles. E.g.: cost of filling up hydrogen is GBP50 to GBP75.

Source: DBS Bank

FCEVs opportunity



Source: International Energy Agency

GLOBAL AUTOMAKERS' FCEV STRATEGIES

Automakers with FCEV strategies

TOYOTA	• Being one of the pioneer companies of manufacturing Fuel Cell Vehicles (FCEV), Toyota has rolled out second-generation Mirai FCEV in Nov 2020. This FCEV is expected to drive around 402 miles on a single charge, proving more than 90 miles compared to the first-generation. Toyota also plans to increase production of Mirai to 30,000 units per annum in the future. • According to Toyota, Hino Motors (Toyota's subsidiary), which focuses on trucks and buses, plans to develop Hino Profia fuel cell truck. Generally, fuel cell trucks demonstrate higher loading capacity compared to electric vehicles. Initially, Toei transportation introduced Toyota's fuel cell buses and then Keikyu introduced fuel cell buses for the first time among private bus operators. • Furthermore, Toyota has signed joint fuel investment contracts for commercial vehicles with five Chinese companies including BAIC, SinoHytec, FAW, and GAC. It is also collaborating with Hitachi and JR East to develop a hydrogen-electric hybrid train which is planned for its test run in Mar 2022. Hydrogen is considered a better fuel for heavy-duty vehicles compared to electric vehicles because they are lighter and have longer driving ranges. • Despite lower demand for hydrogen vehicles at the moment, especially due to the price factor, Toyota still sees an opportunity in producing hydrogen fuel-cell vehicles as it does not want to fully commit to producing only electric vehicles, which is the strategy taken by many auto makers. • Toyota is also developing a 'cow to car' fuel supply model in California, where it plans to use anaerobic digesters on farms to convert animal waste into methane, which can be run through a fuel cell to produce hydrogen and electricity.
HYUNDAI	• Hyundai exports both fuel cell systems and fuel cell electric vehicles. The automaker giant announced its first fuel cell electric vehicle, the Santa Fe FCEV in 2000, followed by ix53 in 2013, which was the world's first mass produced FCEV. Furthermore, it manufactured NEXO, the second-generation fuel-cell SUV back in 2018. • The South Korean automaker plans to invest c.KRW7.6tn (USD6.7 bn) through 2030 to increase production of fuel cells by more than 200 times. Hyundai announced that it will enhance annual production capacity of fuel-cell systems to 700,000 units from the current 3,000 over the next 12 years. • Hyundai being the fifth-largest auto group in the world expects to produce 500,000 units for fuel-cell powered passenger and commercial vehicles, where another 200,000 units will be produced for drones, vessels and rolling stocks. • In 2019, Hyundai announced its own hydrogen-powered truck concept, HDC-6 Neptune, and it started fuel cell trucks into a pilot programme in Switzerland last year. In 2022, it aims to commercialise this technology in North America and is also looking at other transportation mediums like boats and trains for applications. Hyundai also sells the commercial fuel-cell truck Xcient Fuel Cell, which is considered as the world's first mass-produced, heavy-duty truck powered by hydrogen.
DAIMLER TRUCK AG AND VOLVO GROUP	• Daimler Truck and Volvo group together launched a joint venture called 'Cellcentric' to develop and sell fuel cell systems for long-haul trucks and heavy-duty vehicle applications. Daimler Truck will consolidate all its current fuel cell activities in the joint venture and Volvo Group acquired 50% stake in the joint venture for a value of EUR0.6 bn. • The joint venture, Cellcentric will run as an independent entity where the two giants will still be competitors in other business areas. This collaboration is expected to decrease development costs for both the companies and smoothen the development of fuel cell systems for long-haul applications. In 2025, Cellcentric will build and operate one of Europe's largest planned series production of fuel cell systems and is also planning to become carbon-neutral by 2050.

HONDA	• Honda also plans to manufacture more hydrogen-based FCEVs in the future, given its already long history of researching, developing, and commercialising FC technologies. • The Japanese car maker has set a target for FCEVs and EVs to make up the total portfolio of vehicles sold globally by 2040. Honda expects EVs and FCVs to make up of 40% of sales by 2030 and further increase to 80% by 2035 in all major markets (including North America and China). The company has also set a phasing out of the gasoline vehicles, which are expected to disappear over the next 20 years. • Honda is working on continuous improvements to its hydrogen fuel cell vehicles due to the competition from Toyota and Hyundai. Honda is working on the next-generation fuel-cell stack, which it hopes to sell in ten thousands compared to the previous model, which sold in thousands.

Source: Companies, DBS Bank

WHO ARE THE COMPANIES INVOLVED IN GREEN HYDROGEN VALUE CHAIN?

- EXPLORING SOME PIONEERING BUSINESS MODELS

CASE STUDY 1 – BLOOM ENERGY

CASE STUDY 2 – PLUG POWER

CASE STUDY 3 – LINDE

CASE STUDY 4 – FUELCELL ENERGY

CASE STUDY 5 – BEIJING SINOHYTEC

CASE STUDY 6 – SYDROGEN

Summary of key players in green hydrogen economy and business models

Metrics	Company	Key hydrogen-related business	Highlights
Production	Linde	PEM electrolysers, liquefaction	▪ Largest liquid hydrogen capacity and distribution system in the world ▪ Offers the latest PEM electrolysis technology through newly formed joint venture ITM Linde Electrolysis
	ITM Power	PEM electrolysers	▪ One of the world's largest electrolyser manufacturers with solutions from 600kW to 100MW
	Bloom Energy	Solid oxide electrolysers	▪ Unique solid oxide technology promises to use less electricity to produce hydrogen, unveiled in July 2021
	Nel ASA	Alkaline and PEM electrolysers	▪ Norwegian company with long track record in hydrogen production equipment through electrolysis
	Plug Power	PEM electrolysers	▪ Building 5 green hydrogen factories in the US with in- house electrolyser and renewable energy sources
	Cummins	PEM and alkaline elctrolysers	▪ Provided a 20-megawatt PEM electrolyser system to generate green hydrogen, making it the largest in operation in the world, installed at Air Liquide facility in Canada
	Hanwha Solutions	Alkaline electrolysers	▪ Developing alkaline electrolysis technology with a view to commercialisation by 2023
	POSCO	Green hydrogen for steelmaking	▪ Plans to complete 2 million tons of production capacity of green hydrogen by 2040 and then expand the production to 5 million tons by 2050, and construct green hydrogen-based steel works

Metrics	Company	Key hydrogen-related business	Highlights
Storage & Transmission	Linde	Pipelines, storage, hydrogen refuelling stations	▪ Operates the world's first high-purity hydrogen storage cavern ▪ Installed over 200 hydrogen fuelling stations and 80 hydrogen electrolysis plants worldwide ▪ Will build and operate the world's first hydrogen refuelling station for passenger trains in Germany.
	Plug Power	Hydrogen dispensers for refuelling, services for storage	▪ Services include the design, procurement, construction, commissioning, and maintenance for all of the components required to successfully store and dispense hydrogen
	Nel ASA	Hydrogen refuelling stations	▪ Hydrogen refuelling of FCEVs, dispensers, storage, and unloading products
	FuelCell	Hydrogen storage	▪ Using reversible solid oxide fuel cell technology
	Iwatani	Hydrogen refuelling stations	▪ Leading player in Japanese hydrogen fuel stations market, investing in Australia for future supplies
	Hyosung Heavy Ind	Hydrogen liquefaction, storage, refuelling stations	▪ Constructing hydrogen liquefaction plant in Ulsan, Korea along with Linde
	KOGAS	Hydrogen refuelling stations	▪ Plans to build 25 hydrogen production bases and 132 HRSs in Korea by 2030
	Doosan Heavy Ind	Hydrogen liquefaction (EPC)	▪ Won EPC contract for Korea's first hydrogen liquefaction plant in Changwon
	Hanwha Solutions	Hydrogen storage	▪ Expanding investment in hydrogen tanks, recently took over TK-Fujikin, thereby securing technologies for hydrogen tanks for passenger vehicles, trucks and refuelling stations.
	ITM Power	Hydrogen refuelling stations	▪ ITM Motive is a subsidiary that builds and operates hydrogen refuelling stations in the UK ▪ Ambition to run a 100 stations within next five years from 7 currently
Applications	Bloom Energy	Solid oxide fuel cells (SOFC)	▪ Distributed generation/microgrids/electric utility power storage/back-up for critical applications across health care, data centres, critical manufacturing retailers, and others
	Plug Power	Fuel cell engines (PEM)	▪ Developing fuel cell products for light commercial vehicles, forklifts, back-up power boxes
	FuelCell Energy	Fuel cell systems (MCFC and SOFC)	▪ For baseload power applications, turnkey EPC and long-term O&M
	Ballard Power	Fuel cells (PEM)	▪ For transportation industry including marine, stationary power systems, and back-up power
	Ceres Power	Fuel Cells (SOFC)	▪ Solid oxide fuel cell on a steel backbone for both stationary and transport applications
	Doosan Fuel Cell	Manufactures fuel cells (PAFC)	▪ Stationary fuel cell (PAFC) market leader in Korea

Metrics	Company	Key hydrogen-related business	Highlights
	S-Fuelcell	Fuel cells for buildings (PEM)	▪ Manufactures PEM hydrogen fuel cells for buildings, started exports to China
	STX Heavy	Fuel cell for vessels	▪ Development of hydrogen fuel cell for shipping
	SFC Energy	Fuel cells (PEM and DMFC)	▪ Hydrogen (PEM) and direct methanol fuel cells (DMFC)
	Cummins	Fuel cells (PEM and SOFC)	▪ Acquired Hydrogenics in 2019 to accelerate the process ▪ Cummins uses fuel cell technologies to power a variety of applications, including transit buses, semi-trucks, delivery trucks, refuse trucks, and trains
	Iljin Diamond	Storage tanks for FCEV	▪ Exclusive supplier of type-4 hydrogen storage tanks for use in Hyundai Motor Company (HMC)'s NEXO FCEV
	SFTC (Sang-a Frontec)	Fuel cell components	▪ Has production technology of ePTFE, a core material for fuel cells
	Hyosung Advanced Materials	Fuel tank component for FCEV	▪ Produces carbon fibre used in hydrogen fuel tanks ▪ Investing US$850m annually through 2028 to expand capacity in its carbon fibre plant in Korea
	Kolon Industries	Fuel cell components	▪ Makes membrane components for hydrogen fuel cells used in FCEVs
	SK Group	Solid oxide fuel cells (SOFC)	▪ Established JV with Bloom Energy in Korea to produce and supply SOFC in local market
	Aisin	Household Solid oxide fuel cells (SOFC)	▪ Sells residential-use gas cogeneration systems based on hydrogen-fuelled SOFC fuel cells to generate electricity and heating
	Weichai Power	Fuel cells, compressor technology, FCEV	▪ Key investor in Ballard Power and Ceres Power, who are into PEMFC and SOFC respectively ▪ Strategic cooperation with FISCHER Group in Switzerland for fuel cell compressor business
	Beijing SinoHytec	Fuel cell technology (PEM)	▪ Leading supplier to Chinese FCEV industry ▪ Hydrogen fuel cell engine as the core product, including bipolar plates, stacks, intelligent DC/DC, hydrogen systems, and test platforms

Source: DBS Bank

CASE STUDY 1 – BLOOM ENERGY

From space to earth. Bloom Energy traces its roots to work performed by KR Sridhar, Bloom Founder and CEO, for NASA's Mars Exploration programme. Dr. Sridhar and his team built a fuel cell capable of producing air and fuel from electricity generated by a solar panel, with the vision of one day being able to support life on Mars.

Originally using natural gas as fuel for the fuel cells, but transitioning to hydrogen now. Originally, the company has focused on the use of natural gas for its fuel cell technology, but it was not a green option. It sold boxes, which it calls energy servers, which emits a nearly pure stream of carbon dioxide, a major greenhouse gas, but supposedly less than traditional power plants, and much less other pollutants like nitrogen oxide and sulfur oxides. Bloom Energy is now pivoting and plans to capitalise on the production of hydrogen through green hydrogen via electrolysis or to produce blue hydrogen by using carbon capture.

Bloom Energy fuel cell energy servers

Source: Bloom Energy

The company can utilise its fuel cell business track record to tap on hydrogen story. Bloom Energy has installed several thousands of 15-ton fuel cell boxes or energy servers worldwide for big tech companies (Apple, AT&T etc.), who are willing to pay for stable power. Back in 2008, Bloom Energy installed its first Bloom Box at Google. In July 2021, the company unveiled the Bloom Electrolyzer to produce green hydrogen, which it claims to be 15-45% more efficient than competing products. Commercial shipments for the Bloom Electrolyzer are expected to begin in late 2022.

More hydrogen ventures in Asian markets. In July 2020, the company announced plans to enter the commercial hydrogen market to set up a 1 MWh hydrogen-powered energy server installation with the Korean partner by 2022. In April 2021, Bloom Energy announced a collaboration with SK Engineering & Construction Co. Ltd (Korean Partner) that its successfully set up 100 kWhs of solid-oxide fuel cells powered solely by hydrogen in South Korea, generating zero-carbon onsite electricity.

Future plans. The **company** signed a deal with Samsung Heavy Industries in 2020 to design and develop fuel cell powered ships. Furthermore, Bloom's fuel cells are expected to strengthen power grids, which are necessary to charge electric vehicles that are expected to drastically increase over the next 10 years. In May 2021, Bloom Energy announced a collaboration with Baker Hughes to explore commercialization and deployment collaborations in many areas. The companies will look to pair the Bloom Electrolyzer with Baker Hughes' compression technology for efficient production, compression, transport, and storage of hydrogen. Bloom Energy is also looking to harness excess nuclear power in the grid to create green hydrogen and is collaborating with the US Department of Energy's Idaho National Laboratory to test the same.

Bloom Energy also plans to deploy fuel cells that can run on biogas from landfills, food processing plants, and other sources, which require additional processing but yield a carbon-neutral energy source.

CASE STUDY 2 – PLUG POWER

Plug Power is an innovator and a leader in the green hydrogen economy, with over 40,000 fuel cell systems, 150 fuelling stations deployed globally, and dispensing more than 40 tons of hydrogen daily. The company also has a comprehensive solution for generating green hydrogen including its electrolyser technology and liquefaction capabilities.

Started with fuel cell engines for forklifts. Plug Power is an innovative company that has taken hydrogen and fuel cell technology from concept to commercialisation. Plug Power has historically been the maker of fuel cells for forklifts and other work vehicles. Plug Power has revolutionised the material handling industry with its full-service GenKey solution. With proven hydrogen and fuel cell products, Plug Power replaces lead-acid batteries in power electric industrial vehicles, such as the lift trucks customers use in their distribution centres. Currently, the company uses about 20 tons of liquid hydrogen per day to fuel roughly 40,000 fuel-cell-powered forklifts used by customers including Amazon, Walmart, DHL, and Home Depot.

Then on-road vehicles. Extending its reach into the on-road electric vehicle market, Plug Power's ProGen platform of modular fuel cell engines empowers OEMs and system integrators to rapidly adopt hydrogen fuel cell technology. ProGen engines are proven today, with thousands in service, supporting some of the most rugged operations in the world. Plug Power has recently entered a collaboration with Renault to build a hydrogen-fuelled commercial vehicle market in Europe through its JV, which has been christened HYVIA.

Expanded into electrolysers and green hydrogen manufacturing. In February 2021, Plug Power completed raising US$2bn equity to expand its fuel cell and electrolyser manufacturing capacity and to build five large-scale green hydrogen production stations across the US. This fund is planned to be used for opening a massive factory in Rochester, NY which is expected to begin operation in 2021. The factory will lead to the production of 1.5GWhs of fuel cells and about 500MWhs of electrolysers per year. Plug Power has also partnered with Apex Clean Energy and Brookfield Renewable Partners to secure renewable energy to power the planned first two green hydrogen facilities by 2022 and have all five operational by 2024.

Massive investment and leap of faith from SK Group of Korea. In January 2021, the company received a shot in the arm, with an investment of US$1.6bn from leading South Korean conglomerate SK Group to form a JV company in South Korea by 2022 and boost the production of hydrogen fuel cells and green hydrogen electrolysers as a cleaner source of energy for industry and transport around the Asian region. The South Korean government has announced the Hydrogen Economy Roadmap through 2040, with ambitious goals, and, thus, the opportunity to partner with SK presents an attractive and timely opportunity to establish a foothold in this market with one of South Korea's leading industrial conglomerates.

Developing green jet fuel for regional jets. In September 2020, Plug Power announced a partnership with US aircraft developer Universal Hydrogen, followed by a minority investment in March 2021. Under this partnership, the companies plan to develop, build, and certify a commercially viable hydrogen fuel cell-based propulsion system designed to power commercial regional aircraft. The partnership aims to certify and fly the world's first 2-MW hydrogen-electric aircraft powertrain. The carbon-free propulsion system incorporates a lightweight Plug Power ProGen-based hydrogen fuel cell stack designed for aerospace applications and Universal Hydrogen's modular hydrogen distribution and fuel delivery system. This technology will enable a converted mid-sized regional turboprop aircraft (such as the Dash 8 or ATR42/72 families) to fly missions up to 1,000 km.

Plug Power's partnership ecosystem summary

Date	Partner	Collaboration Area
Oct 2021	Fortesque Future Industries	A 50-50 joint venture to build a Gigafactory in Queensland, Australia to produce large-scale proton exchange membrane (PEM) electrolyzers
Oct 2021	Phillips 66	Three key objectives: 1) integrating and scaling low-carbon hydrogen in the industrial sector; 2) advancing hydrogen fueling opportunities for the mobility sector; and 3) developing hydrogen-related infrastructure to support the build-out of the hydrogen value chain
Oct 2021	Airbus	Study the feasibility of bringing green hydrogen to future aircraft and airports worldwide
Jul 2021	Apex Clean Energy	New green hydrogen plant with 100% renewable wind power, can produce up to 30MT of liquid hydrogen per day
Apr 2021	BAE Systems	Hydrogen-fuel electric buses
Feb 2021	Acciona	Green hydrogen production in Spain and Portugal
Jan 2021	Renault	Develop, build, and market electric fuel cell light commercial vehicles (LCVs) powered by hydrogen and green hydrogen ecosystem with refuelling stations across Europe
Jan 2021	SK Group	Hydrogen ecosystem in Asia
Sep 2020	Universal Hydrogen	Hydrogen-powered aircraft

Source: Plug Power, DBS bank

Well positioned for growth. Proceeds from an equity raise transaction and the final closing of the partnership with SK Group will bring the total cash balance of the company to over US$5bn. This liquidity positions Plug Power to execute and accelerate its green hydrogen and overall growth strategy. The company is targeting multiple green hydrogen plants in North America by 2022, and it recently announced its increased green hydrogen generation targets to 500 tons per day by 2025 and 1,000 tons per day before 2028.

Also creating investment ecosystem for hydrogen economy. In May 2021, Plug Power, Chart Industries, Inc. and Baker Hughes announced their intention to become cornerstone investors in the formation of the FiveT Hydrogen Fund, a unique new clean-hydrogen-only private infrastructure fund dedicated to delivering clean hydrogen infrastructure projects at scale. Plug Power intends to commit €160m (US$200m) and Chart Industries and Baker Hughes each intend to commit €50m respectively (US$60m), recognising the unique value proposition that FiveT will bring to the hydrogen sector. These investments enable FiveT to establish itself at the heart of the hydrogen industry and help advance a broader global mission to address climate change and accelerate the energy transition. This euro-denominated Fund, offered only to qualifying and verified investors, has the ambition to raise a total of €1bn from both financial and industrial investors. The fund will exclusively finance projects in the production, storage, and distribution of clean hydrogen.

Annual Plug Symposium generates excitement. At the recently concluded Plug Symposium hosted by Plug Power in October 2021, the company provided updated 2022 sales guidance of US$825-850m – 65% growth over 2021 – and 2025 sales guidance of US$3bn. The company also highlighted recent partnerships (see above table) and the acquisition of Applied Cryo Technologies, a leading provider of technology, equipment and services for the transportation, storage and distribution of liquified hydrogen, oxygen, argon, nitrogen and other cryogenic gases. The company confirmed its plan for 500 tons per day of liquid green hydrogen generation capacity by the end of 2025, which will include installing 13 green hydrogen plants by the end of 2025 and is projecting ambitious electrolyzer sales of over 100 megawatts (MW) by 2022, which will generate 50 tons per day of green hydrogen

CASE STUDY 3 – LINDE

Biggest established player in industrial gases and hydrogen. Linde has been harnessing the power of hydrogen for over 100 years and is the global leader in the production, processing, storage, and distribution of hydrogen. They are founding members of the Hydrogen Council and the Hydrogen Mobility association and actively advocate for clean hydrogen policies and initiatives through more than 20 industry and government-sponsored organisations around the world. Linde is one of the founders of the largest P2G (Power to Gas) plant, in terms of capacity, in the world. It converts wind power into green hydrogen through electrolysis and has been running since 2015.

Transitioning to clean hydrogen. The company is at the forefront in the transition to clean hydrogen with the largest liquid hydrogen capacity and distribution system in the world. In Aug 2020, Linde was selected as a new member of the European Clean Hydrogen Alliance by the European commission. Given Linde's leading position in the clean hydrogen industry, it will add value to the work of the Alliance. This alliance is expected to improve production and demand for renewable and low-carbon hydrogen in Europe. They operate the world's first high-purity hydrogen storage cavern, coupled with a pipeline network of approximately 1,000 kilometres to supply customers. They have installed over 200 hydrogen fuelling stations and 80 hydrogen electrolysis plants worldwide and offer the latest electrolysis technology through a newly formed joint venture ITM Linde Electrolysis.

Developing new generation PEM electrolyser with ITM Power's technology. Linde (a Germany-based hydrogen company) is to build the world's largest PEM electrolyser to produce green hydrogen through a joint venture with UK based ITM Power. This 24MW Proton Exchange Membrane (PEM) electrolyser is to be built at Leuna, Germany by 1H22. Green hydrogen produced is expected to be transported through Linde's existing pipeline network. These PEM electrolysers are currently viewed as the most cost-efficient to produce green hydrogen from renewable power.

Liquefaction is another core area of expertise. Linde has mastered the use of hydrogen Claude processes for large-capacity liquefaction and has also separate cold boxes for large-scale systems. Currently, these latest technologies have led to the company to achieve liquefaction capacities of more than 30 metric tons per day.

Developing new application areas in trains and trucks. In collaboration with Alstom, Linde will build and operate the world's first hydrogen refuelling station for passenger trains in Germany. The station, which is planned to start operations in 2021, will serve 14 hydrogen-powered trains. Alstom is among the first railway manufacturers in the world to develop a passenger train based on such technology. Being one of the largest industrial gas companies, Linde operates close to 200 hydrogen refuelling stations and is planning work on new hydrogen refuelling technology with Daimler Trucks by 2023.

Attempting to decarbonise heavy industries like steel. In early 2020, Linde and OVAKO conducted the world's first test to demonstrate that hydrogen fuel can help the steel industry reduce emissions by using hydrogen instead of fossil fuel to heat steel. Comprehensive analysis of the steel's properties revealed that heating with hydrogen did not adversely affect the steel's quality, while having the potential to significantly reduce CO_2 emissions.

CASE STUDY 4 – FUELCELL ENERGY

FuelCell Energy is a company that designs and produces carbonate and solid oxide fuel cells that run on hydrogen-rich fuels such as natural gas and biogas. Across the world, FuelCell Energy operates over 50 fuel cell power plants, with more than 250MW capacity. The global fleet of SureSource™ power plants span three continents. The SureSource plants provide environmentally responsible solutions for various applications such as utility-scale and on-site power generation, carbon capture, local hydrogen production for both transportation and industry, and long duration energy storage. The company is headquartered in the US, with manufacturing in Connecticut. It services the European market through its manufacturing and service centre in Germany. SureSource fuel cell systems provide continuous baseload power and are deployed with utility, municipal, university, and industrial and commercial enterprise customers.

Fast forward to hydrogen fuel cells for power. In March 2021, FuelCell Energy (a global leader in fuel cell technology) announced that it joined with Hydrogen Europe, which is a community comprising of major companies working towards improving the hydrogen economy. According to management, FuelCell Energy had been investing and developing hydrogen production technology over the last two decades as the company recognises hydrogen to be the main source to decarbonise the energy environment.

Also developing the storage business. Apart from distributed generation projects that are already operational, the company is in the process of developing and commercialising hydrogen storage and transmission and carbon capture projects. Current pipeline includes the following:

- The company's SureSource Storage solution is a developing, market-driven energy storage system that utilises solid oxide electrolysis cells (SOEC) to affordably and efficiently convert excess power into hydrogen for long duration storage applications. The hydrogen produced from SOEC can be stored and used for grid-power, hydrogen fuelling stations or for industrial purposes as an alternative to natural gas reforming. SOEC can also be applied as a clean and highly efficient solution for storing excess power produced by intermittent technologies when their output exceeds the needs of the electric grid. When power is needed, the hydrogen is cleanly and efficiently converted back into power using the same solid oxide system in fuel cell power generation mode. The technology is being developed with support from the US Department of Energy.

- In the distribution space, the company is building a hydrogen distribution platform in Long Beach to support Toyota's operations to fuel zero emission FCEVs and provide clean water.

- The company has also entered a joint development agreement with ExxonMobil Research and Engineering Company (EMRE) to build unique carbon capture technology that captures carbon while producing power.

Future goals. By the end of FY22, as compared to end-FY19, the company aims to i) double generation capacity, ii) achieve a double-digit revenue CAGR, and iii) deliver positive adjusted EBITDA. In terms of longer-term goals, the company aims to deliver positive EBITDA and cash flows, grow its revenue from hydrogen and carbon capture platforms, and achieve Grid Parity Pricing.

CASE STUDY 5 – BEIJING SINOHYTEC

One of the pioneers of China's hydrogen energy industry. Beijing SinoHytec Co., Ltd. (SinoHytec) has been focusing on the research and development and industrialization of hydrogen fuel cell engine technology for quite a few years. At present, SinoHytec has already formed a product series covering various components, with hydrogen fuel cell engine as the core product, and other supporting products like bipolar plates, stacks, intelligent DC/DC, hydrogen systems, test platforms, etc.

Experienced in fuel cell products. On the basis of technical experience of many years, the company has developed the latest generation YHTG series of hydrogen fuel cell engines in 2018, whose products cover the range of 10kW, 30kW, 60kW and 100kW. At present, this series of product has come into industrial volume production.

Co-operation with many OEMs in auto and others for development of hydrogen fuel cell applications. SinoHytec has cooperated with Yutong, Foton, Zhongtong, Sunlong, Higer, Ankai, ZEV, Sinotruk, Shaanxi Automobile, BAIC, GAC, Changan and other mainstream OEMs, to jointly launchfull range of products such as buses, logistic trucks, passenger cars, forklifts, trams, and stationary power supplies.

The company focuses on core cities such as Beijing, Shanghai, Zhangjiakou, Binzhou, Zhengzhou, Chengdu and Suzhou, and adopts the "city-network-region" development model to penetrate and promote the end-to-end ecological construction of the local hydrogen energy industry.

SinoHytec's local partnership ecosystem summary in China

Product	Collaborators
Fuel Cell Bus (FCB)	Foton, Yutong Bus, Sunwin Bus, Higer Bus, Zhong Tong Bus
Fuel Cell Trucks	Foton, Sinotruk, Shaanxi Auto
Fuel Cell Vehicles (FCEVs)	BAIC, Changan, GAC
Fuel Cell Trams	CRRC
Fuel Cell Forklifts	SinoFuelCell
Stationary Power Backup	Zhangbei Power

Source: SinoHytec, DBS bank

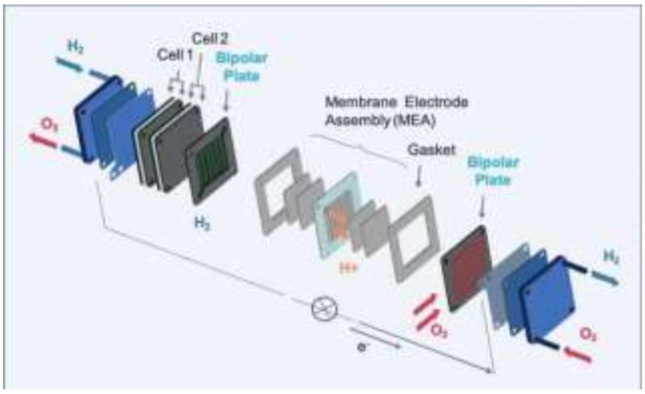
Future plans feature JV with Toyota to make fuel cells for commercial vehicles. In March 2021, Toyota and SinoHytec agreed to set up a 50-50 joint venture to produce fuel cells for commercial vehicles in China. The two companies will invest US$36 million each in the new venture named Toyota SinoHytec Fuel Cell Co. Ltd., which will be located in the Beijing Economic-Technological Development Area and will start operations in 2023. In August 2020, Toyota had set up United Fuel Cell System R&D (Beijing) Co. Ltd. with five Chinese companies, including Beijing SinoHytec, and four Chinese automakers (including China FAW Group, GAC Motor Group and BAIC Group) to develop hydrogen fuel cells for commercial vehicles. The deal means the four state-owned auto companies are thus potential customers for the fuel cell systems that Toyota wil jointly build with SinoHytec.

CASE STUDY 6 – SYDROGEN

Sydrogen is a newly formed JV between Nanofilm (65%) and Temasek (35%) with up to S$140m (c.US$100m) in initial investment. It aims to leverage Nanofilm's core technologies and Temasek's global reach to tap the hydrogen economy, especially the FCEV market, which is estimated to be a US$32bn market globally by 2030.

Aiming to help improve the fuel cell stack. The fuel cell is at the heart of the hydrogen fuel cell electric vehicle. Every fuel cell consists of 400-1,200 biploar plates, making up c.10% of system costs. Sydrogen aims to invest in R&D and reduce the thickness of these bipolar plates from 3mm to less than 1mm, and market the technology to FCEV players.

Hydrogen fuel cell stack and involvement of bipolar plates



Source: Company, DBS Bank

Solving challenges in fuel cell components. Some of the key challenges of fuel cells is the lack of suitable coating materials, corrosion or ion leaching issues and bulky graphite bipolar plates. Sydrogen's proposition is to solve this through the use of innovative materials – "Black Diamond" with improved properties, longer life, and better performance than other materials used for bipolar plates like graphite and coated titanium.

Lowering the cost of fuel cells could accelerate FCEV market development. Sydrogen is targeting the use of "Black Diamond" for bipolar plates in fuel cells and electrolysers, as well as catalyst-coated membranes for Proton Exchange Membrane (PEM) fuel cells and Anion Exchange Membrane (AEM) electrolysers.

Will be targeting the China market first. After Japan and Korea, China will emerge as one of the key players in the Asian FCEV market. Sydrogen will be marketing its solution to Tier-1 automotive customers in the FCEV space but will likely look at Chinese auto companies first. Commercialisation of the technology could take five to seven years, but it is important to be an early player in this market. The demand for bipolar plates in fuel cells will improve substantially in future, with likely a more than 100 million requirement by 2030.

Aiming for maiden revenues in 2022, but meaningful contribution only in medium term. Sydrogen has already commenced work in Shanghai and Singapore. To prepare for commercial opportunities in China, Sydrogen is commissioning and installing its initial pilot production line at the group's Shanghai Plant 2 for customer qualification in an automotive project involving a key component for a hydrogen fuel cell stack. Sydrogen is working towards a maiden revenue contribution in 2022. The application of Nanofilm's technology in the development of protective carbon coatings for metallic bipolar plates of fuel cells offers many advantages as compared to the conventional methods, which are costly and less effective. However, meaningful contribution can only be expected in the medium to long term.

HOW DO THESE COMPANIES STACK UP IN TERMS OF VALUATIONS AND GROWTH?

Peer valuation summary of key players involved in green hydrogen economy

Company	Country	Market cap (US$m)	P/E ratio (x)		EV-to-EBITDA (x)		P/B (x)		P/S (x)	
			CY21F	CY22F	CY21F	CY22F	CY21F	CY22F	CY21F	CY22F
Fuel Cells & Components										
Bloom Energy	US	3,328	N/A	174.9x	60.4x	27.6x	19.9x	5.5x	3.5x	2.8x
Plug Power	US	15,358	N/A	N/A	N/A	390.8x	3.1x	3.2x	31.0x	20.3x
FuelCell Energy	US	2,333	N/A	N/A	N/A	N/A	9.6x	106.1x	30.3x	20.0x
Ballard Power	US	4,143	N/A	N/A	N/A	N/A	3.8x	3.2x	39.6x	27.7x
Ceres Power	UK	2,558	N/A	N/A	N/A	N/A	N/A	N/A	53.9x	49.4x
SFC Energy	Germany	446	N/A	84.1x	87.9x	33.9x	7.4x	6.7x	5.6x	4.2x
Doosan Fuel Cell	Korea	2,669	180.3x	97.9x	74.5x	39.3x	7.5x	6.4x	6.2x	4.0x
Sang-a Frontec	Korea	831	85.9x	45.7x	40.8x	25.9x	6.2x	5.5x	5.1x	3.8x
Hyosung Advanced Materials	Korea	2,691	12.9x	16.1x	7.6x	8.2x	5.7x	4.4x	0.9x	0.9x
S-Fuelcell	Korea	184								
Weichai Power - A Share	China	22,064	10.2x	9.2x	5.0x	4.2x	1.6x	1.5x	0.7x	0.6x
Weichai Power - H Share	China	22,066	13.6x	12.4x	6.3x	5.8x	2.1x	1.9x	0.7x	0.6x
Beijing SinoHytec	China	2,588	155.3x	103.1x	115.8x	73.9x	6.9x	6.3x	14.8x	9.4x
Production & Distribution										
Linde Plc	US	153,696	28.8x	26.3x	16.7x	15.6x	3.2x	3.2x	5.1x	4.9x
Hanwha Solutions	Korea	6,725	9.5x	9.5x	7.9x	6.9x	1.0x	0.9x	0.7x	0.7x
Nel ASA	Norway	2,128	N/A	N/A	N/A	N/A	3.3x	3.5x	23.2x	14.3x
ITM Power	UK	2,992	N/A	N/A	N/A	N/A	27.8x	15.8x	88.6x	32.6x
Average			63.7x	58.8x	43.0x	24.4x	7.3x	4.8x	19.2x	12.3x

Source: Bloomberg Finance L.P., DBS Bank

New age hydrogen plays not profitable yet, can look at Price/ Sales ratio. Pure play Hyfrogen fuel cell and electrolyser plays in the US, Europe or Asia are still very much in the startup phase and not profitable on the bottomline yet, hence looking at P/E or even EV/EBITDA based valuation metrics is not feasible. Hence, we need to fall back on price to sales (P/S) ratio as one of the key valuation comparables. We see companies like Plug Power, FuelCell, Ballard Power, Ceres Power and ITM Power trading at P/S range of between 30x-50x on 1-year forward numbers. Bigger companies like Linde or Korean companies who have just joined the hydrogen bandwagon and have substantial other businesses as the main revenue and profit contributors, of course, trade at somewhat more conventional valuation ranges on P/S basis, though valuations still look elevated on PE or EV/EBITDA basis, barring Linde. Chinese player SinoHytec's valuations look attractive compared to its Western peers.

High P/S ratio can be pegged against strong growth prospects. For the hydrogen related peers under consideration, we see possibilities of very strong revenue growth over the next decade. In terms of Bloomberg consensus forecast average growth rates for revenue for 3-year, 5-year and 10-year (where available) horizons, we see expectations of between 30-40% CAGR in revenue over the next decade. ITM Power has some of the highest growth expectations built in, with close to 73% revenue CAGR forecast over the next 10 years. In terms of near-term growth expectations, apart from ITM Power, market expectations for Plug Power and SinoHytec are also among the highest at 50-60% revenue CAGR.

Consensus growth forecasts and recent share price performance summary

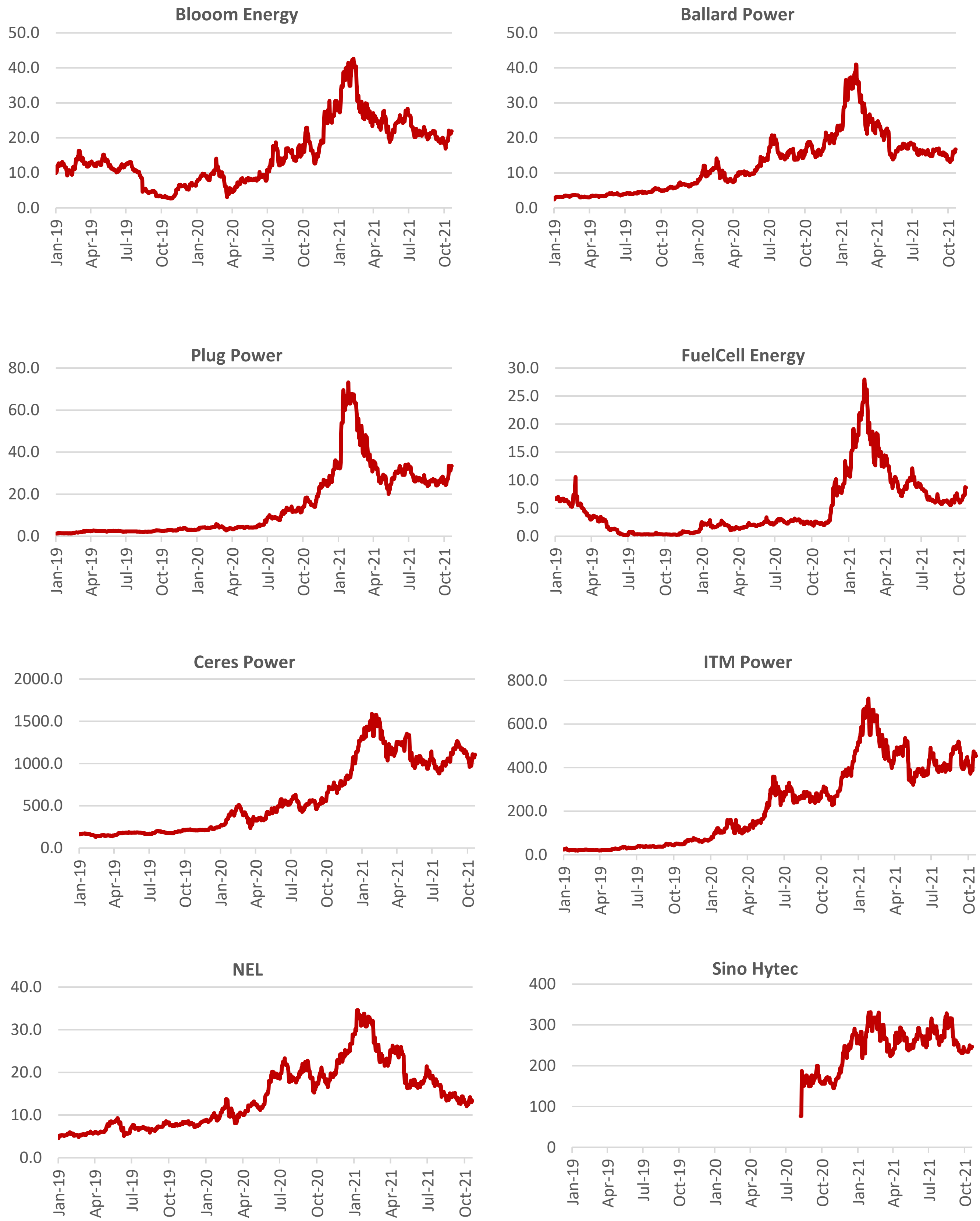
Company	Country	Market cap (US$m)	Bloomberg consensus Revenue CAGR 3-yr	5-yr	10-yr	Share price performance YTD	1-year	Closing/52 week high
Fuel Cells & Components								
Bloom Energy	US	3,328	25%	23%	18%	-32%	-6%	43%
Plug Power	US	15,358	55%	50%	40%	-21%	50%	35%
FuelCell Energy	US	2,333	36%	36%	29%	-43%	167%	22%
Ballard Power	US	4,143	28%	34%	35%	-41%	-21%	32%
Ceres Power	UK	2,558	24%	29%		-25%	37%	61%
SFC Energy	Germany	446	34%	37%	23%	67%	72%	78%
Doosan Fuel Cell	Korea	2,669	36%	26%	22%	-9%	19%	73%
Sang-a Frontec	Korea	831	27%	26%	N/A	38%	46%	80%
Hyosung Advanced Materials	Korea	2,691	14%	N/A	N/A	381%	393%	75%
S-Fuelcell	Korea	184	N/A	N/A	N/A	-14%	-20%	74%
Weichai Power - A Share	China	22,064	6%	1%	1%	5%	-2%	60%
Weichai Power - H Share	China	22,066	7%	N/A	N/A	10%	16%	65%
Beijing SinoHytec	China	2,588	61%	N/A	N/A	-14%	50%	67%
Production & Distribution								
Linde Plc	US	153,696	7%	6%	N/A	15%	28%	94%
Hanwha Solutions	Korea	6,725	11%	8%	N/A	-10%	-11%	72%
Nel ASA	Norway	2,128	50%	N/A	N/A	-57%	-37%	35%
ITM Power	UK	2,992	180%	119%	73%	-23%	32%	53%
Average			37%	33%	30%	14%	49%	60%

Source: Bloomberg Finance L.P., DBS Bank

Share prices are off recent peaks. Share prices of many of the hydrogen under consideration plays did very well since the COVID-related market low of April 2020 and peaked out around early part of 2021, before retreating to more moderate levels, as is evident from the charts on the following page. One of the reasons for this, especially for the US-listed stocks, was disclosure on revenue overstatement in historical statements and subsequent restatement of revenues for some of the players, which dented investor confidence in the stocks, combined with profit taking and possibly a more rational view of the pace of growth for the hydrogen market in future. On average, we see stocks are mostly down YTD in 2021, except for Hysoung Advanced Materials in Korea. We also note that the stocks are on average down around 40% from the early 2021 peaks, and hence may present better entry points for potential investors.

Potential catalysts for the sector in the offing. The 2021 United Nations Climate Change Conference, also known as the COP26 will be held in November 2021 and will further determine the future direction of the fight against global warming. As countries make more ambitious decarbonisation commitments, this should be helpful to the growth of the hydrogen economy. Hydrogen's role as a key enabler for the energy transition process could receive a clearer boost at the summit, with supportive policy decisions. In addition, a slew of strategic partnerships being formed by new age electrolyser/ fuel cell companies and traditional industry counterparts will continue to build excitement for the sector. Real revenue and EBITDA growth performance for FY21 for the US and European hydrogen players will also bolster renewed investor confidence in the sector, which had been shaken earlier this year, as mentioned before.

Share price performance of key hydrogen economy stocks globally since 2019



Source: Bloomberg Finance L.P., DBS Bank

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BUY (>15% total return over the next 12 months for small caps, >10% for large caps)
HOLD (-10% to +15% total return over the next 12 months for small caps, -10% to +10% for large caps)
FULLY VALUED (negative total return, i.e., > -10% over the next 12 months)
SELL (negative total return of > -20% over the next 3 months, with identifiable share price catalysts within this time frame)

**Share price appreciation + dividends*

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